Female microenterprise creation and business models for private sector distribution of low-cost off-grid LED lighting: Multiple Randomized Experiments

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CONTRIBUTING ORGANISATIONS AND AUTHORS

The project is led by the Environmental Economics Policy Research Unit at the University of Cape Town and Innovations for Poverty Action, a leading international NGO specialising in randomised evaluations. This research project makes up a component of a larger overall project with funding from many sources including the UK government's Department for International Development through the ENERGIA Gender and Sustainable Energy Research programme, Grand Challenges Canada, Stars in Global Health; International Growth Centre; INSEAD and Wharton (University of Pennsylvania) Business Schools; the Finnish government's Energy and Environment Partnership; and the Environment for Development Initiative.

We also partner with Nuru Energy (Nuru) - a for-profit, social enterprise with operations in East Africa that aims to address the global issue of energy poverty through the design and manufacture of small LED lights that are distributed and sold to households in rural communities via local enterprises, which provide solar recharge services for both lights and phones.

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EXECUTIVE SUMMARY

I. Introduction

Over 1.3bn people worldwide lack access to modern energy. In Africa alone 600m remain off-grid, 400m live in extreme poverty, and both numbers are expected to grow since grid expansion and economic growth are not predicted to keep pace with population growth. In addition, almost 6 million children under 5 die each year from preventable diseases, preliminary research suggesting that the primary causes are respiratory infections, and smoke from traditional lighting.

Furthermore, the US and UK alone, via Power Africa's Beyond the Grid, have committed to invest over $1 billion into off-grid and small-scale solutions in Sub-Saharan Africa, and this is just a fraction of the amount spent on off-grid solar energy. Yet the impacts of such programs have seldom been rigorously evaluated, their adoption rates remain low, and the question of how to increase use is still to be answered.

In Rwanda where our research is conducted, the government as a way of rebuilding the nation after the 1994 genocide, launched “Vision 2020”. The objective was to transform Rwanda’s economy from a low income to a middle-income economy by the year 2020. The expansion of the energy sector became very important to the realization of this vision. In 2009, the government of Rwanda embarked on its Electricity Access Roll-out Program (EARP) to accelerate national electrification rates (MININFRA, 2016). It has made tremendous strides in the energy sector and the current phase of the program is targeting a 100 per cent access to electricity by 2024.

Despite the efforts by government to increase electricity access, the current connectivity rate stands at only 42 per cent which is far below the 70 per cent target for the year 2018 (ESS,2015). Of the 42 per cent of population connected, 31 per cent are sourced on-grid and 11 per cent from off-grid (EDCL, 2018). The hilly terrain and sparse settlement of households, coupled with affordability issues, have made expansion of electricity to rural areas a challenge. Off -grid solutions, such as home solar systems, have rapidly gained ground in recent years. However, the upfront cost of purchasing these off-grid home solutions poses another challenge.

Gender issues add a further dimension to the electrification problem. Women and girls continue to face significant levels of discrimination. Interventions to empower women economically by providing off grid energy are urgently needed. In Rwanda, the National Gender Policy (2010) states that, at a national level, women’s participation in the workforce is about 56% (of the total female working age population), of which 55.8% have occupations and 87.6% participate in informal agricultural activities. Participation by women is higher (66.3%) in rural areas and in urban areas 53.5% women participate in the workforce. In urban areas, most women perform in supporting roles and are not hired at top-level positions. Only 18% of formal companies are run by women, many which are in the informal sector, generally comprising small businesses. Concerning access to employment, most women are employed as unskilled labourers, traders or craftsmen. Of these, 14.8% women earn cash incomes, 15.7% earn incomes in cash or kind and 57% earn very little.

To address these challenges, we partner with a large social enterprise, Nuru Energy, which has distributed low-cost solar lighting to over 1500 villages, containing 750,000 people, in rural Rwanda including the creation of 1500 microenterprises in charge of distribution and recharge. We carry out a number of intervention studies using multiple large-scale randomized control trials as well as lab-in-the-field experiments and qualitative interviews. These use new automated data collection technologies to combine big data with extensive household surveys.

This research, which forms part of a greater research project, merges the above themes of energy, gender, and poverty. It studies how such inequalities can be overcome by bringing women to the forefront in the establishment of village level enterprises that distribute and recharge LED lights to rural poor households that are not on Rwanda's national electricity grid. We specifically consider the role of gender quota assignment in Village-Level Enterprises to ensure access for potential female entrepreneurs and study the impacts this has on business level outcomes as well as household outcomes such as income, expenditure and girls' aspirations. These empowerment interventions are evaluated through a large-scale RCT. Economic experiments with village level entrepreneurs (VLEs) are also conducted to assess how competitiveness and risk behaviour differ across gender groups, and the impacts of such differences on the successfulness of VLE groups.

The viability of enterprises offering clean, renewable energy products may be limited by the pricing of such products and the financing mechanisms available to end users. Through the village level enterprises that we will be studying, we will also investigate the optimisation of different business models through a number of carefully designed financial and behavioural interventions.

Lastly, we look at the gender and welfare impact of tier 1 energy access (as defined by SEA4All, 2013) on poor rural households in off-grid areas, focusing on the implications of improved lighting to men and boys versus women and girls.

Using large-scale randomised control trials in 272 villages that blend both qualitative and quantitative methods, this research designs, tests, and evaluates strategies to increase the adoption and sustained use of household renewable energy technologies. Using strategically designed business models specifically aimed at empowering local female entrepreneurs in both their communities, and in the energy industry, it also tests the impacts of different gender quotas amongst entrepreneur groups on performance and profitability, and what other lasting impacts such empowerment programs could have in their communities.

II. Research questions

The specific research questions following our objectives are, therefore:

i) Can gender quotas in the renewable lighting sector be implemented to empower prospective female entrepreneurs and their families effectively and still make business sense?

ii) Is there evidence for improved welfare measures in households using renewable lighting?

iii) Is there evidence for systematic differences in risk-seeking and competitiveness between male and female entrepreneurs that might affect their success as VLEs?

iv) How do different business models affect adoption and use of renewable lights?

To answer these questions, we use approaches that include:

A. Testing new microenterprise models, designed to empower rural women and increase microenterprise effectiveness by pro-actively influencing the gender composition of village-level-enterprises and assessing the performance of these enterprises. Evaluating the specific impacts of this intervention on female entrepreneurs and their families, in terms of expenditures on health, schooling and food, and on girls' aspirations.

B. Evaluating through economic experiments differences in competitiveness, risk attitudes and pro-social behaviour between males and females. Using qualitative interviews to further interpret these differences.

C. Testing models for lighting technology-adoption and usage patterns via a series of focused interventions aimed at evaluating: i) the role of different pricing structures (different pricing of the lights, recharge pricing), ii) the efficacy of behavioural interventions aimed at improved recharging habits and iii) the efficacy of behavioural interventions targeting both liquidity constraints and also iv) improved convenience from the perspectives of potential customers and of the VLE.

These research questions are relevant to many renewable technologies, and the answers found to them, should be generalizable. They may also provide impetus for the extension of similar research to a broader group of stakeholders.

We supplement the multiple RCTs with additional interviews of stakeholders in the renewable lighting sector (e.g. Acumen, SolarAid, SunnyMoney, and Colibri), qualitative interviews with VLEs and key figures within these poor rural communities, as well as economic experiments focussed on competitiveness, risk and prosocial behaviour.

III. Background

Despite the efforts by government to increase electricity access, the current connectivity rate stands at only 42 per cent which is far below the 70 per cent target for the year 2018 (ESS,2015). Of the 42 per cent of population connected, 31 per cent are on-grid and 11 per cent are off-grid (EDCL, 2018). The hilly terrain, sparse settlement of households, and affordability issues have made expansion of electricity to rural areas challenging. Off-grid solutions have rapidly gained ground in recent years as a means of providing lights to rural communities. However, the upfront cost of purchasing these off-grid home solutions poses another challenge.

Nuru, a social enterprise in the renewable lighting industry, has been engaged in Rwanda for some time expanding its model for LED-lighting distribution (over 1500 villages; it also has the largest market share in Rwanda (GVEP, 2012)). The research team has been working alongside Nuru to develop a means of evaluating different business interventions and the impact of the distribution of LED-lighting in poor rural villages.

One of the key features of the existing model for implementation through village level enterprises (VLEs) has been the skewed gender distribution of the VLEs (in favour of males), despite preliminary empirical evidence from Nuru's existing database indicating that female VLEs have been more successful than male VLEs in selling LED lights in villages. With the support of ENERGIA and significant other funding, we have therefore been able to focus our proposed research and design actively to test specifically how changing the VLE gender composition may impact the Nuru-business model. We also test how empowering female entrepreneurs in rural villages may have an impact on the overall wellbeing of households, with attention to the impact on female children in households and villages with more active female VLE representation.

Our earlier scoping report covered a review of the evidence in detail, which included a literature review of the role of gender entrepreneurship in the energy sector, as well as an overview of Nuru's business model and a review of existing business models. Our scoping research also included a mapping of stakeholders in this field and a motivation for using randomized control trials.

IV. Results and policy implications

This research project studied the roll-out of a gendered micro-enterprise program in the renewable lighting sector amongst poor rural households in Rwanda. In partnership with Nuru, a social enterprise committed to scaling up LED lighting and mobile phone charging to the rural poor, it tested the impact of randomized gender assignments of Village Level Enterprises as well as business models that varied the upfront prices of lights, the recharge fees or price of usage, behavioural factors (habit formation, information) and liquidity constraints, in facilitating frequent usage of the lights.

The project used multiple large-scale randomized control trials. These were conducted in 272 villages across two districts in Rwanda; Ruhango and Rulindo. This is the most rigorous way to prove causality and determine whether interventions and programs are effective. The RCTs are complemented with additional qualitative interviews, of program

participants and of a number of stakeholders, and with 'lab-in-the-field' experiments with VLEs to deepen our understanding of the barriers and enablers of becoming successful as a VLE for males and females respectively.

A. The impact of women's empowerment quotas on business performance and prosocial welfare outcomes

After assigning gender quotas to enterprises via all-male, all-female and mixed-gender groups, the study assessed the extent to which female empowerment initiatives are successful in a number of dimensions using multiple unique data sources from a large-scale randomized control trial in 272 villages.

Firstly, results from the randomly assigned women's quota system show that business performance is similar across gendered microenterprise groups: female teams of entrepreneurs perform as well as male teams. Women were clearly excluded from participation in the traditional model, which had village leaders choose entrepreneur teams, even when they were perfectly qualified to take part. Even when enterprises were jointly managed with men, there were no gender differences in the division of revenues from the business. The results have important policy implications for redressing gender inequalities in the rural workforce in Rwanda.

Secondly, in households of all-female VLEs, there are noticeable educational effects among school-age children, in the form of increased time spent reading or studying at home, compared to all-female controls and male VLES (almost an hour more per week). We also find that female VLEs are more likely than the female controls to report expecting that their children will be studying in 3 years' time. Children from female VLE households are more likely than those from female control households to expect to find a job that they enjoy. On the other hand, we do not find differences in the happiness or life satisfaction of the household head.

Thirdly, we find broad welfare impacts. Evidence shows that the overall microenterprise program raised household consumption and expenditure levels, one of the best measures of poverty, and thus increased general welfare significantly. Moreover, the low cost lighting programme saved households money on lighting expenditures, reduced the use of dirty lighting, and increased the probability children study with a clean light source.

There are multiple significant policy implications from our results. Quotas can be implemented with no negative impact on profitability, while dramatically increasing participation by women from 10 to 50 percent. Indeed, all-female teams perform 9 per cent better than male teams. but this difference is not significant. Furthermore, a quota system has positive spill overs, leading to prosocial welfare impacts on entrepreneur households such as on children's studying time. Moreover, we also find direct general welfare impacts from the provision of ultra-low-cost solar lighting. This research provides motivation for further scaling of the program, which would lead to significant welfare impacts.

B. Additional evidence from mixed methods: lab experiments and qualitative results

The qualitative results of this study indicate that the benefits of becoming a VLE are many, ranging from improved access to lighting (allowing females to work after dark and males to spend time on finding food for livestock, while children benefit from additional time to study), supplementary income (e.g. increased food purchases amongst female VLEs and increased leisure expenditures and savings amongst male VLEs), and an elevated status in the community.

The experimental results also suggest that the majority of the entrepreneurs in the study are not risk-takers. In this context, women are even less willing to take risks than men. Nevertheless, women operating as village level entrepreneurs (VLEs) in rural Rwanda do not shy away from competition. Controlling for VLE's experimental performance, result shows no gender difference in the number of VLE's who preferred to enter competition.

C. How to increase adoption of off-grid solar: the role of pricing, liquidity, and behavioural factors

In a field experiment covering 2000 households in 18 villages, the price of lights payable by the households was made to vary from 0 to full price using pricing vouchers. Subsidies are required if the rural poor are to be reached; the rate of adoption of rechargeable solar LEDs being high at low or zero prices, but very low at market prices.

Data on upfront price paid and unique big data from remotely captured long-term usage shows that lights are still valued and used over the long run even when received for free, refuting the notion that people don't value and use free goods.

The policy implication is that lights should be subsidized if full access is to be achieved and that doing so will not negatively affect how much households use or value their lights. If subsidies are not possible, lights should be given away for free initially, with pay-as-you-go (PAYG) micropayments used to recoup costs over the longer term.

In a second randomized trial of 3300 households and 35 villages, however, that long-run use of lights was found to be highly elastic with respect to micropayments. At zero price the expected usage increases by 169 per cent. Therefore, even charging low PAYG rates, such as USD$0.15-0.30 PPP per recharge, will reduce adoption and use substantially, making subsidies preferable.

What, then, can development actors do to increase adoption of their products amongst the extreme poor? A third study presents one intervention which does increase adoption and long-run usage in a profitable way: short-run subsidies, or a free trial period (user fee micropayments set to zero for 3 months), have a significant positive impact on long-run use and micropayments after the free trial is discontinued. A novel contribution is a follow-up study to unpack the underlying causal mechanisms behind this successful intervention. There is no evidence for price anchoring or information frictions and

positive learning. Instead, the likely driver of the result is a persistence in behaviour, or habit formation.

Even charging zero initial prices and zero user PAYG micropayments does not lead to adoption rates of 100 per cent. This is likely because of the inconvenience associated with travel to centralised village level recharging stations is also associated with reduced usage and recharging. Theoretical work indicates that at zero inconvenience the expected number of recharges may increase by 100 per cent. Removing this barrier could increase use but implementation would be challenging given principal agent problems, and a key advantage of the centralised recharge model is its PAYG nature.

Taken together, the results of the three studies have significant policy implications and provide strong support for subsidies, both for the upfront price of lights and for PAYG micropayments for long-run use, in order to ensure full adoption by the ultra-poor. Where this is not possible, a reduced pricing strategy that makes use of PAYG micropayments exclusively is recommended. Short-run subsidies or a free trial period increase adoption in a profitable way.

V. Limitations and Discussion

While randomized controlled trials are considered the gold standard, they like all methods, have limitations. Results are not economy-wide, and impacts found in an individual study may not scale. We attempt to address this by carrying out very large randomized trials (272 villages, well above the average study size) in three different regions or districts (one location is the norm in development RCTs). We also work with a highly scalable program, a simple 'business in a box' intervention of technology transfers. This has already been scaled to over 1000 villages in multiple countries and is readily implementable. The results do not just apply to this organisation, model, or country. Nuru has operations in other countries, and there are, for example, other organisations which operate a similar model, such as Sunlabob in Laos and Shidhulai in Bangladesh. While we have partnered with Nuru to do the largest quantitative part of this study, the pricing and behavioural interventions we test are much more broadly applicable to other renewable lighting contexts and arguably to any organisation which distributes a product in a market aimed at the ultra-poor. For instance, we contribute valuable evidence to the literature on pricing products for the poor and technology adoption in general.

Overall this research program has provided many new insights into empowerment programs in the LED sector and provides encouraging evidence that simple gender quotas may be an effective means of levelling the playing field in the renewable sector, ensuring females access to work, which in turn provides positive spill overs for their households. This is particularly important in a country like Rwanda where, irrespective of national policy attempts to redress gender inequalities, significant differences in opportunities still exist between men and women, in terms of access to light, unevenness in work tasks and basic rights at home, and opportunities to enter the job market. Working with hundreds of homogeneous enterprises, and experimentally varying their gender composition, the program has obtained important and unique evidence on gender and entrepreneurship,

affirmative action and quota systems, and the associated welfare impacts of such interventions.

The welfare results are also arguably general and do not depend to a significant degree on the organisation providing tier one LED lighting. Nevertheless, because of an ambitious data collection program involving baseline and end line surveys, multiple RCTs, economic experiments, and qualitative work, one of the limitations of the current report is that that we are not able to present more detailed results of the welfare analysis, drawing comparisons between male and female VLE households or showing impacts for end-user (non-VLE) households at this stage, since this would require more in-depth and detailed analysis. This is an important area for further research.

The results obtained from the business model provide a powerful message about the critical need for subsides or a reduced pay-as-you-go pricing strategy in order to ensure full adoption by the poorest of the poor. The behavioural experiments indicate that, while inconvenience related to centralised recharge stations is a barrier to usage, short run subsidies, or a free trial period, can profitably and sustainably increase long-run adoption of off grid lighting and potentially other products with repeated purchases.

Acknowledgements
We would like to acknowledge the IPA field work team and management for helping us to successfully conduct a complicated series of randomized control trials. We would also like to than Nuru for partnering with us on the innovative project and being flexible in scaling up their operations, to accommodate us. Further we would like to thank our various funders, including Energia and the TAG team, who has provided us with very valuable input and support throughout the project.

Abbreviations

PAYG – Pay as you go
VLE – Village Level Entrepreneur
IPA – Innovations for Poverty Action
RCT – Randomized control trial
SSA – Sub Saharan Africa

Glossary

VLE – Village Level Entrepreneur: Nuru's business model operates on the principle that VLEs operate micro-enterprises in teams of 4 within villages where Nuru's LED solar lights has been rolled out and that the VLE is responsible for recharging LED lights for villagers at a fee.

IPA – Innovations for Poverty Action: An organization specializing in the roll-out of Randomized Control Trials in various Developing Countries.

PAYG – Pay as you go: Pay-as-you-go is a system in which a person or organization pays for the costs of something when they occur rather than before or afterwards.

Social Enterprise - A social enterprise is an organization that applies commercial strategies to maximize improvements in financial, social and environmental well-being—this may include maximizing social impact alongside profits for external shareholders.

Randomized control trial (RCT): A randomized controlled trial (or randomized control trial; RCT) is a type of scientific (often medical) experiment which aims to reduce bias when testing a new treatment. The people participating in the trial are randomly allocated to either the group receiving the treatment under investigation or to a group receiving standard treatment (or placebo treatment) as the control.

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1. CHAPTER: BACKGROUND

Chapter 1 provides an overview of our overall research objectives, research questions and methods used for data collection and analysis.

1.1 Overview of the Research

One of the most important challenges facing the world today is extreme poverty. Women and girls are often the worst victims of poverty in developing countries; starting from a young age, boys are given priority over girls in getting an education or forming an identity outside of their family. This disadvantages women wishing to access work opportunities, and unfairly burdens them with domestic responsibilities that limit their ability to participate in the workforce. This research studies an attempt to overcome these inequalities in gender roles and perceptions by bringing women to the forefront in the establishment of local enterprises within their communities. These enterprises, hereafter referred to as village level enterprises (VLEs), have a particular focus on distributing renewable lighting options to rural poor households who are not on the Rwandan national electricity grid. Beyond the impact on the livelihood of the potential female entrepreneurs, we also hope to identify broader spill-overs into the household ethos including access to lighting within the family and gender related patterns of household expenditure and decision-making.

Rural communities tend to systematically discriminate against women when they are selecting persons to head village-level enterprises, according to sources in the literature and preliminary empirical evidence from Nuru Energy (Nuru) - a for-profit, social enterprise with operations in Rwanda that aims to address the global issue of energy poverty through the design and manufacture of small LED lights that are distributed and sold to households in rural communities. This research partners with Nuru to test the impact on the empowerment of females of systematically influencing the gender composition of village-level enterprises in the areas in which Nuru will operate.

Limited access to grid electrification has made solar-LEDs and pay-as-you-go home-solar-lighting-systems attractive options for most rural households. While these products have expanded their shares of the renewable energy market in many developing countries, the initial capital outlays involved may make them unaffordable to under-$1.25-per-day consumers who continue using unhealthy and environmentally harmful kerosene and torches.

With this in mind, the research also investigates the optimisation of the current business model of the village level enterprises, through a number of financial and behavioural interventions, the viability of alternative decentralised models for energy provision to the poor in rural areas of Rwanda, and the role of newly emerging social enterprises in filling that gap.

By interacting with a range of stakeholders within the renewable energy sector, we investigate the feasibility of different business models, specifically models aimed at empowering female entrepreneurs in this industry. We use both qualitative and quantitative methods to evaluate strategies to increase both the adoption of new technologies and the regular use of technologies, as well as to increase the level of gender empowerment achieved in these models.

The research uses large-scale randomised control trials which test new female microenterprise designs and business-adoption models that are generalizable or transferable to other enterprises in the renewable energy sector. It will also test how different gender quotas among entrepreneur groups will impact both profitability and the empowerment of females in their respective communities. Along with these gendered trials, the study will use variations in the pricing of the product to examine the ways in which behavioural interventions may impact the uptake and usage of products.

Improved access to renewable energy potentially has many positive impacts on well-being, health, and economic growth. Even low levels of access can have substantial benefits in the form of improvements in health (as a result of the switch from kerosene to electricity), changes in household labour-division patterns, improved safety, and improved studying conditions. Through the household survey, we look at the impacts of tier 1 energy access (as defined by SEA4All, 2013) on poor rural households in off-grid areas, particularly focusing on the implications of improved lighting for women and girls within the household.

The end-line customer survey data indicates that 71% of households are extremely poor, and rated Ubudehe 1 or 2. The VLE baseline survey revealed, using household expenditure figures, that 80% live in extreme poverty (living on less than US$2.07 in 2017, the World Bank definition of extreme poverty) and that this figure is even higher (90%) when considering household labour income. Moreover, 27% of these VLE households use a dirty lighting source, i.e. candle or kerosene. Overall the data shows the sample to be amongst the poorest in Rwanda, making the study of both gender empowerment and optimal business models for effective distribution of lights a critical matter for further investigation.

This research is led by the Environmental Economics Policy Research Unit (EPRU) in the School of Economics at the University of Cape Town; Innovations for Poverty Action (IPA), a leading international NGO specializing in randomised evaluations based; and researchers from INSEAD, a top business school[1] with campuses in France, Singapore, Abu Dhabi, and the University of California Santa Cruz. It is funded primarily by the UK government's Department for International Development (DFID) through the Energia Gender and Energy Research Program, but also Grand Challenges Canada, Stars in Global Health (health impacts), the International Growth Centre, and INSEAD business school, allowing expansion of data collection and business model testing. The lighting and recharge equipment provided by Nuru is funded by Finland's Energy and Environment Partnership (EEP).

[1] INSEAD is a top-ranked business school outside of the United States, and one of the top ten in the world.

Photo 1.1: A woman, her children, and kerosene candle in rural Rwanda. Photo by Rowan Clarke

1.2 Research Aims

1.2.1 Evaluating different micro-enterprise models designed to empower female entrepreneurs

Our first aim is to test new microenterprise models, designed to empower rural women and increase microenterprise effectiveness, by pro-actively influencing the gender composition of village-level-enterprises and assessing the performance of these enterprises by gender, and also evaluating the specific impact of this intervention on female entrepreneurs and their families, in terms of expenditure on health, schooling, and food, as well as assessing the impact of female entrepreneurs on girls' aspirations.

1.2.2 Testing different business models in the LED lighting sector

Secondly, we aim to test the optimisation of the adoption of LED lighting technology and their usage patterns via a series of focused interventions aimed at evaluating: i) the role of different pricing structures (different pricing of the lights, recharge pricing, and revenue sharing models); ii) behavioural interventions aimed at improved recharging habits; iii) behavioural interventions targeting liquidity constraints; iv) behavioural interventions targeting improved convenience for the potential customer; and v) behavioural interventions aimed at incentivising sales through differing reward/incentive structures.

1.2.3 Understanding the impacts of LED scale-up to the rural poor on the well-being of rural households

Our third aim is to evaluate quantitatively, via household-level surveys, the impact on household well-being of providing tier 1-level, low-cost renewable off-grid lighting. We focus specifically on VLE households in this analysis.

1.3 Research Questions

There are a series of relevant research questions that arise from the research aims outlined above:

1.3.1 Can gender quotas in the renewable lighting sector be implemented to empower prospective female entrepreneurs and their families effectively and still make business sense?

To what extent have different renewable lighting businesses endeavoured to empower women, compared with men, in the way that they have structured their business models? Specifically, could gender quotas help prospective entrepreneurs secure entry to the market, and what would be the impact on business profitability? What would be the effect on other welfare measures, such as girls' aspirations, prosocial expenditures, and gender attitudes?

1.3.2 Is there evidence for improved welfare measures in households using renewable lighting?

What is the welfare impacts of access to renewable lighting for poor households? Does increased access to renewable lighting have positive impacts on outcome measures such as expenditure and aspirations? Are there health impacts due to kerosene and other hazardous lighting materials being displaced?

1.3.3 Is there evidence for systematic differences in risk-seeking and competitiveness between male and female entrepreneurs that might affect their success as VLEs?

How does risk preferences and measures for competitiveness gleaned via economic experiments and survey methods differ for male and female VLEs?

1.3.4 How do different business models impact uptake and use of renewable lights?

How are different business models structured in terms of pricing and behavioural modifications, and does their structure ensure optimal uptake and usage of renewable

lighting technologies? How does Nuru's business model compare to those of other business enterprises in the renewable energy lighting sector who work with poor communities? How can behavioural interventions help to encourage regular usage by clients and incentivize entrepreneurs to promote uptake and usage?

Photo 1.2: Kerosene as typically sold in 100ml amounts. Shop in rural Rwanda. Photo Rowan Clarke

Photo 1.3: A woman holding her child and kerosene candle in Huye district, Rwanda, March 2015. Photo by Rowan Clarke

1.4 Overview of Study Area

Rwanda is one of the smallest countries in Africa with a surface area of 26,338 square kilometres[2] and a population of 12,089,721 (NISR, 2018). The government of Rwanda, as a way of rebuilding the nation after the 1994 genocide, launched "Vision 2020"in the year 2000. The objective was to transform Rwanda from a low-income to a middle-income economy by the year 2020. The expansion of the energy sector became very important to the realization of this vision. Rwanda has since been making tremendous strides in the energy sector, with the current phase of the program targeting a 100% access to electricity by 2024.

Despite the efforts by government to increase access to electricity, the current connectivity rate stands at only 42% which is far below the 70% target for 2018 (ESS,2015). Of the 42% of population connected, 31% and 11% are sourced from on-grid and off-grid respectively (EDCL, 2018). The hilly terrain and sparse settlement, coupled with affordability issues, have made the expansion of electricity to rural areas of the country a challenge. Off-grid solutions, such as home solar systems, have rapidly gained ground in recent years as a means of providing light to rural communities. However, the amount involved in initially purchasing these off-grid home systems poses another challenge.

Nuru Energy has been operating in the Rulindo and Ruhango districts, distributing off-grid lights that are designed to mimic the regular fueling of traditional kerosene lamps by regularly recharging these lights at a fee. See Figure 1 below for an overview of these two districts.

Rulindo District

Rulindo is in the Northern Province of Rwanda and has a total population of about 295,808 people, of which 139,030 are male and 156,778 females (NSIR, 2012). Thus, more than 50 per cent of Rulindo's population are females. 26.4 per cent of households in Rulindo are female-headed and an additional 2.5 per cent are headed by females in the absence of a male head. The district offers a strategic link to most of Rwanda's tourist destinations, such as Lake Kivu, Musanze, Ruhondo Beach, and to the capital city, Kigali. With an estimated surface area of 567km^2, the district has 17 administrative sectors, 71 cells[3], and 494 villages (DDS,2018). Although the district is strategically positioned as a link to tourist destinations, 48.1% of people living in Rulindo are poor and 20.2% are facing extreme poverty (NISR,2015) The average income per day is RWF 1000 and the agriculture is the most dominant sector of the economy in the district (DDS,2018).

The district also has many hills, including the Tumba, Cyungo and Tare hills. The nature of the district's topography means that households are sparsely distributed, resulting in low accessibility as grid expansion to villages in the district is very challenging and costly. Only 15.6 per cent of households have access to electricity (DDS, 2018). The district therefore augments its on-grid connection with various forms of off-grid solutions to reach the majority of people who do not have access to cleaner energy.

Ruhango District

Ruhango District is in the Southern Province of Rwanda. The district has 9 sectors, 59 cells, and 533 villages. Ruhango's population is estimated at 322,021 (NSIR, 2015); 52.4%

[2] See http://data.un.org/CountryProfile.aspx?crName=RWANDA.1.

[3] A cell is an administrative subset of a sector in Rwanda

female and 47.6% male, distributed over an area of 626.8 km^2 and 71,000 households. Like Rulindo, most people work on farms, but agricultural productivity in Rulindo is higher than in Ruhango. Most women in the district are employed in the small-scale farming sector, whilst men are employed in almost all sectors in the district and earn higher wages than women (DDP, 2013). 35.6% of households in Ruhango are headed by females. 37.8% of Ruhango's population live under the poverty line and 12% are living in extreme poverty (NSIR,2015).

Electricity access rates in Ruhango are much higher than in Rulindo, and with more households recently connected to the grid, Ruhango's electricity access rate now stands at 40% of its population. Yet the district still has a substantial number of people living in the dark.

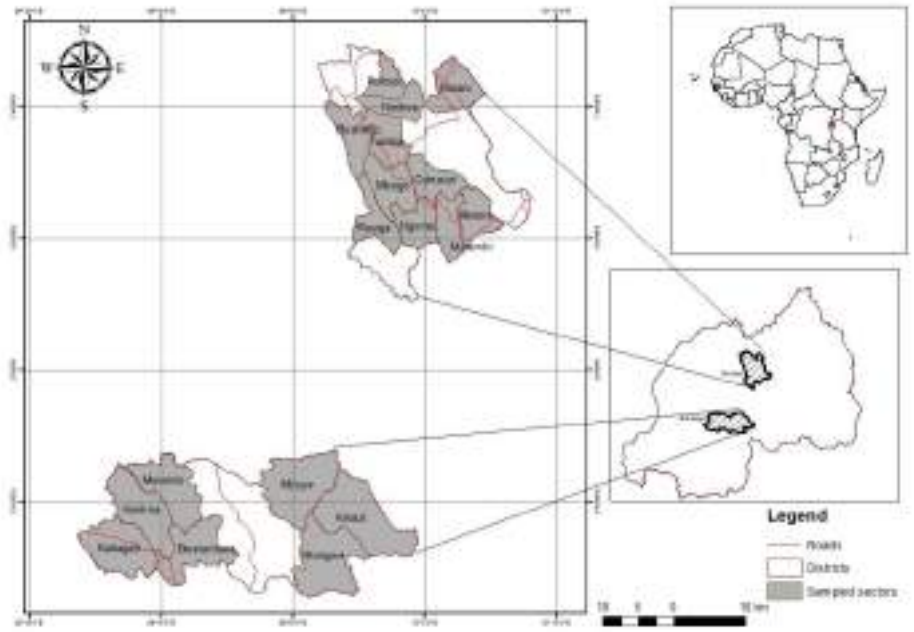


Figure 1.1: Study Area in Ruhango and Rulindo Districts of Rwanda

1.5 Main elements from Scoping Phase

1.5.1 Literature Review on Gender Empowerment Initiatives and Preliminary evidence on gender empowerment

Globally, 1.3 billion individuals are without modern power; about 600 million of these are living in Africa, and that number is projected to grow as population growth outstrips grid expansion capabilities, rising to 700 million affected by 2030 (Lighting Africa, 2012). That energy poverty is related to income poverty is clear (Casillas and Kammen, 2010). Recent economic research has highlighted the positive role that the introduction of electricity, infrastructure, and technology in general, plays in important economic outcomes (Dinkelman, 2010; for long-term effects see Banerjee et al., 2012). Given poor households' large fuel expenditures (e.g. up to 40% of household income in rural Rwanda

is spent on kerosene (UN, 2012) while in Malawi, lighting costs comprise 19% of household expenditure (Adkins et al., 2010)), the reductions in costs promise to have significant positive welfare impacts for the poorest of the poor (Berry, 2009; Adkins et al, 2010).

Women and girls continue to have the highest demand for energy resources for activities within the household and yet, due to social, cultural, and traditional barriers, they are left out of that decision-making process. Outside of the household, "women represent almost 40 per cent of entrepreneurs in Africa. Yet, they are disproportionately represented among the self-employed and in the informal sector and among those operating smaller firms. As such, women are often earning lower returns on their time and investment than men" (Hallward Driemeie, 2011). Many programmes under a wide set of strategies have aimed at reducing existing inequalities by empowering women; in most cases, these programmes aim at economic empowerment, under the premise that economic empowerment will unleash empowerment in other dimensions.

According to Batliwala and Reddy (2003) a change of mind-set is necessary on the part of energy planners and activists to successfully empower women as energy entrepreneurs, as they must promote the notion of women as managers and entrepreneurs, and not just beneficiaries of improved energy service. To cement the effects of empowerment, it is crucial that the enterprises have some degree of financial success. Chaurey et al., (2012) analyses business models to enhance energy access at the bottom of the pyramid, identifies community ownership, capacity building and training as key factors in business success. However, it is important to keep in mind that even if the enterprises are not highly profitable, they may still have important effects on the entrepreneurs and their households as women's enterprises provide crucial sources of household income (Clancy and Dutta, 2005).

The scoping phase of the study has yielded important findings regarding the role of females within the Rwandan system, both at national level and within the corporate and domestic spheres. While there are several programmes and initiatives aimed at uplifting women and strengthening their roles in society, particularly in the workplace, women's decision making power and general role within the household is still highly constrained. This impacts on their economic activities, educational opportunities, time-use and general wellbeing (defined here more broadly to include material- and subjective-wellbeing e.g. economic assets, employment, food expenditure and general expenditures, subjective wellbeing, life satisfaction, emotional wellbeing, self-reported physical health).

In Rwanda, the National Gender Policy (2010) states that, at a national level, women's participation in the workforce is about 56% (of the total female working age population), of which 55.8% have occupations and 87.6% participate in informal agricultural activities. Participation by women is higher (66.3%) in rural areas and in urban areas 53.5% women participate in the workforce. In urban areas, most women perform in supporting roles and are not hired at top-level positions. Only 18% of well-structured companies are run by women, a large number of which are in the informal sector, generally comprising small businesses. Concerning access to employment, the majority of women are employed as unskilled labourers, traders or craftsmen. Of these, 14.8% women earn cash incomes, 15.7% earn incomes in cash or kind and 57% earn very little.

Most of the available evidence on gender and entrepreneurship, is in the form of case studies. Although insightful, these studies are based on very small samples and their results are difficult to generalise. Two interesting exceptions are provided by Kanagawa and Nakata (2007) and Sovacool (2013). Kanagawa and Nakata (2007) analyse socio-economic impacts of changes in stoves adopted by rural households in India, while Sovacool (2013) analyses a collection of eight case studies. This study will provide high quality, gender-disaggregated data on the relation between gender, entrepreneurship, and renewable energy.

1.5.2 Review of existing business models

With one in every five of humankind not having access to electricity and given that this population mainly resides in the poor countries in Africa and Asia living on a daily income of $1.25-2/day it is unsurprising that most households still rely on unhealthy, hazardous and costly fuels such as kerosene for their light needs (Lighting Africa, 2012). Grid-based electricity-supply models are cost intensive and may not be easily implementable in these countries. As advocated by Prahalad and Hart (2002), we need innovative and fundamentally different business models at the bottom of the pyramid.

As previously noted, grid-based electrification favours higher-income communities, and when communities are electrified, low-income households frequently cannot afford the connection charges (Lee et al., 2015). There is emerging evidence of an 'energy ladder' whereby smaller lights pave the way for the emergence of pay-as-you-go and solar home system segments as markets grow. But even though cheaper rechargeable lighting technologies (e.g. bulbs which could be recharged using mechanical/solar energy) are available, their adoption is low, and many consumers still use kerosene (IEA, 2014). As Wong (2012) states: "Financial exclusion is among the main obstacles that constrain poor people from obtaining solar lighting". Specific examples from our overview of other business models (Section 3.4.1) in the renewable lighting industry has for instance indicated that with most renewable lighting products using pay-as-you-go (PAYG) financing mechanisms, households face upfront down payments of $18-75, where after they are expected to pay weekly (or monthly) instalments ranging from $2.73-$5.24 per week ($0.39-0.75 per day) over a period of 18 – 36 months. It is clear that barring the upfront payment which would already be very challenging for households living on $1.25/day to come by, the down-payments itself would swallow up to half their daily income for a period of 1.5-3 years.
The importance of optimal pricing is further underscored by a study currently being executed by researchers from ETC-Zurich and IPA Kenya, in partnership with SunnyMoney at SolarAid. Preliminary results from their study in Kenya show that, even with significantly higher marketing and distribution costs, only 27% of households purchased just one solar lantern at the full price of $9, whereas 72% did so when provided with subsidies [note: as these are only preliminary findings, this information is not for publication].

The five distribution models identified to be prevalent by Scott et al., (2015) are as follows: institutional partnerships, distributor-dealer channels, proprietary distribution channels, franchise model, and the rental/leasing system. In some countries, distribution

can account for up to 50% of the final product cost. By 2010, the vast majority of companies relied on the distributor/dealer (outsourcing to an in-country dealer) or proprietary distribution (i.e., direct-to-consumer) models (Lighting Africa, 2010). We discuss each of these models linked with examples of such models in the renewable lighting industry in the main scoping paper.

Ultra-poor households who are accustomed to purchasing energy in small increments might find some energy services prohibitively expensive. For this reason, providers should design financing and payment schemes to help consumers purchase products that fit their energy budgets. The World Resources Institute (WRI) brought together the experiences of 25 socially oriented energy enterprises, organisations and financiers, and described the specific financing strategies to overcome the challenges previously mentioned. The six respective business models that focus on the financial sustainability of the provision of energy products are: one-stop-shop model, a financial institution partnered with an energy enterprise, the umbrella partnership model, the franchise/dealership model, the brokering model, and the pay-as-you-go model (Ballesteros et al, 2013). The main trend is the emergence of pay-as-you-go technology, which enables customers to pay over time. Examples of these are described in more depth in the main document.

1.5.3 Nuru's business model and comparative context

Nuru's distribution model falls under the ***Rental/leasing system*** as discussed above: The company franchises or contracts to micro-entrepreneurs (Village level Entrepreneurs) who set up charging kiosks, which work with the solar/human powered recharging "Octopus". These micro-entrepreneurs then sell rechargeable, LED lights (that provide around 20 hours of illumination per recharge) without a power source to the client, to reduce the upfront price of lights faced by customers. The entrepreneur offers recharges at a fixed fee.

The Nuru VLE remains the only source for recharging of the LED light by Nuru customers. This creates a sustained income generating activity through recharge for the micro-entrepreneur, for as long as there are Nuru light users in his/her village. This distribution model allows access to light for customers who cannot afford the full cost of other renewable energy technologies by mimicking the incremental small purchases of kerosene or dry batteries which customers already use.

From a financial point of view, Nuru's model is also fairly unique; most financial models for solar panel customers involve payment schemes that immediately or eventually pay off the panel and have customers become the owners of the technology. Nuru customers, however, will continue paying for recharging the lights through VLEs, without reaching ownership of any charging source (although they will be able to buy the same solar panel that the VLE uses for recharging, if they can afford it).

Nuru lights, are specifically designed to be entry-level lights to households who can't afford alternative sources of clean lighting, like solar lamps. Since the lights are sold at

reduced upfront prices, upfront cost is unlikely to be a barrier to adoption. Moreover, ultra-affordable micropayments for recharges help consumers to combat their liquidity constraints. Nuru LED lights costs around $0.13 per recharge (every 10-14 days) while the VLE recuperates the cost of the equipment, and then drops to half that price, once the equipment has been paid off. This in comparison with weekly down-payments (PAYG) for many solar products which as mentioned earlier can be up to half the daily income over a period of 1.5-3 years for a household living on $1.25/day.

Nuru's financing model functions by selling the hours of light rather than selling the recharge equipment to the end-users. It therefore resembles the pay-per-use service provided by grid-connections (cash-power). The act of visiting the recharge centre to purchase light resembles the act of purchasing kerosene from a village shopkeeper. This may be an advantage as it is observed that although often economically inconvenient, customers are reluctant to modify habits away from kerosene due to, among other causes, resistance to habit changes.

The model does, however, fall under the Pay-As-You-Go (PAYG) umbrella, providing an amount of lighting energy in exchange for ongoing payments. In this case, though, the payments are not going towards the acquisition of the recharge technology, as they do in PAYG schemes used by Mobisol, M-Kopa, Helvetic Solar, and Azuri Technologies (see table 3.1), but rather to the recharging of already-owned light sources (e.g. customers own the lights, they just don't own the recharge station which is owned by the microenterprise). This model minimizes transaction costs and has the dynamism required to fit the technology and financial circumstances of ultra-poor consumers. It also accommodates increments at times preferred by consumers, who can recharge according to their liquidity (no fixed payment plans).

There has been recognition of the crucial role of women in energy and lighting use, as well as their improved achievements as micro-entrepreneurs and more pro-social management of income. These qualities and efforts for empowerment have led to the call for gender-focused initiatives in solar lighting distribution. Although Nuru's VLEs have predominantly been male, with women taking a back seat in enterprise development, a main aim of this study is to rigorously test the impact of varying the proportion of female VLEs on both the women and their families.

Preliminary empirical evidence from Nuru's business level data that supports our hypothesis that female entrepreneurs should be as successful as males if given enabled by business models in this sector to become Village Level Entrepreneurs (VLEs). An abstract of our short paper, "Gender and Entrepreneurial ability in the renewable energy sector in rural East Africa", based on the scoping report, follows:

‘‘Participation in traditionally male-dominated industries, such as energy, poses significant challenges for women entrepreneurs. Until recently women (especially those living in rural areas) have not been seen as having potential for entrepreneurial success. Yet women's engagement in the energy sector could substantially improve access and distribution to those most under-served, especially given that the majority of household energy customers are women. This paper examines the role of women as energy entrepreneurs from the perspective of gender inequality within the energy industry, and also from the perspective of effective

business strategy at the industry level. Data from Nuru, a social business focused on providing solar lighting solutions to the ultra-poor in Rwanda and Kenya, provide insights on how inclusion of women sales agents can increase sales and how strategic modifications to the social business model can further support female-led businesses. Observational data from over 1000 village level enterprises (VLE) show that women, on average, sold significantly more units than men, in what has previously been a male-led domain. Moreover, collective agency-based business models that supported women participating in groups with other entrepreneurs per village, had higher average sales per VLE as compared with villages with male-led teams. These data suggest that when operating in groups, women tend to outperform men even more than when operating alone."

1.5.4 Stakeholder engagement

As part of the initial scoping phase of this study, we conducted an in-depth stakeholder mapping of firms in the renewable lighting sector, to establish the guidelines and approaches, values, and variations in business models in this sector. Through a series of interviews with various development professionals operating in African and Latin American countries, we gathered information about six solar energy distribution programmes carried out by non-profits (Kopernik), social businesses (Solar Sister, Colibrí, Great Lakes Energy, Waka Waka) or by a partnership of several national development agencies (EnDev). Kopernik's "Wonder Women Indonesia" program and Solar Sister distribute their products mostly through micro-franchises. They explicitly aim at economically empowering women by helping them to become successful business owners. Colibrí and Waka Waka distribute their products through a mix of direct sales and micro-franchises. Despite including a strong gender-sensitivity component in their approach, they accept both men and women as retailers. The other two programmes operate at different levels: Great Lakes Energy used to sell solar lanterns on consignment to existing stores without much success and shifted to direct sales of larger solar systems to the health infrastructure. EnDev manages a result-based financing program open to any Lighting Africa certified solar lanterns importer in Rwanda. In the main scoping report, we discuss each of these stakeholders in terms of their gender focus, focus on the poorest sector in the market, and financing solutions (for retailers and end-users).

We further produced a short paper "*A role for subsidies in the provision of renewable energy for the rural poor? Evidence from stakeholder interviews and large-scale pricing tests*" detailing the stakeholder mapping exercise.

1.6 Methodology

While randomized control trials are often mentioned as the "gold standard" of evaluation in identifying causal inference for evidence-based policy in the context of program evaluation, as it is "unique in the control that the researcher has over the assignment mechanism" (Anthey and Imbens, 2016, Bannerjee, Du Flo and Kremer,

2016), we also recognize the limitations of RCTs (Shaefer 2011; Cowen *et al*. 2017) and therefore opt for a multi-method approach in this research project.

The study employs several methodological approaches, with randomized control trials (RCTs) forming the basis of both the gender empowerment and business model tests (pricing and behavioural) conducted. This rigorous empirical research is further supplemented by qualitative interviews with different stakeholders from the communities in which the lights have been rolled out. Economic experiments were conducted to assess differences in competitiveness and risk seeking behaviour between males and female VLEs.

Another series of Randomised control trials specifically seeks to unpack the impact of pricing on uptake and use of the LED lights, as well as the role of behavioural factors (inconvenience and liquidity constraints) on uptake and use. While we are confident about the general findings for the results reported, our analysis is ongoing, and the magnitude of our results may change upon further analysis. Statistical results reported in Appendix 1 will be open access by end-March 2019.

Lastly, the study extends the survey to non-VLE households. By comparing outcomes from VLE and non-VLE households in villages where Nuru has been operating, the impact of scaling up LED lighting on welfare of these households (VLE and non-VLE)[4] is assessed.

This study was done in collaboration with a social business, Nuru, focused on scaling up affordable renewable lighting to the ultra-poor in Rwanda and Kenya. Each village has a microenterprise that sells low-cost rechargeable LED lights to their community and provides a solar recharge service for a small fee. The upfront price of lights is subsidized by Nuru, and the recharge fee, while cheaper than kerosene, is set slightly higher than marginal cost to recover the subsidy in the upfront price. Teams of four micro-entrepreneurs, mostly all-male teams, operate the solar recharge stations.

Piloting of the RCTs (gender and pricing) began in late November 2015 and concluded in April 2016. The pilot took place in 11 villages, amounting to close to ten per cent of the main study. After analysing the performance of the different business models being tested in the pilot, we commenced with the full-scale study, for which we cover the methods of sampling and rolling out of interventions briefly below.

[4] These additional observations of non-VLE households are not included in this report since the analysis is still in progress.

Photo 1.4: A village gathered to discuss their lack of lighting with researchers. Photo Rowan Clarke

1.6.1 Randomized Control Trials aimed at evaluating gender randomized business models.

Both the gender empowerment and business model tests involve clustered randomized control trials (clustered at the village level). These study the performance of micro-entrepreneur teams by gender composition, where teams operate at the village level, and test the impacts of various pricing and behavioural models.

In order to accurately evaluate gender empowerment initiatives for business performance of male versus female teams, we experimentally vary gender composition of the microenterprises, in three types of teams: all-male, all-female, and mixed teams (two males and two females).

The study was conducted in two districts of Rwanda: Ruhango and Rulindo, in which Nuru had plans to expand its operations. It was agreed with Nuru Recruitment that no roll-out of the business would happen in control villages until the end of the study.

of 272 villages into the sample occurred via the same plan of action as our implementing partner, allowing for later scale-up. Next Nuru and IPA (evaluation implementing partner) teams approached the village leaders to elicit interest in setting up solar recharge stations, each station to be run by a four-person micro-entrepreneur team. Whereas Nuru normally allow teams to organize themselves into groups, for RCT purposes randomly sorted interested villages into three groups (all-

male, all-female, mixed) and requested a specific gender composition of the micro-entrepreneur teams in each village. In line with the standard Nuru model, a commitment fee of 40,000 Rwandan francs (around 50 US dollars) as co-investment ("commitment fee") was requested from the prospective micro-entrepreneur teams. This fee was also a deposit for the recharging station equipment. The commitment fee was raised from all 272 villages prior to treatment assignment and potential micro-entrepreneur teams were informed that their village had a 50% chance of being selected into the next phase of Nuru's business expansion into the area. If the village was selected in the control group, the money was returned to the teams. If the village was selected in the treatment group, each village would receive 100 lights (one per household). These would be randomly allocated amongst households for free; thereafter kiosks were set up at which the lights could be recharged.

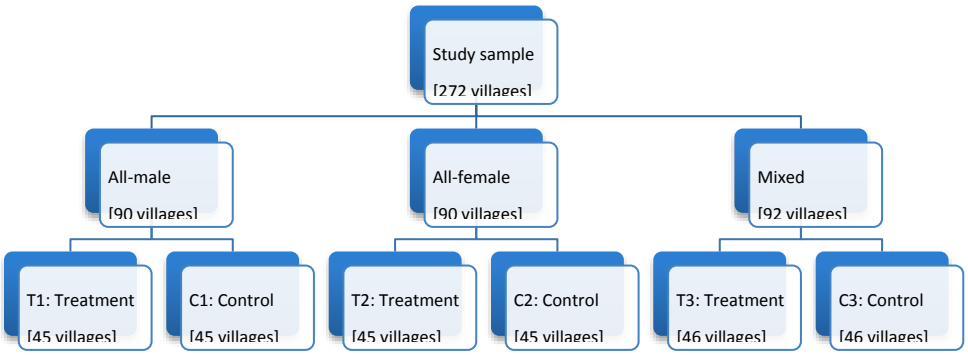


Figure 1.2 presents an overview of the different treatment arms of the study

The data for this study comes from two key sources: baseline and end line household surveys and recharge station data. The expected sample size wasis 1088 micro-entrepreneur households taken from 272 villages. There were 136 teams (544 micro-entrepreneurs) in treatment villages and 136 teams (544 prospective micro-entrepreneurs) in control villages.

Survey data: By using data obtained from the baseline and end line surveys for the 272 new microenterprises consisting of 4 individuals each in 272 villages, we are able to evaluate the welfare outcomes of rolling out LED lighting. Survey data on general welfare was collected from a sample of over 5000 people from 1088 entrepreneur households. All 4 members of each group were surveyed, as was one teen girl-child in each household, both before the intervention and 18 months after its roll-out. The timeline for the entire study was as follows: Baseline data collection period: September 9th, 2016 – November 29th, 2016; Implementation start December 2016; End line survey: June 2018 – August 2018.

Regarding the recharge data: All Nuru lights have codes that are automatically transmitted to recharge stations each time they are recharged. After each charge, the recharge stations sent data, including the light ID and a time-stamp, by GSM to servers.

This provided approximately six months of high-frequency longitudinal data from over 12,000 lights, one per household.

1.6.2 Qualitative Analysis - stakeholder communities

Semi-structured interviews based on open-ended questions were conducted with VLEs. VLEs could express themselves freely, providing room for further follow-up questions and respondents' own elaborations. The semi-structured guide covered demographic information, VLEs operations, livelihoods before and after becoming a VLE, and general gender awareness. Using a different guide,interviews were also conducted with customers of VLEs, non-customers of VLEs and professional village workers or leaders. These interviews provided a different perspective and a broader overview of VLEs activities. Observational data was collected by also interviewers who stayed in the village while VLEs went on with their daily activities. Interactions with VLEs took the following form: On the scheduled day of the visit the interviewers arrive in the village in the morning and locate the VLEs; after following the required protocols and obtaining consent from the VLEs, the team conducts the interviews, usually in the VLEs' homes. After the formal interview, if the respondent is comfortable with it, the interviewer will accompany them on their daily visits to farms, shops, and village centres. The interviewers remain in the village, interacting with other village members and observing the VLEs' activities throughout the entire day. All interviews were recorded with the permission of the respondents.

Photo 1.4: A VLE is working in her backyard farm during our interactions. Photo credit: Emmanuel Kwizera

A total of 30 respondents were interviewed. These consist of 15 VLEs, well distributed across the 13 sectors of Rulindo, five village members who use the services of these VLEs, five village members who do not use these services, and five professionals or village leaders. In all subgroups, the female to male ratio was deliberately sampled to be two-thirds females, one-third males.

A thematic analysis approach was used to analyse the data. As the interview was conducted in Kinyarwanda, all recorded conversations had first to be translated and transcribed. Recurring responses were then identified across the entire data range. These responses were summarised under various themes and used to develop a coding scheme. The codes were then applied to the data to obtain meaningful insights.

1.6.3 Economics Experiments aimed at assessing risk aversion and competitiveness among Male and Female VLEs

Economics experiments were conducted with subsamples of VLEs from both Rulindo and Ruhango districts. A total of 375 out of 516 entrepreneurs operating in off-grid renewable energy village level microenterprises in 129 villages of Rwanda participated in the experiment. The 129 operational microenterprises (one enterprise per village) were randomly assigned to gender treatment groups of four, so that in each village, entrepreneurs work together in either single-sex groups or mixed-gender groups with equal representation of both males and females. This provides a unique natural set up to explore the performance levels of these gender groups.

Although the experiment was originally designed to mimic these gender groups of four people, it was in practice necessary to work with two to six people in the experimental groups. This was because there was no control over the number and gender of participants who showed up per session. Of the 375 VLEs who participated in the experiment, 224 were in groups of four (a total of 56 groups) and 151 were in groups with either more or fewer than four members (a total of 35 groups).
The experimental design of the experiment was based on the original design of Niederle and Vesterlund (2007), in which VLEs performed real tasks under self-competition (Piece rate) and group competition (Tournament) conditions. In each session, participants were given a set of two-digit numbers to add in five minutes under different compensation schemes. A total of 20 random sets of problems were presented to participants for every task. In the first task (Piece rate), participants received 50 RWF for each problem solved correctly. In the second task (Tournament), participants competed in randomly assigned gender groups (mixed and single-sex) of two to six members. Participants' performance in this task is compared to that of other members of their group. The winner in each group receives 150 RWF (three times the Piece rate amount) for each correct answer. Other group members receive nothing. In a situation where two or more people have the highest score in a group, the winnings are split equally. The final task measures individual attitudes towards competition. Here, participants are given the option to play either under the piece rate or the tournament compensation scheme. The experiment was conducted using pens and paper, as the participants in rural Rwanda have little or no experience of using programmed computers. The experiment was conducted between March and July 2017. The entire experiment was conducted in the official local language Kinyarwanda, which is widely spoken by Rwandans. Twenty sessions in all were held.

The risk experiment adopts the multiple price list design to elicit risk preferences of entrepreneurs. This is a standard design where participants are asked to choose

between a set of gains framed paired lotteries (Tanaka et al., 2016; Brick & Visser, 2015): a certainty or a gamble. The probability of success in the gamble is represented using a spinning wheel which is pegged at 30%. This makes it easier for entrepreneurs to understand the tasks on the basis of which they are to make their decisions. JAs with the competition experiments, a total 375 entrepreneurs participated in the risk experiment.

1.6.4 Business Model Experiments: Pricing and Behavioural interventions

Upfront price of the Lights:

This part of the study focussed on testing the role of pricing in both the upfront costs of the lights and the user fees (or recharge costs). It includes two (Phase1 and Phase 2) separate randomized field experiments. The first focusses on exogenously varying the upfront price of lights (initial stage – Phase 1 - where the lights are sold to the households), while the second varies the user fee. The aim here is to asses both the optimal upfront pricing policy and also to understand how the upfront price paid impacts subsequent long-term usage. The upfront pricing RCT was conducted with 1987 households from 18 villages.

Varying the Recharge Price:

In Phase 2 households are faced with randomized user fees for long-term usage, in order to determine the optimal pricing for long-term usage. The way in which short-term subsidies of the user fees impacted long-term demand was also tested. The user fee RCTs were conducted with 3273 households from 37 villages. Unlike households in Phase 1, who faced varying upfront prices for the lights, these households received a light for free, to ensure that adoption would be 100%, and instead faced randomly differing user fees, with some households receiving a 3-month period of free use. This allows the team to study the impact of a randomly assigned free trial period on long-run usage rates after the end of the trial period.

Liquidity vs Inconvenience:

In order to understand the impact that behavioural considerations, such as liquidity constraints amongst customers and the nuisance or inconvenience factor for households of having to walk to VLE stations to recharge lights, reduced for and structural models were formulated to predict the impact of behavioural factors compared to that of changes in the recharge price, allowing the team to estimate the parameters associated with each of these factors empirically in the field.

The RCTs related to this part of the study were administered in 29 villages in the Ruhango district of Rwanda. Only 22 of these villages are reported on in the final paper, owing to GSM breakages. Lights were allocated for free, but bulb capacity and the recharge price faced by consumers varied. There were a total of 10 treatment conditions: (i) seven conditions with seven different price/recharge levels (1, 50, 60, 70, 80, 100, 120 RWF) and a bulb capacity of 18 hours per charge, (ii) two conditions with two price levels (80 and 100RWF) and a bulb capacity of 14 hours per charge, and (iii) a treatment condition where every fourth recharge was free (with a regular recharge price of 100 RWF and bulb capacity of 18 hours per recharge).

A total of 2500 households (80-90 households per village) were randomly selected from the 29 villages and assigned to one of the above 10 conditions. We stratified at the village level in order to achieve balance, resulting in about 8-9 villages per treatment condition. The treatments ran for three months from the beginning of December 2016 to the end of February 2017. Consumers received coupon cards (which expired after three months) with their lights upfront, which specifically stated the recharge price. GPS coordinates for recharge centres and all households in the sample were recorded in order to measure recharge inconvenience (distance from household to recharge centre).

1.6.5 Benefits of using RCTs and economic experiments in gender and energy research

Randomisation is well established as the optimal design for avoiding study bias (Bannerjee and Duflo, 2009) and given the research team's main focus on causal questions, the choice of methodology follows naturally. The project uses a series of large-scale longitudinal randomised field experiments – informed by practice, relevant literature, qualitative findings, theoretical modelling, and extensive piloting – to establish results that policymakers can treat with a significant degree of confidence. High-quality individual RCTs provide solid unbiased building blocks to synthesize a body of evidence using meta-analyses, systematic reviews, and comparative analyses.

When correctly implemented, RCTs provide the best answers to the counterfactual question - what would have occurred in the absence of an intervention? (Glewwe *et al*., 2004; Arceneaux, Gerber, & Green, 2006; Angrist and Pischke, 2010; Imbens, 2010, DFID, 2014). Randomisation solves the counterfactual problem by creating a comparison group that is, in large enough samples, identical to the treatment group on both observable or measurable and unobservable or unmeasurable characteristics, thus eliminating bias (Takavarasha & Glennerster, 2013).

As the UK Department for International Development's guide on assessing evidence argues, there is no one-size-fits-all research design (DFID, 2014: p2). This research project therefore includes multiple RCTs, but also includes economic experiments and qualitative research.

The study illustrates that rigorous RCTs can be successfully used in the renewable lighting sector to provide evidence-based research related to empowering females. Economic experiments are also increasingly used to test theoretical models for behaviour in the laboratory (typically with students) but also in the field. Conducting economic experiments in conjunction with RCTs and qualitative studies means that the findings can be triangulated using different methodologies. The findings here are particularly important as they serve as a robustness test and confirm the initial hypothesis that female entrepreneurs perform as well as males. There is ample scope to extend economic experiments into the field of energy and gender research.

In conclusion, the study provides several positive lessons, underpinning the importance of RCTs and their application to both behavioural economics and gender and energy related studies. RCTs were applied to evaluate the impacts on microenterprise profitability *and* the gender dynamics within microenterprises and their households. Various business models were tested with the aim of raising usage rates - proxied by the recharge frequency transmitted by the automated GSM system. While statistical tests show some of the results as robust and generalizable, the study was not without typical RCT challenges including attrition and spill overs. The attrition rate of 11% was statistically acceptable. Spillover occurs when households share one or more of the lights they received and may lead to under-estimation of the treatment effect if unaccounted for. Comparing households that received free lights to households in control villages indicates the effect of the lights. Comparing households that did not receive lights despite being in "free lights" villages, to households from the control villages, provides an estimate of the spillover effects. Hence, our study measured a lower bound of the true potential impacts. To get a grasp of the extent to which households shared their lights, relevant questions were included in the household questionnaire.

1.6.6 Generalizability of gender empowerment interventions we test in this study in other contexts?

The Nuru business model ordinarily works with village level enterprise groups consisting of 5 - 10 entrepreneurs. By varying the composition of females within each enterprise, such groups were used to assess the impact of gender mix on business profitability and empowerment.

A very limited number of other participants in this sector (such as Solar Sister and SSP India) exclusively use groups of women to promote and distribute their products. Most of these enterprises have obtained qualitative feedback about the positive impacts of such arrangements, but very little quantitative evidence has been collected to support it.

Although this is apparently the first study specifically to use randomized control trials to study female empowerment in the renewable energy sector, this research and its findings create an opportunity for similar methods to be used in energy and gender studies more broadly, given the importance of simulating these results in different contexts and with different business models.

Outside of the energy sector, studying how to increase the participation of females in local entrepreneurial ventures adds relevance to the entrepreneurship sector across industries and provides evidence regarding the gains in terms of business sustainability and gender empowerment, and the potential for spillover in both the household and in the community. We hope that our research will provide further impetus for tackling this important area of research and expanding on the use of rigorous quantitative methods to motivate evidence-based policy formulation pertaining to gender empowerment.

2 CHAPTER: EMPIRICAL EVIDENCE OF THE IMPACT OF GENDER MICROENTERPRISE RANDOMIZATIONS ON FEMALE EMPOWERMENT

This chapter presents the results of the VLE gender randomizations conducted in the LED renewables sector. The study was a clustered randomized controlled trial in 272 villages in two districts in rural Rwanda. The intervention involved the recruitment of teams of micro-entrepreneurs, varying the gender composition of teams experimentally into, all-male, all-female, and mixed-gender (2 males, 2 females). The results indicate the impact of empowering female entrepreneurs on business performance, and on such household level outcomes as, prosocial expenditures, girls' aspirations, gender attitudes and time-use.

2.1 Background

The main problem motivating our study is systematic discrimination against female participation businesses management, even where both genders are equally qualified. This discrimination has two consequences: (i) women are less likely to operate businesses, and (ii) women who operate businesses are usually confined to low-paying activities. Moreover, even women who manage to access businesses in profitable sectors face a number of social barriers that makes their firms less profitable than male-operated firms (Buvinic and Furst-Nichols 2014). An important aggravating factor identified in the literature seems to be the perceived disadvantages of women as entrepreneurs (Baron, Markman & Hirsa, 2001). Some experimental studies show that women tend to perform better when competing exclusively against other females (Gneezy et al., 2003; Niederle & Vesterlund, 2007). This is worsened by cultural and social barriers that can affect a female-run enterprise, like access to credit, which can be constrained by lack of collateral (Bushell, 2008), lack of role models, and low social approval (Rodríguez & Santos 2009).

Uncovering solutions to this problem is vital for development since gender discrimination generates allocative inefficiency, reducing current production as well as the welfare of women. In this particular case, allocative inefficiency is especially problematic since it also

hinders future growth, given that females typically invest more of their income in their children's human capital formation than males.

An important body of literature the effects of transfers of physical capital, skills, and grants on business performance. Transfers of physical capital (e.g. provision of machinery) have been shown to have positive returns, albeit influenced by the owner's socio-economic status (Fafchamps et al. 2014, de Mel et al. 2009). When asset transfers were complemented with skill training, earnings of poor women increased, however, grants without skill training were effective only among large female-owned enterprises (Bandiera et al. 2013). In Sri Lanka, cash grants invested in the business also increased both profits and the numbers of hours worked (de Mel et al., 2008). In Uganda, cash grants increased earnings and capital stock of female more than males (Blattman et al., 2014). Other researchers provide subtler solutions, such as Dupas and Robinson (2013), who provide female micro-entrepreneurs in Kenya with access to bank accounts, increasing savings and investment in business.

Another branch of the literature pays close attention to the role of networks, providing evidence that family support, social ties, and internal motivation, as well as close role models, affect positively the success of female entrepreneurs in small businesses (Alam, Jani and Omar, 2011; Halkias *et al*., 2011; Fairlie & Robb, 2007; Campos *et al*. 2013). An experiment conducted by Field *et al*. (2014) with Indian women shows that attending informative sessions with a friend increased the propensity to take out a loan for business, which subsequently improved business performance.

Besides increasing income, this type of intervention can increase a female's social standing (Bandiera *et al*., 2013). For instance, Bandiera *et al*. (2014) study the transfers of human capital in a large-scale randomized control trial in Uganda. In this study, adolescent girls were given an opportunity to simultaneously accumulate "hard" vocational skills (to enable them to start small-scale income-generating activities) and "soft" life skills (to make informed choices about sex, reproduction and marriage). This combination of skills generated substantial advances in economic and gender empowerment, through girls' improved control over their bodies (Bandiera *et al*., 2014).

The consequences of program failure must not be overlooked, although we usually know less of failed interventions, partly because of publication bias. Participants in empowerment programs usually belong to poor and vulnerable households that have invested important resources in the program. Failure would put them in an especially vulnerable situation. For instance, Leach & Sitaram (2002) report that, as a result of business failure in their study setting, some beneficiaries almost lost their houses, which had been used as loan collateral. An additional cause of failure is not taking the context into account (Surender and Van Niekerk, 2008). To minimize the probability of business failure, the team randomly allocated 100 lights per village for free, thus creating demand from the start.

The study contributes more specifically to the literature on capital transfer. Its main contribution lies in experimentally varying the gender composition of micro-entrepreneurial teams in the context of very low female participation, as well as in having prospective teams that were randomly sorted into the control group in a large number of villages. To our knowledge this has not been done before. The intervention research

design allows comparison between the performance of female (and mixed-gender) teams and male teams, and further comparison with female and mixed-gender teams hat did not receive any intervention. How the business proceeds are spent, particularly investment in children's health and education, wil be examined in the study. The next section provides details on the intervention described in the methodology under section 1.6.1, specifcally outlining the findings pertaining to our gender treatments aimed at empowering female VLEs and then goes on to highlight welfare impacts of the treatments for VLE households.

2.2 Results

Business Performance:

*Result 1: Business performance is similar across Village-Level Entrepreneur (VLE) groups, indicating that **female VLEs perform as well as male VLEs**.*

Our analysis of the business data from GSM and that provided by Nuru indicated that there is no significant difference in performance between male and female VLEs. This is also confirmed by the self-reported microenterprise income obtained in the endline surveys of VLEs. Appendix I, Table 1 shows the results for business level revenues (based on recharge frequency) obtained via GSM and self-reported individual microenterprise income. Our findings indicate that there is no significant difference in the performance of female teams and mixed teams compared to the all-male teams. This is important in terms of the potential for including more women in the renewable lighting sector, by simply including gender quotas, since there is no financial risk for Nuru (and potentially not for other renewable energy businesses) from using such gendered microenterprise models.

The section below briefly discusses some additional findings with respect to education, health and aspirations. Other welfare impacts obtained through the surveys are still being analysed and will appear in the academic papers emanating from this work.

Secondly, in all-female VLE households, there is a significant effect on the education of school-age children, because of increased time spent reading or studying at home, compared to all-female controls and male VLEs (almost an hour more per week). Female VLEs are also more likely than the female controls to report expecting their children will be studying in 3 years' time. Children from female VLE households are more likely than those from female control households to report that they expect to find a job they enjoy. On the other hand, there do not seem to be any differences in the well-being or life satisfaction of the household head.

Effects on Education

*Result 2: In **VLE household's children study one hour more per week than children in the control group**. Further to this, **children in Female-VLE households' study 51 minutes per week more than those in male-VLE households**. These treatment effects were all significant.*

There are a number of interesting impacts on education variables. For instance, **access to a VLE position increased average study time among school age children in households of all-female VLE teams by 15 minutes per day (one hour per week) with respect to the female control group, and by 9 minutes per day (51 minutes per week) with respect to all-male VLEs (See chart 1). Mixed groups saw increases of 18 (compared to the mixed control group) and 12 minutes (compared to the all-male group), respectively, although these changes are not statistically significant.** These are sizeable effects, especially after considering that study time is more effective given the better lighting conditions. We can however not draw any conclusions on what the impacts of these gains in studying time means in terms of other education outcomes such as improvements in school performance or attendance. There are also no effects on education expenditure variables, like lagging in school fees.

Chart 1: Children's education

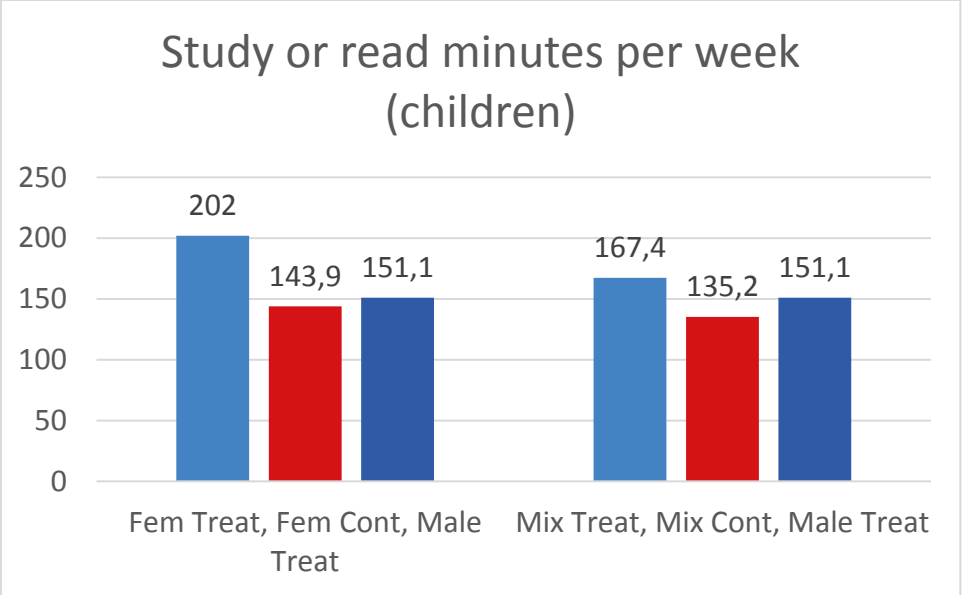


Photo 2.1: A child in rural Rwanda. Photo Bhavani Shanker Uppari

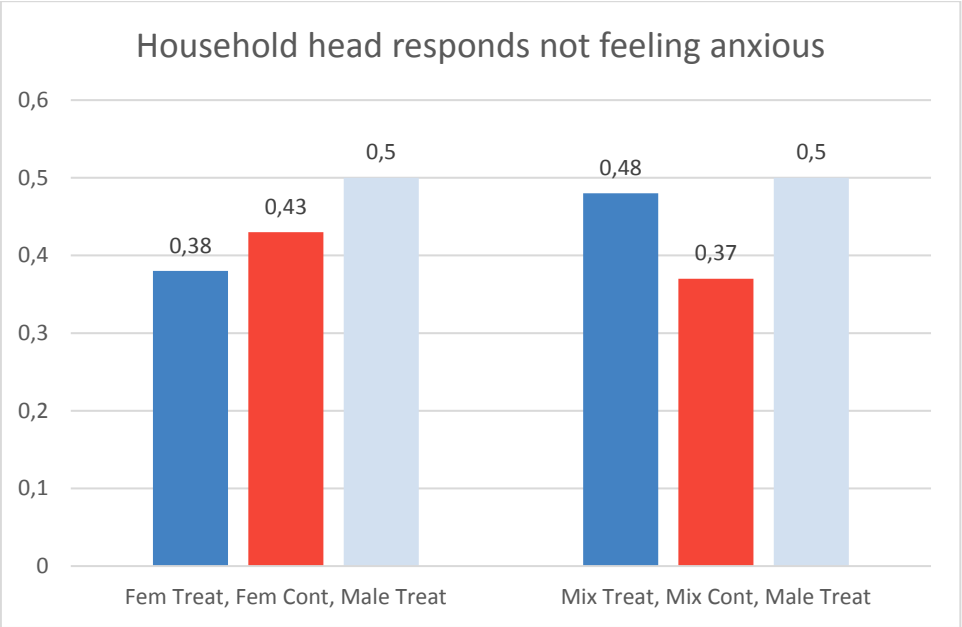
Effects on Health

Result 3: Satisfaction with light increased markedly (and significantly), by around 24 percentage points among all VLEs, with no differences by VLE group composition.

There do not seem to be major effects on physical health status, like the number of ill days or perception of overall health. However, there are important effects on mental health. For instance, teens from female VLE households are 16 percentage points more likely to report feeling happy than teens from female controls. *Overall **satisfaction with lighting** increased by 24% points for all VLE groups compared to control groups, while we did not find significant differences between all-male, all-female or mixed groups.* While ***satisfaction with light*** **increased**, satisfaction with life in general and happiness right now, did not increase. Other dimensions, like feeling in control of their life were also not affected by treatment.

Interestingly **VLEs from all-male groups reported significantly greater anxiety than the control group, and also compared to the other VLE groups (See chart 2).** It is worth exploring why male VLEs reported higher anxiety levels.

Chart 2: Mental health

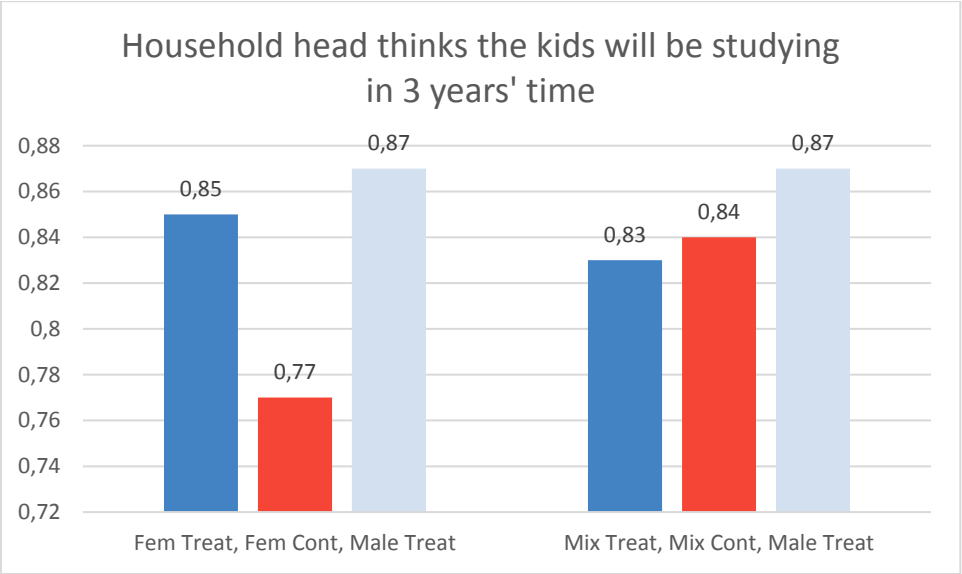


Effects on aspirations

Result 4: Female VLEs are more likely to report they expect their children will be studying three years after the survey (compared to females in the control). *Evidence on other aspirations outcome variables are mixed.*

We find that female VLEs are 8 percentage points more likely to report they expect their children will be studying three years after the survey (compared to females in the control) and that this is significant (chart 3). Once again, there are no statistically significant changes in the mixed VLE groups. However, against our expectations, there do not seem to be large effects on other expectations, like expectations of a well-paid job, or expected education level, expectation of working now, immediately upon graduation, or five years after graduation. Children of all-female and mixed VLE households are less prone than children of all-male VLE households to report they are likely to get a job upon graduation.

Chart 3: Aspirations



Result 5: Expenditure levels in VLE treatment households are higher than those in control households.

In terms of welfare impacts of the overall microenterprise program we find preliminary evidence of raised household expenditure levels for the treatment VLE households compared to those in the control group which are significantly different.

As shown in charts 4 and 5, we find a significant and large increase in non-lighting expenditures (see appendix I for greater detail). Specifically, food expenditure increases, and this is significant. Household savings also rise but this effect is not statistically significant. Given recording detailed household consumption and expenditure is considered the most accurate way to measure changes in poverty, our results are therefore more significant. Note that results are preliminary and subject to change. All differences in the following charts are significantly different at conventional statistical significance levels.

Chart 4: The impact on household expenditure

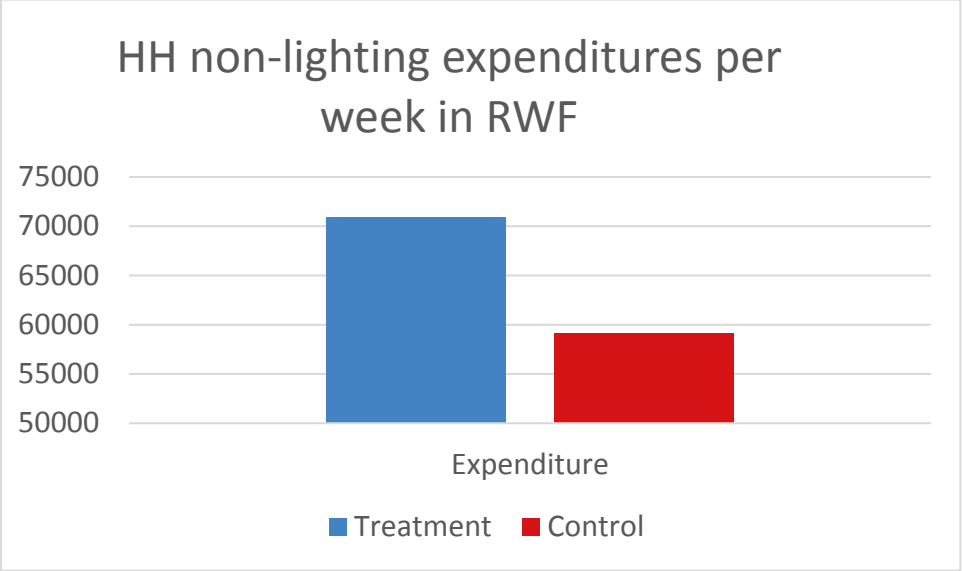
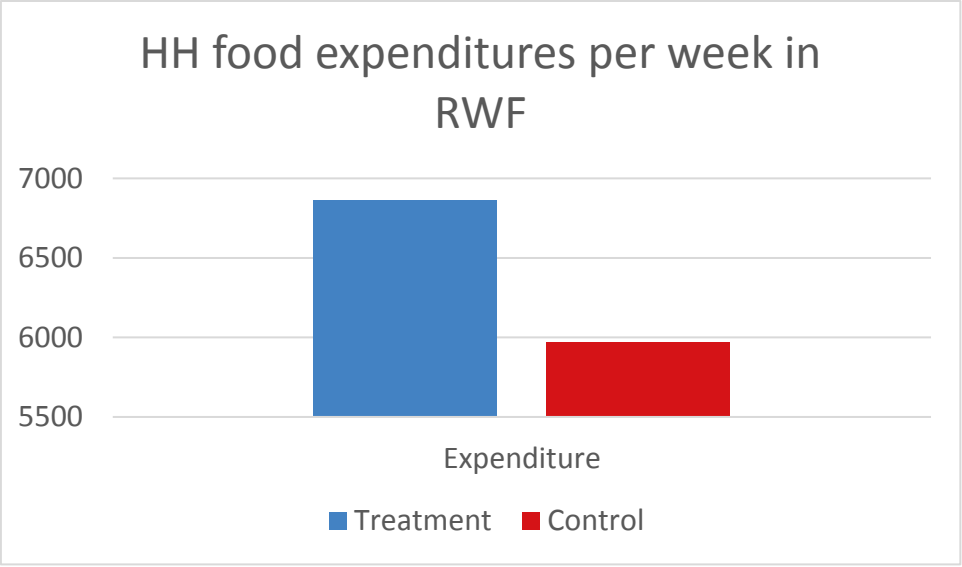


Chart 5: The impact on household food expenditures



Result 6: Welfare impacts of Scaling up LED access to the rural poor: The intervention reduced the probability of households using dirty lighting by 14 percent. There was also a reduction in the use of low-quality battery-operated lights such as cheap flashlights. Importantly overall expenditure on lighting went down by 23 percent and on dirty lighting by 59 percent. The probability that children studied with a dirty lighting source decreased, whereas it increased the probability they studied with a clean source.

Chart 6: Proportion of households using a dirty lighting source at endline

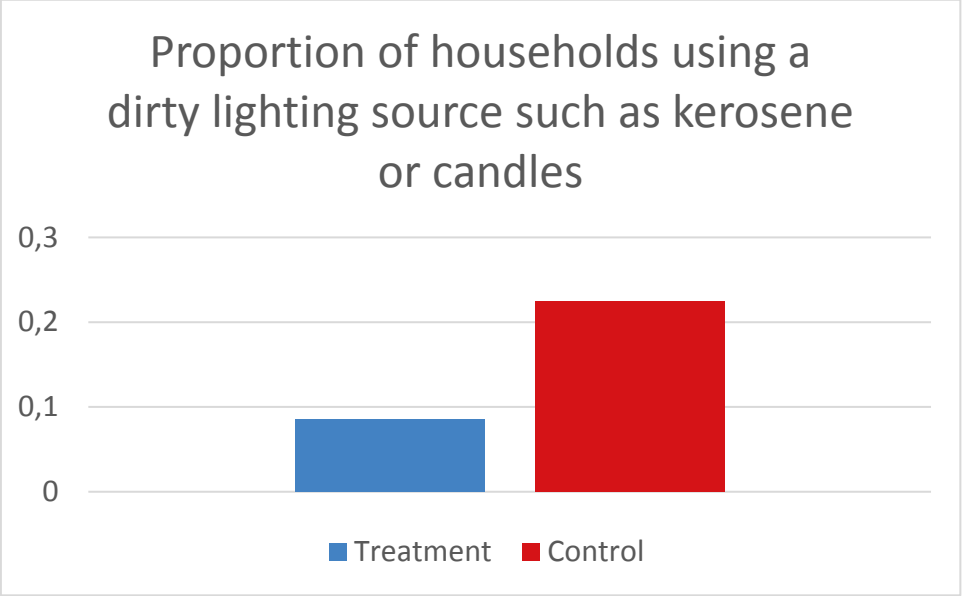


Chart 7: Household expenditures on lighting

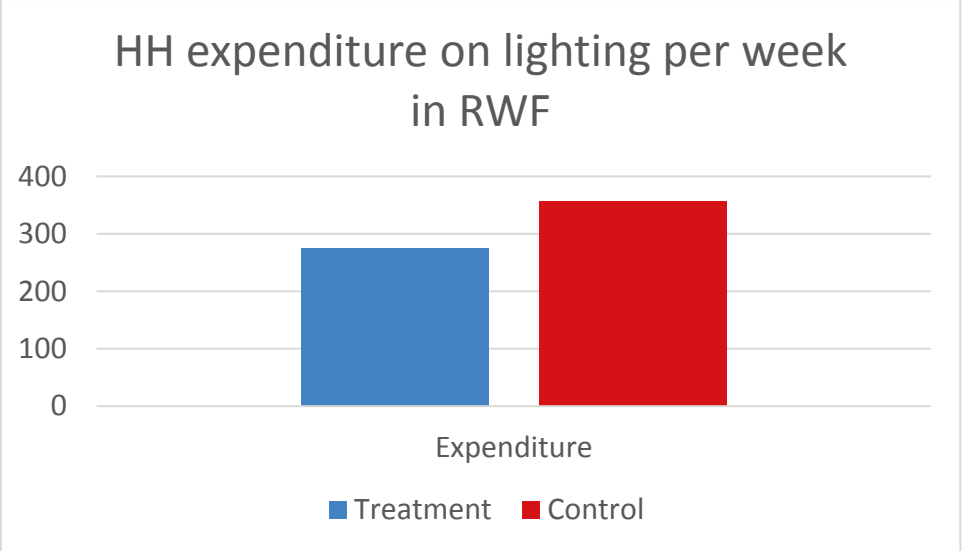


Chart 8: Household expenditures on dirty lighting

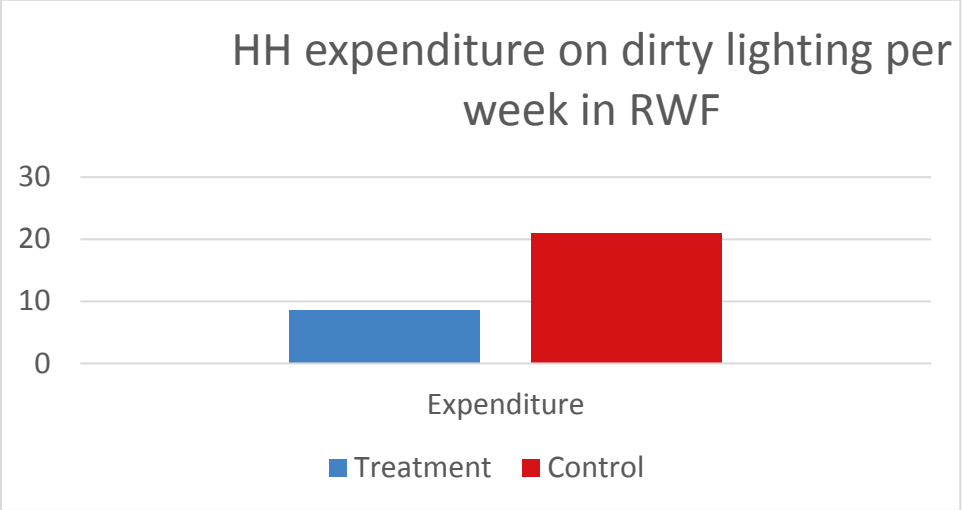


Table III (Appendix I, as well as charts 6 to 8 inclusive) presents the main welfare impacts of lighting. All standard errors are clustered at the village level, the level of randomization. The table reports the coefficients, and standard errors in parentheses, from OLS regressions of outcome variables on treatment - two solar lights. Column 1 reports the impact on the probability a household uses a dirty lighting source, defined as kerosene, candles, and fire. The intervention reduced the probability of households using dirty lighting by 14 percent. There was no impact however on whether a household used kerosene, but there was a reduction in the use of low-quality battery-operated lights such as cheap flashlights. Importantly overall expenditure on lighting went down by 23 percent and on dirty lighting by 59 percent. Finally, solar lights reduced the probability children studied with a dirty lighting source and increased the probability they studied with a clean source. All results are statistically significant. There was no impact on accidental fires or study-time, results not shown.

Overall there are significant policy implications related to these findings from our study. In the context of this business model, quotas can be implemented with no negative impact on profitability, while dramatically increasing participation by women from 10 to 50 per cent. Indeed, all-female teams perform 9 per cent better than male teams, but this difference is not statistically significant. Furthermore, such a quota system has positive spillover effects, leading to prosocial impacts on entrepreneur households. And lastly, significant welfare impacts can be expected if the program is scaled further. This research provides motivation to do so. On the policy front – these findings hold much promise for redressing gender inequality and also to tackle social norms related to gender issues.

3 CHAPTER: A QUALITATIVE PERSPECTIVE ON EMPOWERMENT OF FEMALE ENTREPRENEURS

3.1 Background

The world today tends to place a lot of weight on statistics and facts that can be verified. Despite this preference, one cannot completely rule out human experience. Entrepreneurs can have different and unique experiences which are not fully captured by quantitative datasets.

To supplement the different quantitative approaches already discussed, the team also had personal encounters with VLEs. The objective of these encounters was to understand better the extent to which establishing energy microenterprises has empowered VLEs, especially female ones, and how this may have affected their livelihoods either positively or negatively. However, unlike the quantitative aspect of this study which was conducted on a large scale, the results discussed in this chapter are based on a smaller sample of 15 VLE's and 15 key informants including users and non- users of Nuru lights in the Rulindo district of Rwanda. Findings here, only provides us with key insights about VLE's operations. The motivation and methodology for our survey methods utilized is described in section 1.6.2.

Case Study: VLE Group operations

A typical VLE group has four members operating a central recharge station in each village. One of them is usually selected by group members to keep the central charging system known as the "Octopus". The designated person's house becomes the central recharge station for customers in the village.

The choice of where the "Octopus" is stationed depends on which of the VLEs lives closest to the village centre. This proximity makes it very easy for customers to access recharge stations. The VLE in whose house the "Octopus" is stationed automatically becomes responsible for recharging customer's lights. Other roles, such as the VLE group leader, the treasurer, and a person to follow up complaints of broken lights, are agreed upon by members of the group. Even though one person is designated to operate the "Octopus" and charge lights for customers, other VLE group members visit the recharge centre frequently to assist.

On a typical day, VLEs charge from four to six lights on average and between twenty and sixty lights per week, depending on the demand by customers. VLEs usually leave home early in the morning to go to either their farms or their place of work, and frequently return by 1 p.m. This is the usual routine of most people living in rural Rwanda. Thus, VLEs return from their place of work at the same time people start visiting the village centre for either recreation or to buy food. Most customers visit the recharge stations to charge their lights during this period.

Normally, since customers prefer to leave the lights at the recharge station and return for them hours later, VLEs do other domestic activities once the lights are plugged into the "Octopus".

VLE groups usually meet either once a week or twice in a month to take stock, buy units and discuss other challenges facing their enterprise.

3.2 Key Findings

Qualitative Result: Our qualitative results indicate that benefits from becoming a VLE are manifold, ranging from improved access to lighting (allowing females to work after dark and males to spend time on finding food for livestock, while children benefit from additional time to study), supplementary income (e.g. increased food purchases amongst female VLEs and increased leisure expenditures as well as savings amongst male VLEs) and an elevated status in the community.

Photo 3.1: Interacting with a VLE during our visit. Photo credit: Emmanuel Kwizera

In Figure 3.1 we show (by gender) how VLEs feel they and their household benefited from becoming energy entrepreneurs. Generally, we see that becoming a VLE have positive effects. According to entrepreneurs, access to clean lighting is the primary benefit of operating their respective enterprises. These lights are very portable and assist them with daily activities both at home and in shops. The uses and therefore the benefits of these modern portable lights vary with gender and age. While women often use lights for domestic activities which are now shifted into the night, men use these lights for harvesting grass for their livestock – most households in rural Rwanda engage in some form of livestock rearing. Children on the other hand, according to our respondents, normally use these lights to revise their notes after school.

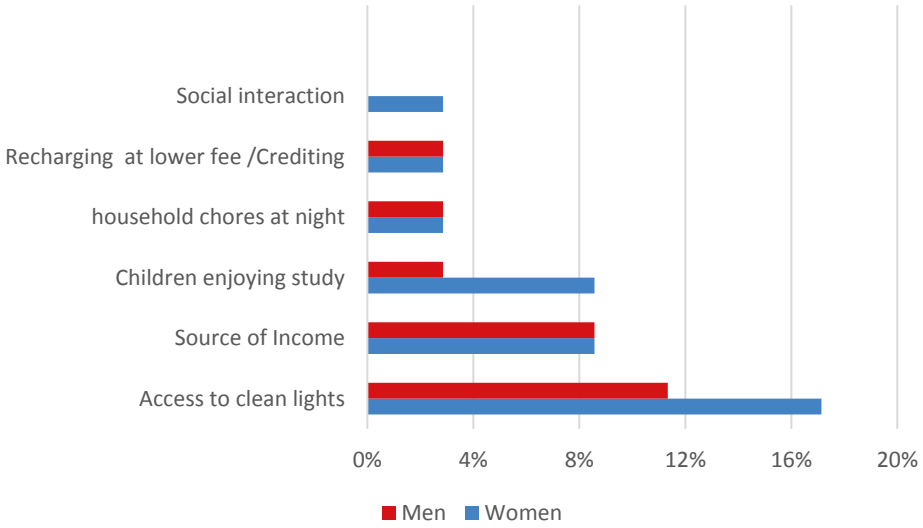


Figure 3.1: Benefits of becoming a VLE by gender

Both men and women viewed VLE activities as a source of income. People living in Ruhango and Rulindo (our study area) are mainly subsistence farmers and traders. However, more people in Rulindo engage in food crop production for commercial purposes than in Ruhango. Becoming a village level entrepreneur did not prevent them from participating in their traditional activities. Instead, by combining the responsibility of being a VLE with their day to day activities, they were able to make extra income.

Most of the respondents use their extra income to buy groceries and food items for their households. However, women were more likely than men to use their money for household items. Only one woman reported saving her extra income; all other women in the sample used their money to purchase food items. Men, on the other hand, are more likely to spend their extra money on drink or buy livestock, and sometimes to save their money with informal savings groups.[5]

It was also clear that female VLEs gained some level of social recognition in the villages. They were able to meet more people and sometimes serve as mediators in disputes. As one VLE explained, *"…because I am a VLE I get to now meet a lot of people and others come for advice from me. I am trusted, and I think I can now contest for the position of a village leader."*
Although the primary goal of the research project was the economic empowerment of women and the provision of lights for the poor, the knowledge that female VLEs are gaining recognition and status in their communities is an additional insight gained from the study.

Time Use:

Access to clean lights has been shown to reduce the time spent on domestic activities such as cooking, collecting firewood or other types of fuel, and doing other household

[5] This is not to say that women do not participate in informal savings but, as far as income from the Nuru business model is concerned, men are more likely to save while women spend their income on basic needs for their households.

chores. When respondents were asked what difference becoming a VLE and using clean lights made to their use of time, the majority believed that nothing had changed, as charging lights for customers did not occupy much time in the day and did not prevent the VLE from doing other things. Also, because VLEs are working in groups of four, they are able to share the workload between them.

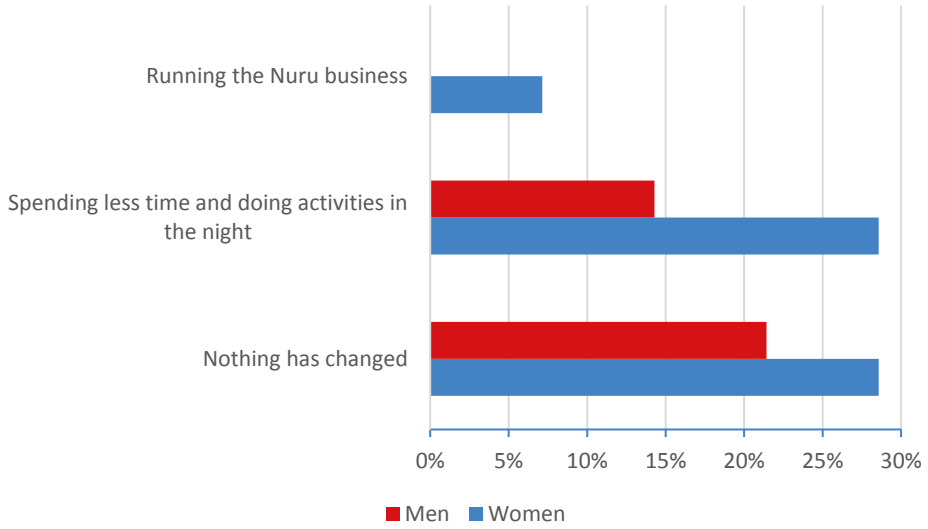


Figure 3.2: How differently VLEs perceive their time use after the commencement of their businesses

However, because of the use of lights, VLEs apparently spend less time on household activities. Major activities such as cooking, and washing are now delayed to the night. Women now spend more time cultivating crops, as they no longer rush to get home early. This is because they can do other chores in the evening when they get home without worrying about darkness. Also, owing to the portability of the lights and the ability to carry the lights around the waist, users are able to work freely while the lights are on. Women are therefore able to cook and wash with light at night. Thus, access to lights enables women specially to redistribute the time they spend on household chores more efficiently.

VLEs' Aspirations:

To establish if VLEs' aspirations have changed as a result participating in the entrepreneurship program, VLEs were first asked what their aspirations were before they became entrepreneurs (see Figure 3.3 for their responses). The rectangular shaded area shows that most VLEs wanted to engage in some form of business to enable them to increase their income. The second significant response from VLEs was that they aspired to own a house and livestock. Having house and cattle is an indication of wealth in rural Rwanda and brings prestige and status in the villages. It is not surprising that VLEs aspire to become house and livestock owners.

However, while more men aspired to become homeowners, more women aspired to engage in business activities, join cooperative associations, own some livestock for fertilization purposes, become a teacher, or get rich. Further, VLEs did not seem to

change their aspirations after becoming entrepreneurs. When respondents were asked how their aspirations had changed after becoming VLEs, 44% stated their ambitions were still the same, and another 44% were undecided. Only 12% of respondents showed a change in aspirations after becoming VLEs.

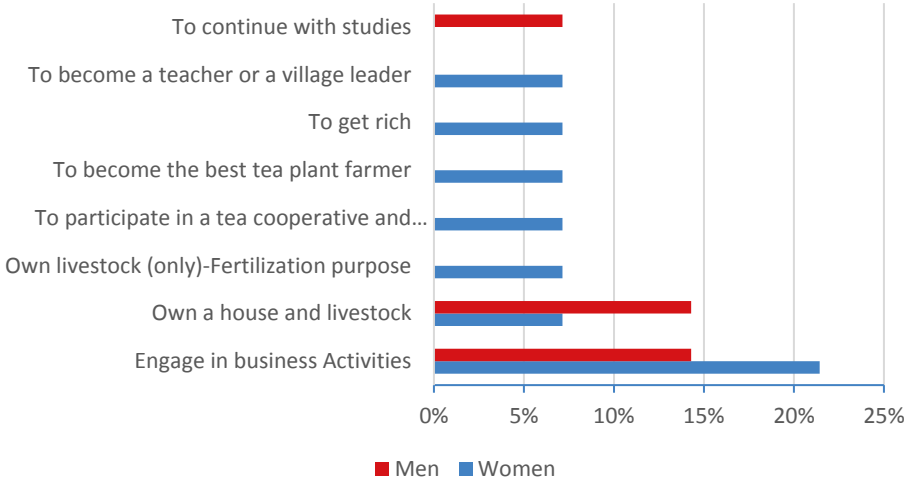


Figure 3.3: VLEs aspirations before becoming VLEs

Apart from access to clean light, becoming an entrepreneur also provided additional income and investment opportunities for VLEs. This extra income is used by women to support their households. Additionally, women gain social recognition which has given them some level of prestige in their communities. Access to lights has also allowed women to shift domestic activities to the evenings, freeing up time during the day for other activities. Finally, VLEs' aspirations have remained the same even after becoming entrepreneurs, showing that the program has not affected the original ambitions of the respondents.

Photo 3.2: An excited VLE holding her charging system "Octopus" during our visit. Photo credit: Rebecca Klege

4 CHAPTER: GENDER DIFFERENCES, RISK AND COMPETITION

4.1 Introduction

Entrepreneurship is a critical tool for generating livelihoods and empowering women (Baruah, 2017). Over recent years, the renewable energy sector has not only provided communities with access to modern energy sources but has also become an enabling environment for entrepreneurship and self-employment, with a focus on women. Nevertheless, gender differences in employment are still extensive. The most obvious gap is in participation rates and performance levels of women in the labour market. Shane, Locke and Collins (2003) identified two predominant characteristics associated with successful entrepreneurship; risk-taking abilities and the willingness to compete.

Existing evidence shows that:

1. Attitudes towards competition and performance levels in competitive environments differ by gender, with women being reluctant to enter competitions and usually being outperformed by men in these conditions (Dato & Nieken, 2014; Croson & Gneezy, 2009; Niederle & Vesterlund, 2008, 2007).
2. Women generally are less likely than men to take risks (Croson & Gneezy, 2009).

This means that, apart from the well-established socioeconomic barriers affecting women's participation in the labour market, women's willingness to compete and their attitude to risk can also influence their performance levels, even after taking up entrepreneurial roles. Without due consideration of women's attitudes to risk-taking or their competitiveness, deliberate attempts to empower women in the renewable energy sector through entrepreneurship initiatives, such as Solar Sisters, Women Integration into Renewable Energy (WIRE), Women's Entrepreneurship in Renewables (wPOWER), and the purpose-designed Nuru business model which empowers women, women still might not reach their full potential.

Further, behavioural insights have been increasingly used in the fields of Psychology and (more broadly) Economics. Environmental and energy economists in recent times are attracted to field and laboratory experiments because of their ability to offer researchers the advantage of making precise causal inferences about specific problems. Energy economists have used key behavioural insights from field and laboratory experiments to understand issues such as the adoption of modern cook stoves, the transition from traditional to modern cooking fuels, the uptake of new technologies in the renewable energy sector, and many other energy-related topics (Bench & Peters, 2015; Dupas, 2014a; Hartmann & Apaolaza-Ibáñez, 2012; Willis et.al., 2011). This is because understanding individual behaviours is key to answering questions such as why, despite obvious health hazards associated with indoor pollution, people still find it difficult to switch from traditional stoves to modern ones even when they are distributed free?

Similarly, gender economists have been able to use several laboratory experiments to answer questions on the wage gap between the genders and female performance levels in schools using the controlled environment such methodologies provide. Surprisingly, studies related to both energy and gender have not yet fully exploited the ability to make causal inferences, owing to an overreliance on qualitative and traditional quantitative research techniques.

This chapter introduces for the first time in the energy- gender literature how methodologies borrowed from behavioural economics can enable researchers make inferences about gender differences and behavioural attitudes among VLEs, which are key determinants for running a successful enterprise. We specifically discuss findings from economic experiments on how competitiveness and risk-taking behaviours differ between gender groups and how such differences can determine the success of VLE groups in the business model. The methodology utilized here is described in detail Section 1.6.3.

4.2 Differences in Competition

Running one's own business can be very competitive and may be particularly challenging for women. Discrimination and similar factors could explain why only a few women engage in entrepreneurial activities or take up managerial positions. Women generally dislike the long working hours associated with managerial roles and running a business. This may be due to other domestic responsibilities they are faced with, such as household chores and child care. More recently, it has been suggested that women tend to be less overtly competitive, which may also contribute to the lower representation and performance in entrepreneurial positions (Niderle & Vesturlund, 2008).

The nature/nurture argument in psychology is normally used to substantiate the observed gender differences in competition. According to psychologists, nature and nurture yield a psychological benefit for men while imposing costs on women (Campbell, 2002) which cause inherent differences in competitiveness for men and women. This may explain why at the subsistence level, female-operated firms are less profitable than those operated by men (see Buvinic & Furst-Nichols, 2016)

Despite the importance of competitiveness in contributing to successful business growth, existing energy business models do not consider women's abilities to compete when establishing energy microenterprises. The Nuru business model can explicitly study the differences in competitiveness by gender and how well competitive outcomes mirror the true performance in their respective businesses.

Studying the impacts of gender on competitiveness was done using standard economic laboratory experiments in the field. Such experiments have several advantages. Firstly, using them to study gender differences enables the researcher to eliminate any form of existing or potential gender discrimination. Secondly, real- life issues such as child rearing and time commitment, which influence differences in preferences, can be ruled out. Finally, these experiments enable precise measurement of performance levels (Niederle & Vesturlund, 2008).

Photo 4.1: Cross section of village level entrepreneurs participating in competition experiments Photo credit: Rebecca Klege

4.2.1 Key Findings on Competitiveness

Result 1: Overall, women operating as village level entrepreneurs in rural Rwanda do not shy away from competition. Controlling for performance shows no gender difference in the uptake of tournament, and thus competitiveness.

Women operating village level microenterprises select competition 43% of the time while men 49% of the time as depicted in Figure 4.1. Despite the marginal difference between women and men competition entry, we see no substantial difference (P=0.299). Like Dariel et al., (2017) recent finding that Emirati women do not shy away from competition, these results run counter to the general observation that women are less willing to enter competition. However, there may have been some selection-bias in the sample as women who end up as entrepreneurs are likely to be more competitive than women in the general population.

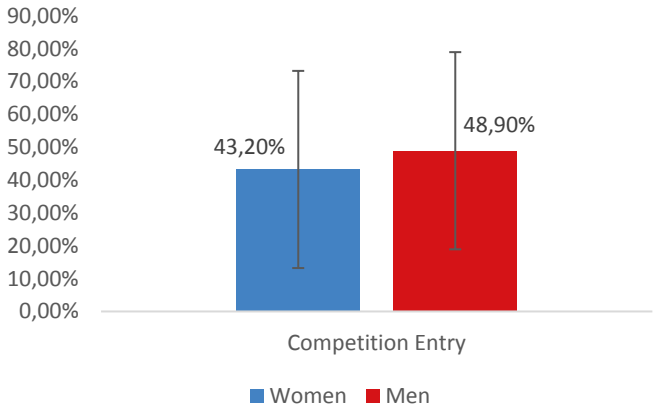


Figure 41: VLE's Tournament Entry Decisions

Nevertheless, the finding is unsurprising in the context of Rwanda. After the genocide, seventy percent of Rwanda's population were women. This forced the country to involve women in the rebuilding of the nation. As a result, traditional male dominated positions were offered to them. The progressive women empowerment policies in Rwanda could be a contributing factor why women in Rwanda show such competitive behaviours.

We also explored factors influencing the competitiveness of individual entrepreneur's - See Appendix I, Table IV. The results show that whereas VLE's performance significantly affects their decision to enter competitions, their decision to either opt in or out of the tournament is not influenced by gender. Education (measured in number years) on the other hand, mainly affects VLE's competition entry decisions such that, the higher the education level of VLE's the more willing they are to engage in competition.

Result 2: Women under competitive situation perform as well as men.

There was no visible gender difference in the number of problems solved by VLEs who entered the tournament (See Appendix I, Figure I). In terms of performance, although that by men was slightly higher, the difference was not significant.

To contextualize these findings, performance and competition attitudes of VLEs under experimental situations were compared to the actual performance of the off-grid renewable microenterprises operated by VLEs. The results show that women operated microenterprises are able to recharge lights for their customers equally well as their male counterparts. In addition, female operated microenterprises performed as well as male ones, implying that results from the economic experiments reflect real world operations of the VLEs as reflected in our gender-based trials discussed earlier.

4.3 Differences in Risk-taking attitudes

Running and managing a business involves risk. Individuals' risk preferences influence economic decisions when outcomes are uncertain, such as with business investments, portfolio allocations, choice of occupation, and time allocation between leisure and work. A successful entrepreneurship activity will require some level of risk-taking behaviour.

The current Nuru Energy business model on which the study is conducted operates in such a way that Nuru Energy sells single rechargeable LEDs to households via local microenterprises at a subsidized cost. These lights, as well as mobile phones, are then fast-recharged by a centralised solar powered recharge station, operated by village level entrepreneurs for a fee. This at first sight seems to be a smooth process with few or no risky decisions to be made by VLEs.

However, village-level entrepreneurs must decide whether or not to buy units in the hope that customers will come recharge their lights. A risk-averse VLE group might be unwilling to commit more financial resources to buying recharge units from Nuru Energy, but by doing so they run the risk of underperforming and eventually failing as a business.

Gender differences in risk-taking preferences have been well documented in several studies (see Croson & Gneezy, 2009 for a detailed review). There is, however, no consensus about the risk-taking abilities of men and women. It is important to understand the risk-taking behaviours of entrepreneurs to enable future assessment of the sustainability of such business models when the empowerment of women is the focus.

Photo 4.2: Village level entrepreneurs anxiously waiting to try out the spinning wheel depicting the probability of taking a gamble. Photo credit: Janvier Rurangwa

4.3.1 Key Findings on Risk Taking

Result: Most of our entrepreneurs are not risk-takers. However, women are less willing to take risks than men.

Figure II, Appendix I shows the distribution of certainty equivalents – the guaranteed return that VLEs would accept rather than taking a gamble on a higher, but uncertain, amount — amongst VLEs for men (Panel A) and women (Panel B). The choices made show that, generally, most VLEs (more than half) prefer not taking any form of risk. We find that at a 30% probability of winning a higher amount in the gamble, 52% of men and 62% of women preferred not taking any form of risk.

As much as most VLEs would prefer not to take any form of risk, when we disaggregate the data by gender, we see that 10% more women than men prefer no form of risk-taking. It is therefore important to consider the different risk attitudes of men and women when tailoring entrepreneurship models for female empowerment.

5 CHAPTER: SUSTAINABLE PRICING OF LOW-COST SOLAR LIGHTS FOR THE RURAL POOR

5.1 The Policy Problem

More than 1.3 billion people worldwide lack access to basic electricity, with the highest concentration in Sub-Saharan Africa. Instead, traditional lighting sources are used, such as candles, kerosene, and open fires such as cooking fires, yet these are associated with severe health problems and make a significant contribution to global warming. Furthermore, almost 400 million Africans live in extreme poverty, with rural areas being the poorest. Given the expense of reaching often hilly rural areas, and the inability of grid expansion to keep pace with population growth, the current policy is to provide off-grid solar solutions via for-profit distribution. However, adoption remains low even though these products are of a higher quality (compared to candles and kerosene) and save on lighting expenses over time.

Barron and Torero (2017) conducted an RCT in El Salvador and found improvements in health from the replacement of dirty lighting, even in a setting of high use of biomass for cooking. Off-grid solar lanterns and home systems have been proposed as an answer. However, adoption of these technologies remains low, and preliminary evidence from RCTs is that many poor households are unable to afford even the lowest cost solar lanterns (Grimm et al, 2016b; Barron, Clarke & Visser, 2017a; Rom et al., 2017).

Empirical evidence from randomized controlled trials suggests that there is high price-sensitivity for products which contain a health component (Ashraf, Berry, and Shapiro, 2010; Cohen and Dupas, 2010; Kremer and Miguel, 2007; Kremer et al., 2009, Bates et al., 2012; Dupas, 2014a; Dupas, 2014b). Demand for such products is very price-elastic, meaning that a very small increase in price results in a large decline in adoption rates (Tarozzi et al, 2014; Dupas, 2014b). The high price elasticity of demand is mainly driven by budget constraints (Cohen and Dupas, 2010).

A review in Science (Dupas, 2014b) illustrates that demand for many low-priced products which contain a health component appears to decline rapidly as the price increases, even though households use and value such goods. “Take-up of water filters costing $14 fell from 89% to 21% when price increased from $1.40 to $4.20. Take-up of bednets costing

$7 was below 20% for any price above $2.50." (Dupas, 2014b). Cohen and Dupas (2010) find that uptake of insecticide-treated bednets dropped by 60% when the price increased from zero to $0.60. A 90% subsidy reduced adoption of the bednets to 10%, whereby free supply of bednets achieved a 99% adoption rate. In addition, Kremer and Miguel (2007) found that requiring a small fee for a deworming drug decreased uptake by 80% and thus significantly reduced treatment rates. The decrease in take-up levels was so sensitive to price levels as to make it counter-productive to charge a small fee. Further, it was found that demand for beneficial preventative health products is significantly lower when households need to make payments up front in cash (Tarozzi et al, 2014).

Photo 5.1: Solar panels used in the project. Photo Rowan Clarke

Similar results have been found in the context of solar light pricing. An RCT in Kenya tested the impact of different pricing structures on demand for solar lanterns across 1,400 households (Rom et al., 2017). The project used Greenlight Planet and d-light products and partners with SolarAid and SunnyMoney with research implementation by IPA Kenya and researchers based at ETH-Zurich. The results indicate that there is a large price elasticity of demand for solar lanterns. Lights were provided for free, $4, $7 and $9 (at cost) and it was found that take-up at $9 was only 29%, 37% at $7 and 69% when lights were subsidized to the level of $4 per lantern. Lastly take-up was 100% when lights were subsidized to zero (Rom et al., 2017).

This evidence from development field experiments has led to a loose policy consensus on the free distribution of health products given: i) very high subsidies are necessary to increase initial adoption. ii) households still value and use goods they paid low or zero prices for and iii) short-term subsidies raise long-term demand (JPAL, 2011; Dupas, 2014b; Fischer et al., 2016).

This is largely because current models are still far too expensive for the rural poor, and where they are successful, they do not reach the ultra-poor (Grimm et al., 2016). As Wong (2012) states: “Financial exclusion is among the main obstacles that constrain poor people from obtaining solar lighting”. Indeed, evidence from an RCT in Kenya showed most households were unable to afford the fee to connect to the grid (Lee et al., 2015).

Importantly, these views have been contested and the policy findings regarding subsidizing health products have not been clear cut. Ashraf et al, (2010) in the context of water chlorination, find prices play a screening role such that higher initial prices stimulate subsequent use, while most significantly Fischer et al. (2016) find a large role for price anchors: Free distribution of medication lowers long-term demand consistent with the predictions of models of reference-dependent preferences (Simonsohn and Loewenstein, 2006; Köszegi and Rabin, 2006; Mazar et al., 2013; Heidhues and Koszegi, 2014; Fischer et al., 2016).

This study adds to the debate by exploring these issues in the context of renewable lighting products.

5.2 This research

The study partnered with a social business focused on providing solar light solutions to the ultra-poor in East Africa with large-scale operations in over 1500 villages in Rwanda, where this research takes place. Using two large randomized trials, we show that price subsidies are required if the rural poor are to be reached, with adoption high with low or zero prices and virtually zero at market prices.

One argument frequently used by development agencies is that people will not value and use free products. The study shows that those who receive free lights use these over the long-term, and pay to use them, as much as those who paid a positive upfront price. Therefore, we recommend solar lights be subsidized for the rural poor.

Given that budget constraints and the policy environment may make subsidies unpalatable, the study also examines how social enterprises, the predominant actors in

the solar off-grid sector, can increase payments for, and use of, their products. Nuru Energy had tried actively but unsuccessfully to raise usage rates.

Many argue that short-run subsidies would lead to anchoring on the original low-price making people less likely to pay full price when the subsidy is removed. To address this a free trial period was introduced, during which usage fees are reduced or set at zero, and this was found to lead to higher long-run payments and usage after the trial ended and full user fees were charged. That is, the effect of positive learning and/or habit formation overrides any effect of price anchoring.

Follow-up surveys will aim to uncover the causal mechanism driving this effect. The free trial or subsidy intervention did not differ from any of the alternatives in providing information about the higher quality of the lights. Positive learning, i.e. a free trial giving households a chance to learn the positive benefits of lights that they were otherwise unaware of, can be ruled out as the main mechanism behind increased long-run use by households that received the short-run subsidy. This leaves habit formation as the most likely mechanism, contributing evidence to the literature on behavioural interventions aimed at nudging consumer behaviour in an optimal and health-promoting direction.

The results in the following section are based on the methodology covered in Section 1.6.4 of this report.

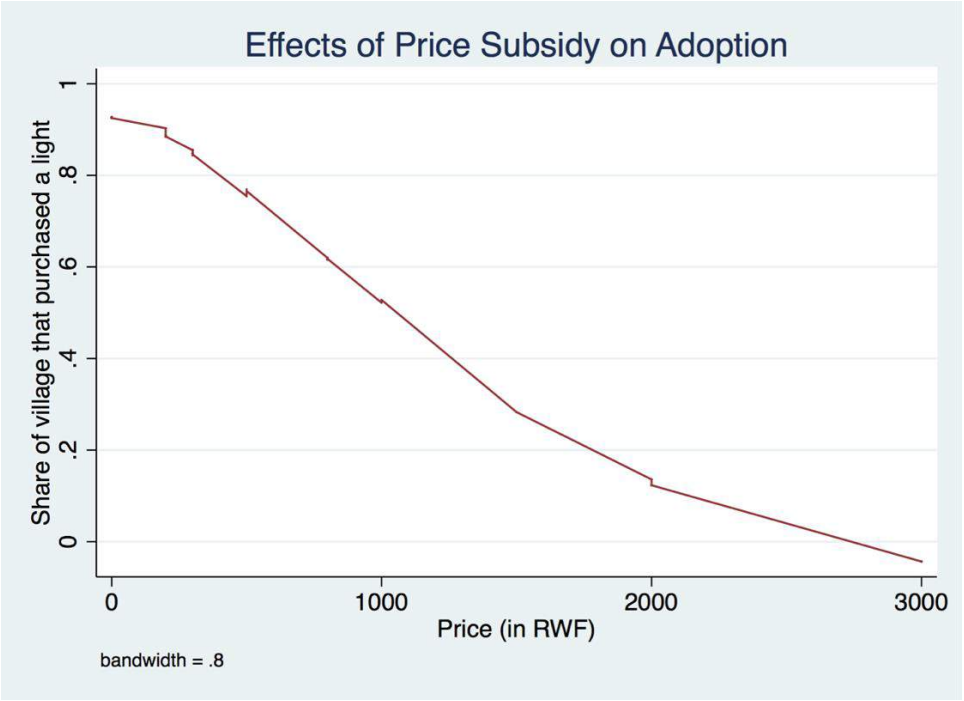
5.3 Empirical Results

5.3.1 Randomized trial I: Varying upfront Pricing of Lights

Result 1 Phase 1 (Upfront Pricing): We find that initial take-up, or adoption, of LEDs is highly price elastic.

The study randomly varied the upfront price of lights. There was strong evidence that subsidies are required if the rural poor are to be reached, with initial adoption of rechargeable solar LEDs very high at low or zero prices and very low at market prices. Figure 5.1 plots the proportion of households purchasing lights at each randomized price level (without use of control variables for regression adjustment). At zero-price, adoption is over 90 per cent, while at the full price of 3000RWF, take-up is zero per cent. From a policy perspective it is advisable, if subsidies are not possible, that lights be distributed at zero price initially, with pay-as-you-go micropayments used to recoup the costs over the longer term.

Figure 5.1 The effects of price subsidies on adoption



Result 2 Phase 1 (Upfront Pricing and long-run use): Varying upfront pricing does not impact the long-term usage of solar lights disproving the notion that people value goods more when they pay for them.

This component of the study relies on new automated data collection technologies to combine big data with household surveys which was specially developed for this research. Using the data on the randomly assigned upfront price paid, and objective remotely captured data on long-term usage, we show lights are still valued and used over the long-run even when received for free. We find no statistically significant effect of price paid (*Purchase Price*) for the lights upfront on the frequency of long-run usage of lights (See Appendix I, Table V). On the contrary, consumers who paid a positive price use their lights in the long-run less often than those that received them for free, although this is not statistically significant.

There is therefore no evidence that households won't use or value subsidized lights. Our results are therefore consistent with other recent studies in the renewable light sector (e.g. see Rom et al., 2017 and Grimm et al., 2017).

5.3.2 Randomized trial II: Varying the user fee or recharge rate

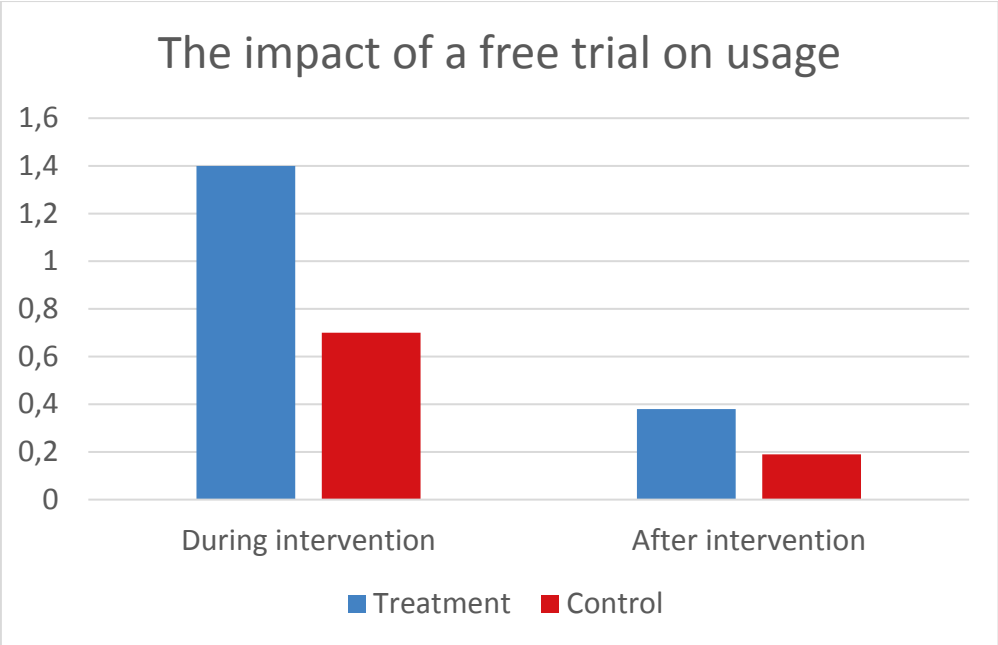
Result 1 Phase 2 (Recharge Pricing – long-run use): Long-run usage is also highly price elastic

In order to study the impact of recharge pricing on long term usage households received a light for free, to ensure adoption is 100 per cent, and instead faced randomly differing user fees. Using this data, we show that long-run use, like upfront price, is also highly elastic with respect to PAYG micropayments. Therefore, even charging very low micropayments, such as $0.20 per month, will reduce adoption and use substantially, again making at least partial subsidies preferable.

Result 2 (Recharge Pricing – long-run use): A free trial period (3-month) positively impacts usage up to 6 months later

If constraints on national budgets or policy preclude subsidized roll-out of solar lighting, how can profit motivated enterprises increase demand for these products amongst the rural poor? This study presents one way to increase long-run usage whilst also increasing revenues: short run subsidies, or a free trial period (user fee micropayments set to zero for 3 months), with cost-recovering micropayments thereafter. Chart 9 graphically presents the effect of the free trial, showing that usage remain higher amongst the treatment group that received the free trial three months after the trial ended.

Chart 9: The impact of a free trial, the intervention, on usage during a 3 month free trial and after the trial ended



These findings contradict those studies that argue that if products are given away for free households won't use or value the product thus reducing the screening effect of prices—where only households which value a good are willing to pay a positive price for it (Cohen and Dupas, 2010; Ashraf, Berry and Shapiro, 2010; Chassang, Padro i Miquel and Snowberg, 2012). Some studies have claimed that giving products to the poor for free leads them to not value or use them. We demonstrate that is not the case on a new product for the poor and using much higher quality data (richer and more objective) on usage than previous studies.

Photo 5.2: Clarke and Uppari in research discussion on one of many field trips in Rwanda, March 2015. Photo by Sameer Hajee

6 CHAPTER: BEHAVIOURAL MODELS

6.1 Background

One-fifth of humankind still does not have access to electricity (IEA 2015), so solar off-grid lighting has been promoted as a solution.

An alternative off-grid lighting model that is becoming prominent in impoverished countries is rechargeable bulb technology. Instead of selling rechargeable bulbs to consumers at full price, under this model firms either rent them or sell them at a subsidized price. Continued use of such bulbs requires that they be recharged at a (usually village-level) recharge centre for a small recharging fee. The revenue stream from repeated recharges makes it possible for the firm to subsidize the upfront price by financing it through ongoing payments. Sunlabob in Laos, Shidhulai in Bangladesh, and Nuru Energy in Rwanda are some companies which operate on this model. This study collaborates with Nuru Energy to explore the consumer behaviour and operational inefficiencies in the rechargeable bulb-based off-grid lighting models.

Because the consumers in the study are poor, their liquidity constraints, reflected in the business model through the recharge price and the bulb capacity (i.e., the amount paid for a recharge and the amount of light obtained in return), naturally play a role in determining the usage of bulbs. Moreover, unlike grid-based and solar-based lighting solutions, the rechargeable bulb-based model requires that consumers travel to the recharge centre to get their bulbs recharged. Villages in East African countries are spread over hills and typically have neither efficient public transportation nor even well-laid roads for walking. The surveys in Rwanda show that, for some consumers, a round trip to a recharge centre can take up to an hour. Since many villagers work as daily labourers, the time required to recharge a bulb is a significant inconvenience, and this impacts bulb usage. The study specifically examines, both theoretically and empirically, the relative impact of liquidity constraints and recharge inconvenience on the usage of bulbs.

6.2 Key Findings

Result 1 (Behavioural Interventions): The inconvenience associated with recharging is an important driver of usage.

Result 2 (Behavioural Interventions): The current recharge price is found to be too high for consumers with liquidity constraints.

This section analyses the determinants of consumer behaviour in a context of off-grid renewable lighting (LEDs) that has to be recharged centrally by Village Level Enterprises. The theoretical model of consumer recharge decisions takes into account the consumer's inconvenience cost related to traveling to the recharge centre, her blackout cost, which is experienced when there is no light, and the consumer's liquidity constraints. The empirical results confirm theoretical predictions, namely that strategies that address inconvenience tend to perform better than the ones that address liquidity constraints.

In a theoretical counterfactual scenario, where inconvenience is set to zero for all consumers, the expected number of recharges increases by 100%. This indicates that the recharge inconvenience is a significant contributor to inefficiency in this business model, leading to low recharge rates. The findings indicate that a door-to-door recharge service might help to realise the ideal case of zero inconvenience but would require a significant investment from the firm and would take time to implement. A more short-term (and relatively cheaper) strategy is to reduce inconvenience by opening more recharge centres.

Some price and liquidity-based strategies are also analysed, showing that the recharge price currently charged by the firm is too high, and that it would be optimal to drop the price. In the current business model, payments are coupled with recharges. To alleviate the liquidity constraints of consumers, the firm can decouple them by offering payment flexibility (e.g., recharges on credit, advanced payment, and micropayment options). Such flexibility can be implemented in practice by a mobile payment mechanism.

The general tendency when operating in poor countries is to focus on price-based strategies. The analysis of this study, however, suggests that implementing inconvenience-based strategies could also be effective, and they deserve careful consideration by both the firms and the policy-making organizations.

Photo 6.1: An example of hilly Rwanda, “the land of a thousand hills”, showing how difficult it is for the electricity grid to reach rural villages. Photo Rowan Clarke

7 CHAPTER: BROADENING THE ANALYSIS

Having conducted interviews with a range of stakeholders in the renewable lighting sector in the scoping phase of the project, there are now sufficient results from the project's own research to re-engage in those conversations to share the study's findings and to compare them with those gleaned from parallel studies conducted in other areas of renewable lighting. This will be done through a potential joint paper with one or two other research groups that have done studies on solar lights and by developing a policy brief to be shared with stakeholders.

As discussed earlier, the gender randomizations in the study have yielded interesting results, indicating that females benefit from being engaged via empowerment initiatives. The quota system is a very simple mechanism for ensuring access for females to microenterprise development. The fact that our business level data indicate that female VLEs are as successful as male VLEs is encouraging. Additional training may however help females overcome some of the innate risk-aversion we observe in our economic experiments and bolster their self-confidence. However, training programs are typically very costly compared to both the costs of this program and to other solar interventions, and especially to the costless quota system used here.

The research on pricing subsidies confirms the earlier hypothesis that the poorest segment of rural communities cannot afford renewable lighting at market prices and that subsidies are crucial in scaling up lighting to the poor. Further analysis yields insights into how successful scaling-up may be fostered. Reducing the upfront price of lights to zero is an optimal and profitable business model: it gets lights into households and does not negatively affect long-run paid usage nor, therefore, profits. Reducing recharge fees is another way to increase adoption and use, as well as profits, as this addresses severe liquidity constraints. Significantly, many interventions were tried which aimed to increase usage. The most successful was the provision of a free trial period which increased paid usage over a period of 9 months. Behavioural analysis also indicates that the inconvenience related to the centralised recharge of lights is an important barrier to the use of lights and that innovation in the business model is needed to overcome this challenge. Two possible approaches to doing this, drawn from theoretical model and empirical calibrations, would be door-to-door recharge services or alternatively opening two or more VLE recharge stations per village to lower the transaction costs associated with walking to recharge stations. Nuru is in a good position to test these interventions in a new wave of scaling-up their business model.

Another issue uncovered was the the way in which liquidity constraints in poor households inhibited the regular recharging of lights. The report discusses the potential for flexible payment mechanisms. This is another innovation that should be further investigated through action research in this business framework.

We foresee that both the inconvenience associated with recharging and liquidity constraints may be issues that affect female-headed households more severely than male-headed households. Females typically have a range of additional duties. like carrying wood, child-care etc., that make walking to a centralised recharge station cumbersome and even potentially unsafe. The empirical data also suggest that females are much more

liquidity-constrained than males. Further research to verify the potential benefits of these business innovations seems appropriate and would be of value in understanding how the scaling-up of energy to the poor and female empowerment go hand in hand.

Further to this, recent reports (see Rwanda: Off-grid Sector Status Report 2017; Ministry of Infrastructure, 2018) and interviews with villagers indicate that PAYG systems in general are proving challenging (with default rates of up to 20%) because of multiple sources of competition entering the market. Significant growth in this market has led to a total cumulative access for of 11%-12.3% of the population. This increase in competition has also been confirmed by recent interviews with VLEs subsequent to the field experiments. Also, of importance from a policy perspective is that the Rwandan government distributed free solar systems during 2017. This seems to have negatively impacted companies in the form of reduced sales as a result of people anticipating free lights (Rwanda: Off-grid Sector Status Report 2017). Although these free distributions have been limited, more clarity on the planned scale and the potential beneficiaries is needed to stabilize the market if the government is planning to scale up such free distribution.

8 CHAPTER: CONCLUSIONS AND RECOMMENDATIONS

This research project has reviewed several aspects of rolling out a gendered micro-enterprise program in the renewable lighting sector amongst poor rural households in Rwanda - a country that has a very high electrification target but has only been able to achieve a 42% connectivity rate, far below its target. With off-grid solutions gaining grounds, Nuru, a social enterprise, is committed to scaling up LED lighting to the rural poor.

Using the Nuru model, the study tested the impact of randomized gender assignments of Village Level Enterprises and of business models which varied the start-up price of lights and the recharge rates, and also examined the role of behavioural factors (inconvenience) and liquidity constraints in facilitating the frequent usage of the lights.

The main methodology revolves around several randomized control trials conducted in 272 villages in the Ruhango and Rulindo districts of Rwanda. This is complemented by additional qualitative interviews and economic experiments with VLEs to deepen understanding of the barriers to and enablers of success as a VLE for males and females.

Assigning gender quotas to VLEs via all-male, all-female and mixed-gender groups, although the analysis at this stage is only preliminary, shows the extent to which female empowerment initiatives are successful. The business level data indicated that business performance is similar across VLE groups, indicating that female VLEs perform as well as male VLEs. This is even more noteworthy given it is in the challenging context of an equality intervention which successfully shifted the proportion of female entrepreneurs from 10 to 50 percent.

In terms of welfare impacts of the gender treatment, assignment to all-female teams caused noticeable educational effects among school-age children, in the form of increased time spent reading or studying at home, compared to all-female controls and male VLES (almost an hour more per week). We also find that female VLEs are more likely than the female controls to report expecting that their children will be studying in 3 years' time. Children from female VLE households are more likely than those from female control households to expect to find a job that they enjoy.

Moving to broader welfare effects, evidence shows that the overall microenterprise program raised household consumption and expenditure levels, one of the best measures of poverty, and thus increased general welfare significantly. Moreover, the low-cost lighting programme saved households money on lighting expenditures, reduced the use of dirty lighting, and increased the probability children study with a clean light source.

Qualitative results indicate that there are manifold benefits to becoming a VLE, ranging from improved access to lighting, supplementary income, and increased status in the community.

The results of the experiments also suggest that the majority of the entrepreneurs in the study are not risk-takers, and that the women were even less willing to take risks than

men. In terms of competitiveness, there was no difference between the women and the men.

The business level experiments yielded further interesting results, indicating that the upfront pricing of the lights may be inhibiting uptake and usage of the lights. We find that initial take-up, or adoption, of LEDs is highly price elastic**.** At a price of zero, adoption is over 90%, while at the full price of 3000RWF ($4), take-up is zero. Varying upfront pricing does not impact the long-term usage of lights, disproving the notion that people value goods more when they pay for them.

Further evidence about pricing can be gleaned from experimentally varying the recharge prices using randomly allocated vouchers. We find that a free trial period (3-month) positively impacts usage up to 6 months after the free trial ended. Additional analysis of customer surveys indicates that this is not so much due to overcoming problems of information and learning, but rather the result of habit formation.

The study found that behavioural factors matter: the inconvenience associated with recharging is an important driver of usage. At zero inconvenience, the expected number of recharges increases by 100%. An alternative would be to increase the number of recharge stations from one to two per village. The current recharge price is found to be too high as users tend to have significant liquidity constraints. The model indicates that flexible payments mechanisms would increase the usage significantly.

Overall the study provides new insights into empowerment programs in the solar lighting sector and offers encouraging evidence that simple gender quotas may be an effective means of levelling the playing field in the renewable sector, ensuring access to females and in turn providing positive spillovers for their households. The results of the business model also indicate the critical need for subsides in order to reach the poorest of the poor. Moreover, the behavioural experiments show that flexible payment mechanisms may help to alleviate liquidity constraints and that the inconvenience related to centralised recharge stations is a significant barrier to usage.

9 CHAPTER: MESSAGES FOR POLICY AND PRACTISE

9.1. Female entrepreneurship

The role of female entrepreneurship in the energy sector is illustrated in the case of entry-level solar LED lights for ultra-poor households in rural Rwanda. The most significant finding with respect to gender from the business level data is that female entrepreneurs perform as well as business owners. We therefore recommend a quota system as a simple policy tool for ensuring female access to microenterprise expansion in rural Africa, and as an empowerment mechanism which is revenue-neutral for solar suppliers (both for-profit and government).

9.2 Pricing of low-cost energy solutions

The results of the study are in line with the literature on pricing health products, which finds that demand is highly price sensitive, with most households not purchasing even at low prices. The conclusion follows that price is the most important factor driving demand and that households are constrained in terms of credit, saving, or liquidity, or that the majority of households simply do not value LEDs at their market price. To ensure high take-up, very low prices, or even a price of zero, are required. This provides motivation for subsidies, particularly for female-headed households who are more vulnerable. In the second experiment, the study estimates demand curves for both the initial price of low-cost LEDs and the subsequent user fee for repeated purchases. It then also estimates the impact of short-run subsidies on long-run demand. Uptake is found to be highly sensitive to initial price, with most households purchasing at zero price and no households purchasing at full cost, providing strong evidence that the initial upfront price of LEDs should be subsidized, which agrees with recent literature (Grimm *et al.*, 2016). Subsidies for the most vulnerable households in the rural areas (female-headed households) would increase the take-up and promote the usage of similar low-cost energy solutions.

The initial demand for lights is extremely price sensitive, with hardly any households purchasing at full price and over 90% purchasing when the price is zero. This has strong implications not just for take-up but for successful business or non-profit distribution models. The evidence provides a strong rationale for subsidies for the upfront price of lights, but also for a reduced upfront pricing strategy for a for-profit business. Subsequent long-term usage rates of LEDs do not depend on the initial price paid, even when usage is not free – i.e., in the context of user fees for repeated use. Thus, the initial price paid does not act as a signal for how much a customer values the good (a standard assumption in economic theory0. Setting user fees to zero initially increases long-run usage rates even when the subsidies are removed, and full-price user fees are charged. These results strongly imply that, for successful business and non-profit distribution models, lights should be priced at zero, or subsidized, ensuring initial take-up is high. This can be implemented in the knowledge that the primary driver of revenue, long-run paid usage rates or recharge frequency, is unaffected. A for-profit distributor can, in the long run, expect to recoup the costs associated with reducing the upfront price of lights through charging maximum user fees. In short, a distributor – a solar company or government –

should minimize the upfront price of lights, maximize the long-term user fee, and provide a free trial period where the user fee is zero.

As mentioned in Section 6, both inconvenience and liquidity constraints negatively affect the uptake and usage of rechargeable LEDs. Our theoretical predictions and the empirical verification thereof indicate that there is an important role for innovation, such as door-to-door services and flexible payment options. While business trials testing these are essential, there is also a crucial role for policy makers to fund further research into innovative support mechanisms for the takeup and use of lighting that does not focus merely on pricing as a policy tool, but also recognizes the importance of behavioral tools to augment business models.

9.3 Operational recommendations

9.3.1 After sales support

There were several challenges which informed the study's findings. It was noted that a proportion of the VLE groups (about 10%) initially created were distorted. This was exhibited in different ways. Some group members had brought in friends and family members (spouses) into the group to replace other members who were not able to raise the commitment fees, regardless of gender. This means that some of those interviewed in the baseline as VLEs were no longer in the business. Some groups had fewer people than when originally formed owing to members dropping out for various reasons. Further, we uncovered the problem of light unlocking by light owners in one of our districts of operation and subsequently in the second district. This means that they could now recharge their lights using electricity in neighbouring on-grid villages, disrupting the study design. There were several reasons for this problem:

1) Due to the perceived 'high' cost of recharge (RWF100; $0.15), some light owners were unable to use their lights as they were unable to afford to recharge them. This was exacerbated by the assignment of some villages to the half-charge treatment (recharge at RWF50 for a shorter period). Some qualitative evidence suggests that if a neighbouring village was on the full-charge treatment, light owners from the half-charge village preferred to walk to the full-charge village for a longer-lasting recharge. Data from the follow-up customer survey, however, shows that the vast majority of households only recharged their lights at their own village enterprise and not at a neighbouring village. VLEs with the half-charge equipment therefore lost business and, in some cases, refused to recharge. However, the half-charge intervention villages still had higher recharge frequency overall.
2) Some villages received electricity and home solar systems under the government of Rwanda's rural electrification program during the course of the study. Light owners may have no longer seen the benefit of the LED lights in such villages.

These challenges had diverse and far-reaching impacts on the research study, as some VLEs were no longer profiting from the recharge business, and therefore may have been willing to drop the business completely. However, the majority of households were still

using their lights 18 months after they received them, and the microenterprise program was still able to increase its income substantially. Furthermore, the main reason for the drop in the recharging of lights was that Nuru, a social business, faced severe cash flow difficulties (between grants) for a period and had to cut after-sale technical support almost completely and lay off a large proportion of staff. A program of fixing lights, equipment, and replacing broken lights was then implemented which largely solved this problem. Moreover, it was still possible to measure the impact of the business, especially on female micro-entrepreneurs, as the unlocking problem did not spread very far. Despite this problem, it was still possible to measure the impact of the ownership of lights on individual households, as this is unaffected by where the lights were recharged. The challenges encountered underline customers' preference for full charge, lower recharge fees, zero purchase price, and, very importantly, the need to implement subsidies in the pricing model as recommended above. It is to be expected that when asked customers naturally would prefer lower prices (or a longer battery life which also lowers costs). Nuru lights, however, are cheaper than competing solar lanterns and were shown to save households money on lighting expenditures over time, meaning they cost less overall than existing alternatives. This makes the claim by some customers that prices are too high suspicious.

One specific recommendation for solar and/or LED light suppliers, based on the above challenges, is to ensure strong and timely after-sales technical support to customers. This will ensure that customers have little room to tamper with the supplied equipment. On the other hand, this increases the manufacturing costs of lights and the staff costs of the program, so it must be balanced against potential benefits.

9.3.2 Targeting and distribution

During the intervention phase of the study, Nuru Energy, the study's implementing partner, has distributed the LED lights and accompanying equipment based on a set criteria focused on 1) connectivity to the grid, 2) creation and operationalization of VLE groups, 3) free distribution (in villages chosen to study coupon use) and, 4) the ability of a household to raise the voucher purchase price (in villages where experimental vouchers were used). We have learnt that in villages where distribution was free or highly subsidized, the selection of beneficiaries when lights were limited to a given number ought to be carefully planned in consultation with village leaders and other gatekeepers. However, although consultation is key, there needs to be a pre-drawn distribution plan from the suppliers – this is mainly because gatekeepers may include their friends and relatives in distribution lists, sometimes even more than once (100 free lights were distributed in each village on average, which is also the average village size: the goal was one free light per household). The high costs of greater logistical involvement by the social business must also be considered as Nuru Energy never travels to individual villages or households.

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APPENDIX I: SUPPLEMENTARY EMPIRICAL RESULTS

Note: All results are preliminary and subject to change

Table I: Impact of gender quotas on business outcomes

	Outcome Variable:			
	Revenue (Recharge Frequency Per Light in a three month period)		Self reported individual microenterprise income	
	Level (number of recharges)	*In Hyp Sin (% change)*	*Level (number of recharges)*	*In Hyp Sin (% change)*
Female team	0.185	0.091	-34.615	0.177
	(0.288)	(0.121)	(269.061)	(0.597)
Mixed team	-0.026	-0.013	-139.751	-0.309
	(0.313)	(0.129)	(240.582)	(0.562)
Observations	12,202	12,202	470	470
R-squared	0.00265	0.00278	0.00442	0.0102

Notes: The table reports the coefficients, and standard errors in parentheses, from OLS regressions where the dependent variable is usage or recharge frequency per light or self-reported microenterprise income. To deal with zeros we use the inverse hyperbolic sine transformation instead of the natural logarithm. All standard errors are clustered at the village level. Randomization was done at the village level so this is the appropriate level to cluster. Controls, in the individual level equations, include entrepreneur age, baseline HH income and HH size. The omitted category is all male teams.

*** p<0.01, ** p<0.05, * p<0.1

Table II: Household expenditure on non-lighting items per week in RWF

Household Expenditures

	Outcome Variables:	
	Log HH non-light expenditures	Log HH food expenditures
Treatment	**0.202****	**0.151****
	(0.091)	(0.069)
Observations	962	961
R-squared	0.109	0.183

Notes: All standard errors are clustered at the village level, the level of randomization. The table reports the coefficients, and standard errors in parentheses, from OLS regressions of log outcome on a treatment dummy and controls including HH size, age of entrepreneur, baseline log HH income and the baseline outcome variable

*** p<0.01, ** p<0.05, * p<0.10

Table III: Impact on Lighting Use and Expenditure, expenditures per week in RWF

	Impact on lighting use and expenditure						
	Outcome Variables:						
	HH uses dirty light source	HH uses kerosene	HH uses battery/flashlight	Log weekly HH lighting expenditure	Log lighting expenditure on dirty sources	Children study with a dirty light source	Children study with a clean light source
Solar lighting	**-0.143*** **	**-0.004**	**-0.109*** **	**-0.230***	**-0.590*** **	**-0.074*** **	**0.042***
	(0.024)	(0.004)	(0.021)	(0.131)	(0.098)	(0.020)	(0.023)
Households	997	997	997	997	997	445	445
R-squared	0.0887	0.863	0.0481	0.0157	0.0747	0.0657	0.0181
Notes: All standard errors are clustered at the village level, the level of randomization. The table reports the coefficients, and standard errors in parentheses, from OLS regressions of outcome variables on treatment – two solar lights. Controls include household size, age of household head, log household income, and the baseline outcome variable							
*** p<0.01, ** p<0.05, * p<0.10							

Table IV: Determinants of VLE's competition entry

VARIABLES	(1)	(2)	(3)
Female	-0.0201	0.299	-0.150
	(0.144)	(0.278)	(0.172)
Tournament	0.0514**	0.115***	0.0220
	(0.0211)	(0.0405)	(0.0260)
Tournament-Piece rate	-0.0573**	-0.111**	-0.0282
	(0.0280)	(0.0515)	(0.0350)
Education	0.0696**	0.0367	0.0896**
	(0.0298)	(0.0496)	(0.0384)
Risk taking: 2. Seldomly	0.121	0.0243	0.108
	(0.278)	(0.519)	(0.333)
3.Sometimes	0.214	0.0807	0.261
	(0.200)	(0.376)	(0.237)
4.Often	0.0981	0.145	0.0875
	(0.225)	(0.436)	(0.266)
5.Always	-0.0432	-0.0190	-0.172
	(0.300)	(0.617)	(0.354)
Constant	-1.089***	-1.530***	-0.925***
	(0.271)	(0.498)	(0.332)
Observations	341	103	238
Notes	All observation	Mixed Groups Only	Single Sex Groups Only

*** p<0.01, ** p<0.05, * p<0.1. Standard errors are in parenthesis

Table V: Impact of Free Lights on subsequent usage

	Outcome Variable:	
	Recharge Frequency Per Light	
	Level (number of recharges)	*Log (% change)*
Purchase Price	**0.109**	**-0.014**
	(0.322)	(0.058)
Village Fixed Effects	YES	YES
Constant intercept	1.938***	0.831***
	(0.263)	(0.078)
Observations	1,377	1,377
R-squared	0.171	0.140
Notes: The table reports the coefficients, and standard errors in parentheses, from OLS regressions where the dependent variable is usage or recharge frequency per light. All standard errors are clustered at the household level, the level of randomisation. The experiments were stratified on village so all regressions include controls for village fixed effects.		
*** p<0.01, ** p<0.05, * p<0.1		

Figure I: Performance under tournament uptake by gender

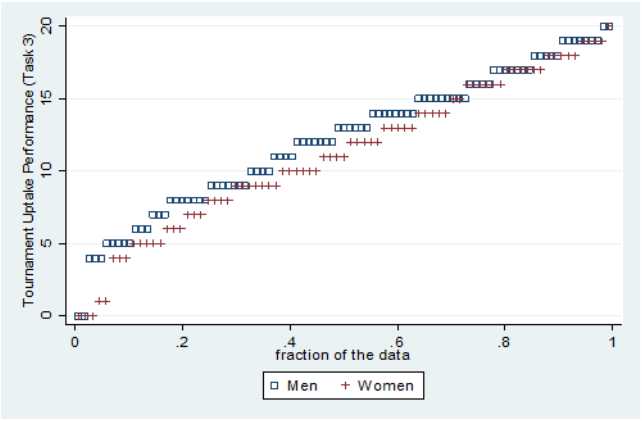
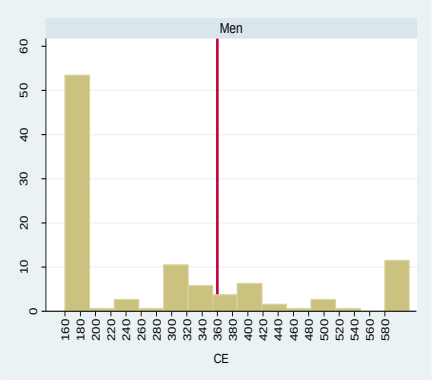


Figure II: Distribution of VLEs' certainty equivalents by gender



A

B

ANNEX 1 NATIONAL LEVEL INDICATORS

	indicator/issue	Metric	Comment
General indicators			
	Area	26,338 Km Sq	
	Population size	12,208,407	Year 2017. World Bank Data: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=RW
	Population density	507 P/Km Sq	Number of people per square kilometre; this is Africa's third highest population density http://statisticstimes.com/population/countries-by-population-density.php UN 2018
	Urban/rural population	3,747,981 (30,7%)/8,460,426(69,3%)	Year 2017. World Bank Data: https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=RW
	GDP	9,137 billion (current USD).	Year 2017. World Bank Data: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=RW
Gender related indicators			
	HDI	0.491 (females); 0,495 (males)	Year 2015. http://hdr.undp.org/en/countries/profiles/RWA#
	GINI	50.4	Year 2013. https://data.worldbank.org/indicator/SI.POV.GINI?locations=RW
	Life expectancy male/female	64.9 years (males)/69.2 years (females)	Year 2016. https://data.worldbank.org/indicator/SP.DYN.LE00.FE.IN?locations=RW
	Literacy male/female	97.3% (males)/98% (females)	Primary, net, year 2016. Ministry of Education http://mineduc.gov.rw/fileadmin/user_upload/pdf_files/2016_Education_Statistical_Yearbook.pdf
	Ownership of telephones male/female	9,321,347	July 2018. Mobile telephone subscriptions. http://www.rura.rw/index.php?id=60
	Participation in the economy women/men	56.4% women; 43.6% men	http://www.migeprof.gov.rw/fileadmin/_migrated/content_uploads/National_Gender_Policy-2.pdf
	quote and reference to key gender objectives in key energy policy documents **GOALS IN GENDER POLICY:** - Mainstream gender and family in planning, budgeting and in all development programmes/projects at national and local levels - Sector strategies and district plans will focus on interventions that reduce poverty levels among men and women - Reduce gender-based violence, malnutrition and other related conflicts at both family and community level		

	- Focus on sector strategies that enable women and men to participate, access, control and benefit equally from growth processes in a way that recognises their different needs **KEY POLICY DOCUMENTS, LAWS AND INITIATIVES IN GENDER POLICY:** - Ministry of infrastructure Gender mainstreaming strategy - Economic Development and Poverty Reduction Strategy II, 2013-2018 - National Gender Policy, 2010 - Gender Based Violence (GBV) law, 2008 - Gender Responsive Budget Initiative, 2008 **LINKAGES GENDER-ENERGY** - **Facts (National Energy Gender Policy, 2010)** • **"**Access to energy is a serious issue for both men and women; however the latter are more concerned as they are the majority involved in seeking firewood for cooking and other related domestic activities. This affects the time that women could use for other activities for the development of their own families and communities." • Limited source of energy affects more women than men as women are more involved in household activities requiring use of energy; - **Actions (National Energy Gender Policy, 2010)** • To facilitate rural transport used in different localities, especially by women, and institute appropriate intervention measures to facilitate access to energy to reduce the household energy burden on women; • To sensitise the populations on the increase of men's participation in firewood collection and other sources of domestic energy management; • To ensure than women and men are involved in the development of renewable sources of energy. • To ensure that rural households are trained in the use of energy saving stoves and are facilitated in accessing them; To ensure that the number of households dependent on firewood and charcoal is reduced		
energy access/access to energy services			
	Installed power generation capacity	216 MW	https://www.researchgate.net/publication/326509225_The_State_of_the_Power_Sector_in_Rwanda_A_Progressive_Sector_With_Ambitious_Targets
	Access to energy	11% Off-grid; 26% on-grid	https://www.researchgate.net/publication/326509225_The_State_of_the_Power_Sector_in_Rwanda_A_Progressive_Sector_With_Ambitious_Targets
	Access to electricity	Tier 0: 73,2% Tier 1: 2,8% Tier 2: 2,1% Tier 3: 10,3% Tier 4: 7,8% Tier 5: 3,7%	2017. MTF Report https://energydata.info/dataset/rwanda---multi-tier-framework--mtf--survey--2018-/resource/547d1558-0109-4b9c-a487-a3a4a5effd2f
	Access to clean cooking	33% of population	2017. MTF Report https://energydata.info/dataset/rwanda---multi-tier-framework--mtf--survey--2018-/resource/547d1558-0109-4b9c-a487-a3a4a5effd2f
	Traditional sold biomass /total energy consumption	85%	https://energypedia.info/wiki/Rwanda_Energy_Situation
	Reference to key energy policy documents including targets on electrification and clean energy, subsidy		
	Sector	Target	

	Access to clean and sustainable cooking	1. To close the gap (currently about 20%) between production and consumption of bioma energy 2. To supply a growing and urbanising population with clean secure supplies of biomass for a. 100% access to much more efficient cookstoves than currently used b. Reduction in losses from charcoal by improving charcoal production and parti pellets c. Increasing production by improving forestry management 3. To ensure that the efficient cookstove solutions noted above address health issues by sign
	Access to electricity	1. To achieve 100% electricity access by 2023/24 through a mix of on-grid (52%) and off-gric 2. Progress to higher quality and quantity of electricity over time, with >50% of the populati
	Renewables	1. Exceed the global SE4All target (26%) of renewable energy as a percentage of the primary 2. Exceed the global SE4All target (44%) of renewable electricity generation as a percentage
	Energy efficiency	1. Increase current power generation from 216 MW to 512 MW 2. At least double the efficiency of biomass energy use 3. Extend current rates of electrical efficiency improvement to 2030
	Reference to key evidence/large studies on energy and/or gender for the country (recent- data collected 2014 or later) • Situation Analysis of Gender and Sustainable Energy in the East African Community, 2018: https://cdn2.b2match.io/event/2901/assets/8478585390-c9af64a444.pdf Gender and infrastructure, Republic of Rwanda, 2017: http://www.gmo.gov.rw/fileadmin/user_upload/profiles/Gender_in_Infrastructure_Booklet__GMO__March_2017.pdf	

ANNEX 2 RESEARCH QUESTIONS AND INDICATORS

Research question 1 **What is the evidence that there are differential outcomes on women/girls and men/boys of current approaches to energy sector interventions?**		
	Evidence	**Source** Literature/empirical (page)
✓	**E1: How are gender issues addressed in energy policy and implementation?**	
	Indicator: VLE female model embraced by NURU and other businesses We already have gender disaggregated data in this regard – female microenterprises perform as well as the male ones, hence we recommend a quota system for private sector and government suppliers	Baseline and endline survey data – RA5
✓	**E2: How are gender issues addressed by organisations in the energy system?**	
	Indicator: increase in # female micro enterprises/jobs created Nuru created 129 microenterprises of which 45 are run by women. The Nuru approach initially led to 10% of village microenterprises being run by women however, they now have a gender employment policy which aims to employ more females' entrepreneurs. They have also increase the number of female-led microentrepreneurial groups to 50%	RA5 Endline survey and subsequent papers Nuru business Policy
✓	**E5 What influences individual's selection of this energy carrier?**	
	Affordability significantly affects individual 's choice of energy. In our case, the upfront price, and the recharge fees affects individual's adoption and continued use of lights	(Barron et al., April 2018: p12) Working Paper.
✓	**E6: Which aspects of energy supply have small impact/high impact on gender equity outcomes?**	
	Indicator: VLE female model (quota system) embraced by NURU and other businesses Household level: Information from our case study shows that using Nuru lights for household activities empower women and children. Nuru VLE model: the Business Model Nuru has rolled out over the last year involved a quota system for females which directly empowers females.	In-depth Interviews with light users in Rulindo-Rwanda; The gendered element of the business model is what we evaluated in this study.
✓	**E7 How is access mediated?**	
	For Households: Nuru lights serves as the energy carrier for households. These simple lights are categorized under Tier 1. Generally, the adoption of lights is decided by household head. Perceived benefit for households is visibility during the evenings.	Survey baseline data (Papers from this data are yet to be written)

	For Enterprise: Nuru VLES provides recharging services to households. Appliances used includes solar panels, power cycle and octopus. The decision to become entrepreneurs is made by VLEs themselves. Perceived benefit for both men and women is income from the business		
✓	**E8 What are the gendered differential determinants of use and benefits?**		
	While women often use Nuru lights for cooking and household activities men are seen to use the light for cutting grass during the night. Children also use it for studying. Information from case study shows that the decision to use the light is dependent on who is in need of it at a particular time, however, baseline survey data indicate that household heads decide how lights are to be used.		In-depth interviews and Baseline Survey data
✓	**E9 What are the gendered differential first order outcomes linked to energy access?**		
	Which Outcome?	**Evidence**	**Source**
	Time Saved	Generally light users now use less time on activities however, women shift some chores such as washing into the night to work long hours doing the day time on their farms.	Qualitative interviews.
	Social Status and Prestige	From our business models, women are now challenged to take more competitive roles. Also, women operating as entrepreneurs have now gained the respect of other community members	Qualitative interviews and experimental data.
	E10 What are the gendered differential second order outcomes linked to energy access? **E11 Which first order outcomes contributed?**		
	Which outcome?	**Evidence**	**Source**
	Gender Attitudes; *Schooling outcomes;* *Aspirations* *E11: First Order Outcomes: VLE employment of females*	Outcome variables measured by endline survey Gendered Quota system implemented by Nuru; Feedback from females of feeling more empowered	In depth interviews (Presentation Slide 13)
Research Question 2 What is the evidence that a gender approach in energy sector interventions would lead to more gender equitable outcomes?			
✓	**C3 How has taken a gender approach influenced access?**		
	Which approach works/doesn't work?	**Evidence – particularly as relates to which aspects, how and why?**	**Source**
	Increasing the number of female entrepreneurs is an approach working in the quest to provide accessible energy to the poor	Female entrepreneurs sell more lights than male ones. Women are more likely to be available at the shop, be it because of limited mobility or because they value the position more highly than males. Second, females who manage to get a spot in the businesses are especially motivated to succeed.	Barron et al. (May 2018; p9)

✓	**C7 Have government agencies, development agencies and the private sector adopted a gendered approach?**		
Who?	**Which approach?**	**Evidence – particularly as relates to which aspects and why?**	**Source**
Yes. Nuru has adopted the gender approach	Nuru increased the number of VLEs from 10% females to 50%females	This method is related to the microenterprises established by Nuru in the rural areas of Rwanda	Nuru administrative data
Research Question 3 What is the evidence that contextual factors influence more gender equitable outcomes from energy interventions?			
	C1: How has the political economy influenced gender equitable energy access?		
	Evidence		**Source**
	With women holding 56% of seats in the lower house of parliament, Rwanda is one of the few countries in which women have moved beyond half of political leadership. Participation of women in leadership has seen a positive drive towards gender-inclusive policies around natural resource management, environment and energy access, with a focus on equitable access to clean energy. The gender equality strategy (2014-2017) points towards Government support for partner efforts to increase women's access to and ownership and management of ecosystem goods and services, including through climate and energy finance. Despite these efforts, equitable energy access is still at a low, with the most affected persons being women in rural areas.		
	C2: What are the socio-cultural, economic and geographical characteristics of the location?		
	Rwanda, Kenya, and East and Central Africa more generally are poor with the majority of their populations living in extreme poverty and relying on subsistence farming as their main livelihood (World Bank, 2018). Over 90% of rural households are without electricity and grid expansion is not predicted to keep pace with population growth (Barron et al., April 2018: p1). Making matters worse, Rwanda is known as the land of a thousand hills, a formidable challenge for connecting households to the electricity grid. The above is in the context of Rwanda's acclaimed grid expansion program which is much lauded throughout the region. Even where connections to the grid are available most households in East Africa, even relatively well-off ones, are unable to afford the typically steep connection fee, such that on paper it looks like electricity access is high when in fact it is far from it (Lee et al., 2016). Further, respiratory infections are the leading cause of death for under-fives in the world while almost 6 million children under the age of five died in 2015 (Liu et al., 2016). Most of these deaths are preventable using simple health technologies such as solar lanterns, insecticide-treated bed-nets, water purification, oral rehydration, and antibiotics amongst others[6]. Moreover, kerosene smoke is a significant risk factor for respiratory infection having a		

[6] https://www.unicef.org/childsurvival/

	larger impact on indoor air pollution and child respiratory health than cookstoves (Barron and Torero, 2017). Partly for these reasons the International Energy Agency predicts that 70% of rural households will have to rely on micro-grid or low-cost off-grid solar, yet adoption of these technologies remains low (IEA, 2012). In the past decade East Africa has begun to focus on gender equality at the highest levels. However, we present data from 1051 rural villages which shows women only manage between 4-19% of village microenterprises (Barron et al., May 2018: p8). Clearly women still face significant obstacles to entrepreneurship in rural areas of Rwanda and Kenya		
	C4 How is access mediated by gender ideologies and norms?		
	Norms about women's roles in society precluded them from having access to jobs or entering business ventures; We found only 4-19% of VLEs were women in Nuru's previous enterprises.		In depth Interviews;
	C5 How is use mediated by gender ideologies and norms?		
	Use includes: Time to study, Female time for cooking		RA5 Endline data
	C6 How are outcomes mediated by gender ideologies and norms?		
	Outcomes includes: Number of Female VLEs; Girl's aspirations and Schooling Outcomes		The new Nuru model now instruments a gender quota following the findings from our research
	C8 Which specific characteristics of the context are most significant in removing barriers to the equity of benefits of the energy value chain?		
	Which characteristic?	**Evidence – particularly how and why?**	**Source**
	Gender Quota **Pricing Subsidies**	By setting minimum requirements for the number of females being included in a VLE group, barriers to access are being addressed; By providing lighting at a cost that is accessible to all and in particulate the poorest of the poor – women automatically benefit through greater access and use	

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