Combining malaria control with rural electrification: Social and behavioural factors that influenced the design, use and sustainability of solar-powered mosquito trapping systems (SMoTS) for malaria elimination on Rusinga Island, western Kenya

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List of Abbreviations

An.: Anopheles

CAB: Community Advisory Board

CBO: Community-Based Organisation

ERC: Ethical Review Committee

FGD: Focus Group Discussion

icipe: International Centre for Insect Physiology and Ecology

IDI: In-depth Interview

IRS: Indoor Residual Spraying

ITN: Insecticide Treated Net

KEMRI: Kenya Medical Research Institute

Kshs: Kenya Shillings

LED: Light-Emitting Diode

LLIN: Long-lasting Insecticidal Net

NGO: Non-governmental Organisation

PV: Photovoltaic

SMoTS: Solar-Powered Mosquito Trapping System

SSC: Scientific Steering Committee

USB: Universal Serial Bus

USD: United States Dollar

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CHAPTER 1

General Introduction

Introduction

The research on which this thesis is based was carried out as part of a multidisciplinary project, "SolarMal", which aimed to evaluate proof of principle for the elimination of malaria from Rusinga Island by augmenting the existing national malaria control programme tools with mass trapping of mosquitoes. As electricity was required to run the mosquito traps and most residents had no electricity, solar systems were also installed, providing lighting and telephone charging as well. Although the main objective of the project was to control malaria and hence a public benefit, the solar-powered mosquito trapping systems (SMoTs) additionally provided a private benefit due to house electrification. Due to this uniqueness, while the theoretical basis of public health research has been based largely on behavioural psychology and biomedical science, this thesis included innovation and social dilemma theories to understand the complex interactions of mobilising diverse actors for social change. The SolarMal project had Entomology, Parasitology, Epidemiology and Health and Demographic Surveillance (HDSS), and Social Sciences components. The research towards this thesis was nested within the Social Studies component of which I was a member. Alongside outcome measures of malaria parasitaemia and entomological data, sociological studies investigated behavioural and contextual factors in the design and use of solar-powered mosquito trapping systems (SMoTS) and how to improve coverage, adherence and sustainability.

Sociocultural issues in malaria control

Studies of malaria control have attributed failure of control programmes to limited understanding of social norms and a society's acceptance of intervention campaigns (Spielman 2003). Malaria control initiatives have recognised the important role human behaviour plays in this public health problem (Mwenesi, Harpham et al. 1995; Williams, Jones et al. 2002; Heggenhougen, Hackenthal et al. 2003). It is recognized that new preventive health interventions can only be considered effective if, in addition to efficacy and safety, they are socially acceptable and widely adhered to in the longer term (D'Alessandro, Olaleye et al. 1995; Alaii 2003; Gysels, Pell et al. 2009), and malaria-related social science research has resulted in improvements in the design and implementation of malaria prevention, management and control strategies (Mwenesi 2005). Notably, optimising the impact of existing programmes is arguably one of the most cost-effective funding strategies that international agencies and national governments can take (Allotey, Reidpath et al. 2008). As many technical interventions that prove efficacious in randomised trials are much less effective in the general population (Glasgow, Eakin et al. 1996; Sorensen, Emmons et al. 1998; Starfield 1998), there has been an increasing emphasis in global health to address the gap between the scientific efficacy of tools and strategies and their practical translation and impact into different local contexts (Bardosh 2014).

Social science research can offer insights into the dynamics of disease control that complement those in biomedicine, epidemiology, parasitology and biology. This focus emphasises an understanding that human practices in a given context both shape and are shaped by several influences (Williams, Jones et al. 2002). The likelihood of success of a mosquito control programme requires integration of information from socially-oriented research in addition to the biologically based research (Bradley and Taegett 1991; Jones and Williams 2004; Mwenesi 2005). Socio-behavioural studies have the capacity to look not only at the beliefs and behaviours of people affected by the disease, but also at the behaviour of various stakeholders in the process of disease control such as donors, programmers, researchers and fieldworkers.

As communities are a key stakeholder in disease control, the role of community participation has become a central tenet in disease prevention and disease treatment strategies (Rifkin 1996; Rifkin 2001; Williams and Jones 2004; Atkinson, Vallely et al. 2011). A high degree of community participation is essential for dealing with diseases where control depends on behavioural changes, as it does with malaria (Spielman 2003). Current malaria control programs such as use of long-lasting insecticidal nets (LLINs) and combination drug therapy heavily rely on resident participation and are therefore generally organised horizontally. These practical reasons drive the current need for a solid understanding of the behavioural and social factors that may inhibit or facilitate particular intervention methods, including SolarMal.

Malaria in Kenya

Malaria is a disease caused by parasites that are transmitted to people through the bites of infected female mosquitoes (World Health Organization. Global Malaria 2012). The epidemiology of malaria in Kenya has been changing with reported reductions in malaria associated hospital admissions and mortality in children under the age of five years (Okiro, Hay et al. 2007; Okiro, Alegana et al. 2009). These changes have been, in part, attributed to the increase in coverage and access to efficacious malaria control interventions such as LLINs, indoor residual spraying (IRS) and artemisinin-based combination therapy (ACT) (Snow, Okiro et al. 2009). In 2014, the proportion of the at-risk population estimated to have access to an LLIN in their household exceeded 50% (World Health Organization. Global Malaria 2012). However, about 80% of the Kenyan population live in areas of malaria risk and malaria remains the leading cause of morbidity and mortality. The World Bank estimates Kenya's 2014 population is 44.7 million people[1]. Among the at-risk population, 27% (~12 million people) live in areas of epidemic and seasonal malaria transmission where *P. falciparum* parasite prevalence is usually less than 5%. However, an estimated 28 million people live in endemic areas, and over a quarter (~11 million people) live in areas where parasite prevalence is estimated to be equal to or greater than 20%.

According to the 2010 Kenya Malaria Indicator Survey (KMIS) (Kenya, Ministry of Public et al. 2011), malaria accounts for 30-50% of all outpatient attendance and 20% of all admissions to health facilities. An estimated 170 million working days are lost to the

[1] World Bank, http://data.worldbank.org/country/kenya. Accessed 28 January 2016.

disease each year. Malaria is also estimated to cause 20% of all deaths in children under five. The most vulnerable groups to malaria infections are pregnant women and children under five years of age. Like other countries in East Africa, the Kenyan malaria strategy is focused on control activities (World Health Organization. Global Malaria 2012).

Malaria transmission and infection risk in Kenya is determined largely by altitude, rainfall patterns and temperature. Therefore, malaria prevalence varies considerably by season and across geographic regions. The variations in altitude and terrain create contrasts in the country's climate, which ranges from tropical along the coast to temperate in the interior to very dry in the north and northeast. Moderate-to-high levels of transmission persist in certain endemic zones; the 2010 KMIS confirmed that malaria prevalence remains more than twice as high in rural areas (12%) compared to urban areas (5%). Malaria prevalence around Lake Victoria is particularly high at 38%, even as prevalence in other epidemiological zones has dropped to less than 5% as shown in Figure 1 (courtesy of Noor et. al.[2]). Consequently, as part of Kenya's revised National Malaria Strategy 2009–2017, prevention and control interventions are tailored to the current epidemiology of malaria, with efforts concentrated in the lake-endemic zone.

Of the five species of *Plasmodium* that can infect humans, four occur in Kenya. *Plasmodium falciparum*, which causes the most severe form of the disease, is the most common accounting for over 98% of all malaria infections in the country. The major malaria vectors in Kenya are *An. gambiae* complex (*An. gambiae ss, An. arabiensis, An. merus*) and *An. funestus*.

The Rusinga Island (Figure 2) community has enjoyed routine malaria control interventions since 2005, when the National Malaria Control Programme (NMCP) of the Ministry of Health, Kenya, introduced free LLINs and clinical care using ACTs provided through health centres. For the endemic zones, such as Rusinga Island, where levels of LLIN use on their own had proved insufficient to lower rates to that achieved in other zones, the NMCP had adopted a business plan to use IRS in conjunction with LLINs to reduce the malaria burden. The degree of bed net coverage and IRS constituted a particularly crucial element in the SolarMal strategy because SMoTs target outdoor biting mosquitoes with the assumption that mosquitoes indoors are either repelled or killed by LLINs. It was therefore important that people did not misunderstand the role of SMoTS and neglect other preventive measures or delay treatment seeking.

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[2] Noor AM, Kinyoki DK, Ochieng JO, Kabaria CW, Alegana VA, Otieno VA, Kiptui R, Soti D, Yé Y, Amin AA, Snow RW. *The epidemiology and control profile of malaria in Kenya: reviewing the evidence to guide the future vector control.* Nairobi: DOMC and KEMRI-Welcome Trust-University of Oxford-Research Programme, 2012.

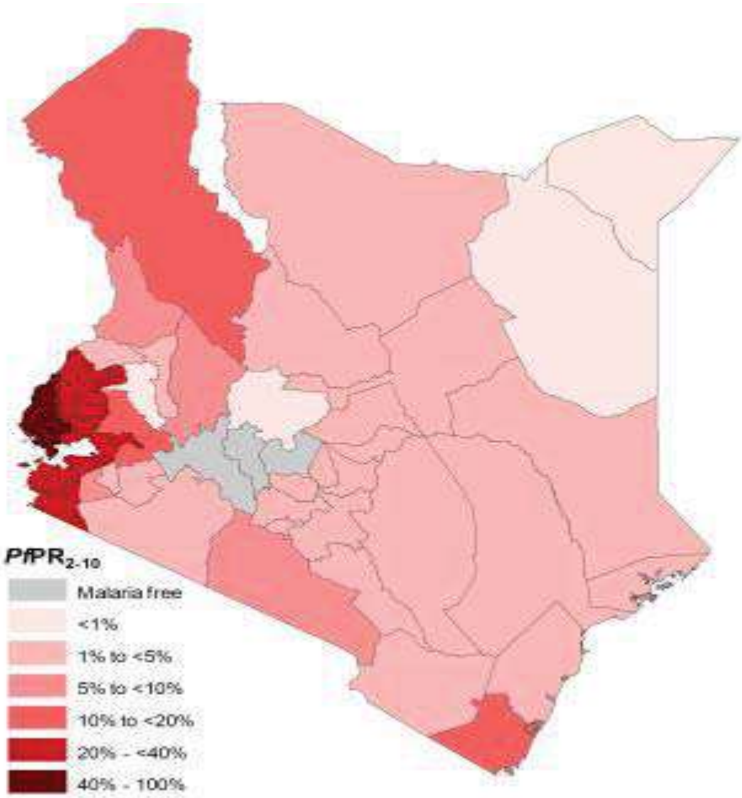

Figure 1. Kenya 2010 population-adjusted P. *falciparum* prevalence by county map (source: Noor et. al.)

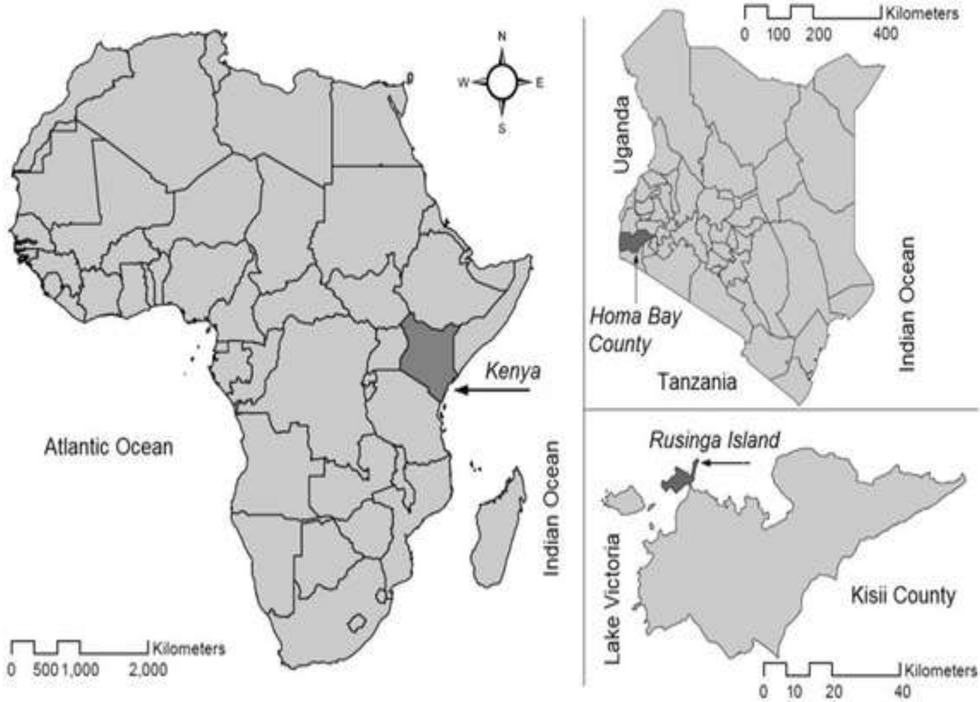

Figure 2. Study site: Africa with Kenya highlighted dark grey; in the right upper corner is Kenya with Homabay County highlighted; and in the right lower corner is Homabay County with Rusinga Island highlighted (source: Homan et. al. In Press)

Since the early 90s, the potential of social science research to inform improved malaria control programmes in Kenya has been evident. Global advances in malaria-related social, behavioural, economic, evaluation, health systems and policy (social science) research have resulted in improvements in the design and implementation of malaria prevention, management and control strategies. Malaria awareness-raising, advocacy, case management, and prevention efforts have reaped the benefits of social science research and as a result, many programmes are implemented and evaluated in a more effective manner (Mwenesi 2005). Such studies have been conducted about: malaria treatment strategies (Snow, Peshu et al. 1992; Mwenesi, Harpham et al. 1995; Ruebush, Kern et al. 1995; Marsh, Mutemi et al. 2004; Zurovac, Rowe et al. 2004; Abuya, Mutemi et al. 2007); LLINs availability, acceptability, affordability and determinants of utilisation at household and community levels (Alaii, Hawley et al. 2003; Alaii, Van Den Borne et al. 2003; Alaii, Van den Borne et al. 2003; Minakawa, Dida et al. 2008; Dye, Apondi et al. 2010; Githinji, Herbst et al. 2010; Hightower, Kiptui et al. 2010; Atieli, Zhou et al. 2011; Mutuku, Khambira et al. 2013); and the economic cost of malaria (Meltzer, Terlouw et al. 2003; Chuma, Thiede et al. 2006).

These insights have informed the fight against malaria by revealing: who to target; what behavioural, economic, social, policy and other contextual barriers must be overcome in order for insecticides and medicines to have their desired effect; which policies and strategies will be most effective; and how to deploy suitable interventions and tools in order to achieve maximum impact and equity. They have thus contributed to a better understanding of socio-economic, ecological, health systems and political processes that mediate viable and sustainable management and control of malaria at all levels (Mwenesi 2005).

Electricity in Kenya

Kenya has low rate of electrification (Ulsrud, Winther et al. 2015). The electricity grid reaches 7% of the rural (Van der Hoeven 2013) and 50% of the urban (Oparanya 2009) population. A means of producing electricity for households not connected to the electricity grid, among families who can afford it, is the use of solar home systems. Although Kenya is one of the world leaders on per capita installation of solar home systems, less than five per cent of rural households had such systems in 2009 (Hankins, Saini et al. 2009; Byrne 2011). The use of solar photovoltaic (PV) technology has been developing and a few mini-grids that supply electricity produced by micro hydropower and/or diesel generators have been established in rural areas (Ulsrud, Winther et al. 2015). Kenya has a relatively well developed sector for solar home systems and government-led installation of solar PV systems at schools and health clinics, as well as various kinds of actors advocating increased use of solar PV through innovative models (Ulsrud, Winther et al. 2015).

More recently, solar lanterns which are smaller and do not require installation by qualified solar technicians have become more popular. The sale of these smaller lighting systems increased by 200 per cent between 2010 to the middle of 2013 with about 700,000 solar lanterns sold to off-grid communities in rural Kenya, according to the Lighting Africa programme (Lighting Africa 2014). A survey conducted before electrification in a rural village in Kenya (Ulsrud, Winther et al. 2015) revealed that households spent an average of 3.2 Euros per month on kerosene for house lighting. The same survey reported an average expenditure of about 1 Euro per month on telephone charging.

The SolarMal project

Integrated vector management through the use of insecticides against mosquitoes, and medicines to treat infection, continue to form the mainstays of malaria control programmes, but the long-term success and sustainability of these approaches is threatened by resistance to artemisinins and mosquito resistance to insecticides (Hiscox, Maire et al. 2012). In Kenya, insecticide resistance has been confirmed by the World Health Organisation (World Health Organization. Global Malaria 2012).

The development by Okumu and others (Okumu, Killeen et al. 2010) of a blend of synthetic chemical attractants which was capable of attracting more *An. gambiae ss* than a human, provided a key breakthrough towards creation of a mass trapping system which could be used for malaria control. The trap contains a mixture of human skin odour mimics which lure mosquitoes into the trap where they die from heat and dehydration. By reducing the density of malaria vector mosquitoes in the environment, the number of potentially infective bites a person receives will be reduced. A reduction in bites should translate into a reduction in malaria transmission intensity and if this can be sustained over time, malaria could eventually be reduced to the point of elimination.

The SolarMal project aimed to demonstrate proof of principle for the elimination of malaria from Rusinga Island using the nationwide adopted strategy of LLINs and case management, augmented by mass trapping of mosquito vectors. The use of novel technology and scientific development underpinned all areas of the project; from the optimisation of chemical baits to attract mosquitoes, to the design of a new mosquito trap and the installation of solar panel systems to provide power to run the traps. Samsung tablets were used to record health and demographic surveillance data (Hiscox, Maire et al. 2012). Each SMoTS consisted of a mosquito trap, a 20-Watts solar panel system which powered the SMoTS during pre-programmed hours, two Light Emitting Diode (LED) light bulbs and an electrical outlet for charging a mobile telephone (Figure 3 courtesy: Oria et. al. Parasites and Vectors 2014). The project was introduced and implemented with the participation of the local community on the island.

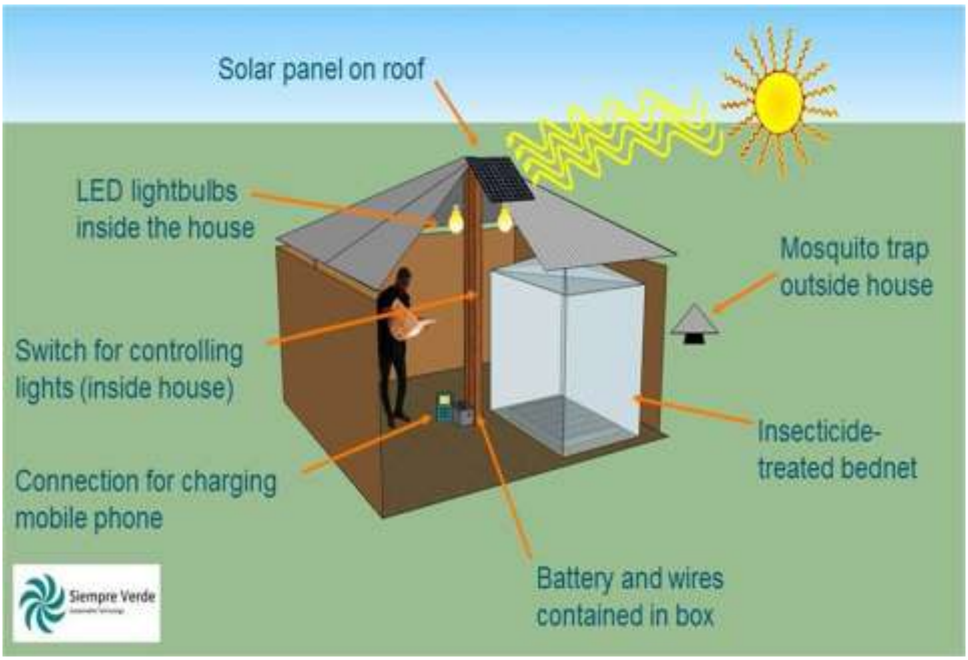

Figure 3. Model house with SMoTS installed (source: Oria et. al. Parasites and Vectors 2014)

During the pre-intervention year, initial ideas about many of the technical design and community engagement were evaluated and re-designed following feedback from various sources. These sources included technical and social research in addition to broader interactions with the social environment. The main aim of the re-design was to customise the intervention to the local setting of the trial community.

To roll-out SMoTS, the project grouped the island into 81 geographically contiguous clusters with 50-51 homesteads per cluster (Figure 4 courtesy: Homan et. al. In Press). A homestead is a single fenced-in house or group of houses occupied by one nuclear or extended family respectively. The homesteads were allocated to a cluster according to a travelling salesman algorithm by which the shortest imaginary route connect every homestead on the island was identified (Homan, Maire et al. 2016). Nine clusters formed a metacluster. The main objective in developing the study design was to ensure that the roll-out of the intervention proceeded in such a way that the project was able to maximise the possibility of detecting an effect of the intervention on malaria clinical incidence and parasite prevalence. A step-wise approach was needed due to logistics of installing the systems and to enable measurement of the time taken for the intervention to be effective in any area. Randomisation at the homestead level could create contamination of effectiveness measures by mosquitoes entering the intervention area of by extending the effect of the intervention to neighbouring houses, thus protecting houses beyond the homestead in which the SMoTS was installed and effectively reaching a situation where the entire study area is intervened with no remaining control area for comparison.

The assignment of homesteads to clusters and metaclusters was completed in May 2013 and any homestead constructed before this point was eligible to receive a SMoTS. Homesteads constructed after this time were eligible to participate in the HDSS, parasitological, entomological and social studies, but were no longer recruited into the technical intervention arm of SolarMal as this could have led to a higher density coverage of traps in areas receiving the technical intervention towards the end of the roll-out (Hiscox et. al. submitted to Trials). The project provided a SMoTS to each homestead on the island. If a homestead had more than one house, project staff requested homestead members to select one house on which the SMoTS should be installed. When two non-related families occupied two adjacent single rooms, as was often the case in commercial areas and fishing beaches, one SMoTS was shared.

The project ran for four years, from January 2012 to December 2015. In June 2013, the installation of SMoTS started and it was completed in June 2015 when 4296 SMoTS had been placed. As some households shared SMoTS, more households were covered compared to the number of SMoTS installed.

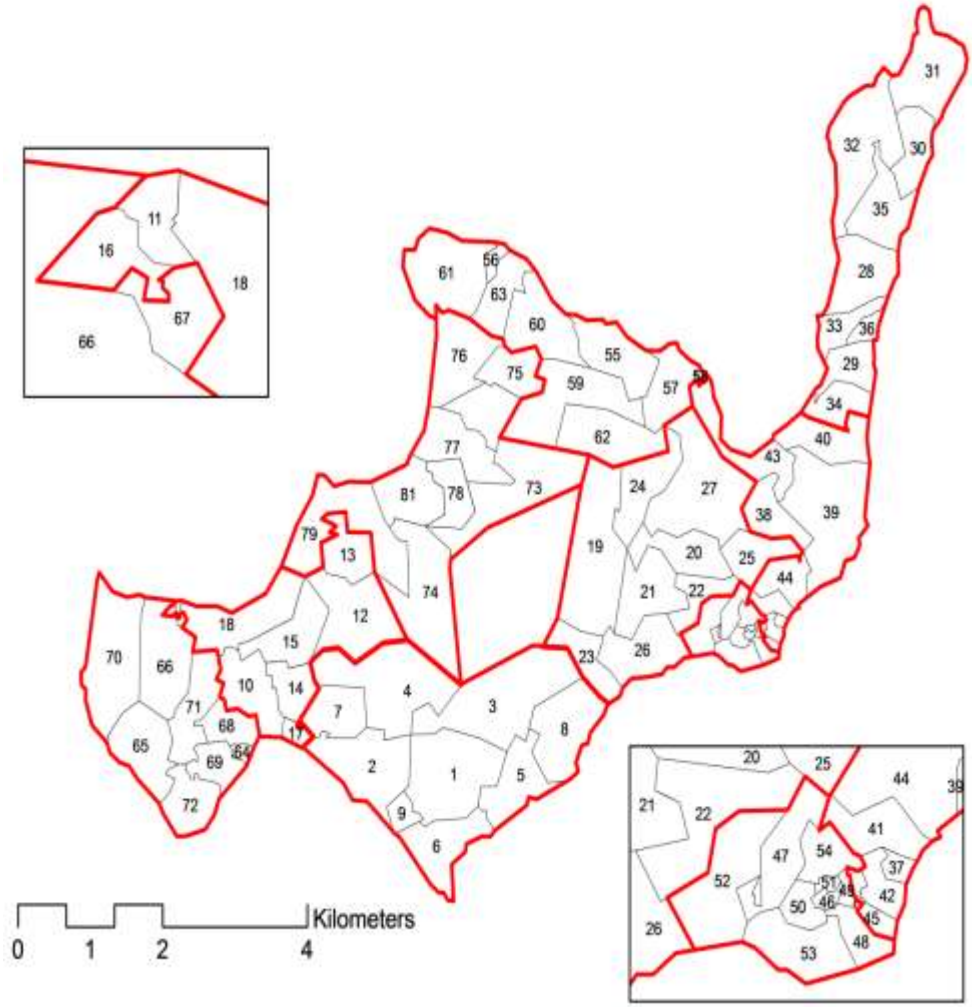

Figure 4. Map showing SolarMal clusters and metaclusters on Rusinga Island (source: Homan et. al. In Press)

The study site

The SolarMal project was carried out in Rusinga Island, an island in Lake Victoria, western Kenya. The island is located between 0°20′51.53″–0°26′33.73″ South, and 34°13′43.19″–34°07′23.78″ East) (Homan, Maire et al. 2016). Administratively, Rusinga Island is part of Homabay County in western Kenya (Figure 4: courtesy of Homan et. al. In Press). It is a rural community located on a 44 square km island which depends economically on fishing, trade and traditional subsistence agriculture. Due to the island's close proximity to the mainland, the waterway separating Rusinga Island from the mainland was filled in 1985 and a causeway to Rusinga Island was constructed to facilitate the transportation of people, goods and services (Opiyo, Mukabana et al. 2007; Nagi, Chadeka et al. 2014). A project-initiated census carried out in 2012 revealed the community consisted roughly of 4,063 homesteads and 23,337 inhabitants(Homan, Maire et al. 2016). Most of the residential areas were situated between 1100 and 1200 metres above sea level around the lakeshore of the island (Homan, Maire et al. 2016). The predominant language spoken is *Dholuo*.

Rusinga has a diverse topography, ranging from flat areas near the shoreline to a central hill and from low to medium density vegetation cover. The island has suffered enormous environmental degradation, soil erosion and extended drought conditions in recent years leaving little productive land and few opportunities to make money other than through fishing (Opiyo, Mukabana et al. 2007). Furthermore, construction activities, deforestation, vegetation clearance, and poorly planned infrastructure development has led to an increased abundance of mosquito larval habitats (Fillinger, Sonye et al. 2004). The long rainfall season is generally expected between March and May and the short rains from October to December, but the seasons are usually not well defined with some years of more or less regular rains and others with prolonged dry periods (Fillinger, Sonye et al. 2004; Okech, Gouagna et al. 2007). Average temperatures range from 20 to 29 °C in the rainy season and from 25 to 34 °C in the dry season (Homan, Maire et al. 2016). Although malaria is transmitted throughout the year, intensity varies greatly according to seasons (Minakawa, Mutero et al. 1999; Shililu, Mbogo et al. 2003; Fillinger, Sonye et al. 2004; Fillinger and Lindsay 2006).

SolarMal targeted all residents of the island and both long and short-term residents were eligible to be included in the project.

Theoretical framework

Research has shown that health behaviours are not simply a function of knowledge or beliefs but are also modified or constrained by social, cultural, economic and political contexts in which they occur (Farmer 1997; Yoder 1997). In addition, the response to an innovation may largely be determined by socio-interactional factors rather than just people's understanding of the science and technology involved (Veen, Gremmen et al. 2011). When people react to an emergent technology, they respond from a context that consists of more than just the technological issues. People's reactions to innovations, whether they accept or reject them or anything in between, are socially significant actions because they serve to accomplish goals in everyday life (Veen, Gremmen et al. 2011). Therefore, in order to understand the reactions of potential users of an emergent technology such as the SMoTS, it is important to know and examine the interactional contexts within which these reactions take place.

In innovation studies it has become increasingly clear that factors influencing spread and use of new ideas, practices or products are not just their static features or features of the adopters. Instead, there is usually a dynamic interaction among features of the invention, intended adopters, and the context or setting where the process is occurring. In other words, innovations have a technical, social and organisational dimension and contributing to successful innovation requires working on all these dimensions simultaneously (Leeuwis 2004; Rogers 2010). This suggests that a wider set of actors and institutions are involved in the innovation process. As a result, innovation requires coordinated action between various stakeholders and necessitates the creation of support networks and negotiations between the various actors (Leeuwis 2004). The research on which this thesis is based was consequently built upon four theoretical frameworks. These include innovation theory (System Innovation), health promotion theory (Health Belief Model), design theory (Experience as Value) and Social Dilemma Theory.

From individual to collective levels

Individuals are essential units of health behaviour theory but the health and well-being of individuals and population across all age groups are influenced by a range of factors both within and outside the individual's control. Therefore, approaches at the individual level may be appropriate to addressing some aspects of a health problem but an exclusive focus at the individual level often ignores the social, structural and physical factors in the environment (Israel, Checkoway et al. 1994). Therefore, whereas earlier approaches to health promotion emphasised the modification of individual's health habits and lifestyles, recent conceptualisations have stressed the importance of linking behavioural strategies with efforts to strengthen environmental support within the broader community that are conducive to personal and collective well-being (Stokols 1996). This comes from the recognition that public health problems are too complex to be adequately understood from a single level and, instead, require more comprehensive approaches.

This thesis therefore explored the perceptions, deployment, adherence to use, and sustainability of SMoTS from the individual to collective levels.

Health belief model: The Health Belief Model (HBM) (Rosenstock, Strecher et al. 1988) suggests that a person's belief in a personal threat of a disease together with a person's belief in the effectiveness of the recommended health behaviour or action will predict the likelihood that the person will adopt the preventive behaviour. According to the HBM, adherence to prescribed practices related to SMoTS is most likely to occur when residents [1] perceive that they are at risk of malaria infection (perceived vulnerability), [2] perceive that exposure to malaria can do them harm (perceived severity), [3] believe that the benefits of adopting the recommended behaviour outweigh obstacles to change (perceived benefits versus perceived losses), [4] notice a reduction in mosquito bites and/or malaria with SMoTS use (stimulus to action).

Experience as value: The notion of user value is important to designers adopting a user-centred approach because it guides their efforts to better understand users and deliver products which are of value to them (Boztepe 2007). The value a user assigns to a product is created at the interface of the product and the user (Frondizi 1971; Cockton 2006). Value resides not in the product but in the user's experiences of the product (Holbrook 2002; Jordan 2002) and what people actually desire is the experiences products provide (Pine and Gilmore 1999). Since products enable an experience for the user, the better the experience, the greater the value of the product to the consumer (Cagan and Vogel 2002). This approach was relevant to SolarMal because although SMoTS main benefit was the control of malaria, a user-centred approach was employed in its design that resulted in the inclusion of house electrification that provided an additional benefit. However, since each of the two components (malaria control versus electrification) could be utilised independently of the other, the user experiences could also accrue and be assessed separately.

Social dilemma: Social dilemmas are situations in which the rational pursuit of self-interest can lead to collective disaster (Kerr 1983). A public good can be provided only if group members contribute something towards its provision; however, both contributors and non-contributors may use it (Komorita and Parks 1995). Public goods confront the individual with the temptation to defect i.e. to take advantage of the public good without contributing to it (Hauert, De Monte et al. 2002). SMoTS had both a private benefit (electrification) and a public good (malaria control) and some of the sustainability components could be organised individually and while others could be optimised when organised collectively. With an interest to assess the conditions under which people cooperate, part of this thesis explored whether the public good had characteristics of a social dilemma, and therefore the inclusion of the social dilemma theory.

System innovation: System innovations are innovations that bring about large-scale transformations in the way a society functions. Technological changes with considerable transformational potential, such as SMoTS, play an important role in fulfilling societal functions but only in association with human agency and social structures and organisations (Elzen, Geels et al. 2004). Therefore, system innovations can be seen as a transformation process where actors build experience with new idea/technology, gradually develop new understandings and practices; frames are modified on the basis of concrete experience, leading to new technical forms and new functionalities (Elzen, Geels et al. 2004). The focus is therefore on networks of heterogeneous elements whose linkages and elements are not automatic, but require continuous reproduction, maintenance and repair work (Elzen, Geels et al. 2004). The system innovations approach emphasises the need to see technical change in terms of systems where flows of knowledge between actors and institutions in the process, and the factors that condition these flows, are central to innovative performance. For such a complex idea such as of trapping mosquitoes using solar power to work, many actors (not just individual household members; but also e.g. SMoTS manufacturers and distributors, learning facilitators, research regulators, healthcare workers, etc.) needed to adjust their practices in a coordinated manner.

System innovations come about by the linking and clustering of multiple technologies. On-going processes in the existing socio-technical regimes and landscape provide windows of opportunity for novelties (Elzen, Geels et al. 2004), such as using odour-baited mosquito traps to control malaria. These windows emerge when tensions occur between elements in the socio-technical regime. For instance when there is diminishing returns of the existing technology (Freeman and Perez 1988). SMoTS, as a complimentary approach to malaria control, has arisen from the threat of resistance to insecticides and therefore concern about sustainability of mainstay strategies of use of insecticides against mosquitoes and medicines against parasites (Hiscox 2012).

Research objective and question

Research Objective

To determine the behavioural, socio-cultural and organisational factors that influence the effective use of SMoTS, and how the innovation can be strengthened to optimise coverage, adherence and sustainability.

Research question

How do Rusinga residents perceive SMoTS and malaria control and how does this influence the design, deployment, maintenance and sustainability of SMoTS and uptake of existing malaria strategies?

Research design

This thesis followed a case study approach which provided me with opportunities to explore the SolarMal project within the context in which it was situated using a variety of data sources (Baxter and Jack 2008). A case study approach ensures that a phenomenon is viewed through multiple lenses which allows for multiple facets of the phenomenon to be revealed and understood. It allows the researcher to explore individuals and networks, simple through complex processes, relationships, communities or programmes (Yin 2003).

The single case under study was the SolarMal project in Rusinga Island. My research was partly participatory action research; contributing to the improvement of the SolarMal intervention process. Action research is guided by the desire to take action and is often carried out to identify areas of concern, develop alternatives and experiment with new approaches (Ranjit 1999). I adopted a mixed methods approach because the immediate objective of my research was to inform the design, implementation and adherence to use of SMoTs. With mixed methods, researchers look to many approaches to collecting and analysing data to provide the best understanding of the research problem (Creswell 2013). Although I collected some quantitative data, the main approach of the research was qualitative and exploratory as SMoTS were being deployed in a field setting for the first time.

Qualitative research is characteristically exploratory, fluid and flexible, data-driven and context sensitive. Qualitative methods celebrate richness, depth, nuance, context, multidimensionality and complexity (Mason 2002). For the qualitative component of my research, I adopted an ethnographic approach responsive to the context and the participants. In an ethnographic approach, the research process is flexible and typically evolves contextually in response to the lived realities encountered in the field setting (LeCompte and Schensul 1999). This was informed by the appreciation that a qualitative research design is more like a journey in which each of the stages builds on previous experiences (Richards 2014). For this thesis, triangulation of methods and sources did not involve just lessons from preceding qualitative studies, but also from the quantitative and from other collaborative disciplines on the project. The pacing of the project activities influenced the sequencing of data gathering and analysis. This required iterative decision-making during the project such as when to stop interviewing, when to return to observing, when to explore new insights, etc. In the end, some predefined data collection points and topics were still useful but because the goals of the project included learning inductively from the data, I also included additional data collection points and topics. I mostly collected open-ended, emerging data with the aim of developing themes from the data.

Research methods

Based on the research objective, I continuously worked with the social studies team to explore possible ways of collecting data within the setting and selected methods that would combine to ensure that the data were sufficiently rich and contextual to address the research questions and support the required analysis. I collected data from primary and secondary sources.

a) Participant observation

Participant observation is a field strategy that simultaneously combines direct participation and observation, interviewing of respondents and informants, document analysis, and introspection (Denzin 1989). Participant observation is based on observational work in particular social settings (Silverman 2013). Observation refers to methods of generating data which entails the researcher immersing herself or himself in a research setting so that they can experience and observe at first hand a range of dimensions in and of that setting (Mason 2002). Choosing to use observational methods was based on the view that answering the research question required depth, complexity, roundedness and multidimensionality of data.

I participated in several project activities with the aim to learn from the participants. These included: installation of SMoTS, community workshops, home visits, Community Advisory Board (CAB) meetings, community meetings, and project meetings. As recommended by Mason (Mason 2002), I constantly kept my role in focus and continually considered how it might shape data and constantly made adjustments.

Installation of SMoTS: This research carried out listening surveys in homesteads during installation of SMoTS. The process involved listening, observing and recording interactions between homestead members and project technicians installing SMoTS. The intention was to monitor immediate responses to the process of installation and SMoTS.

Community workshops: Before distributing SMoTS to homesteads in each cluster, the project invited a representative of each homestead in that cluster to an orientation session henceforth referred to as a community workshop. The community workshop was convened in a central place within the particular cluster, usually in a primary school or church. A community workshop was convened for a new cluster every Friday as it took approximately one week to install SMoTS in a cluster. During the session, project staff reminded participants of the project objective to control malaria, the process of selecting a house to install SMoTS in each homestead and provided practical advice to operate and care for SMoTS. Demonstration SMoTS were used to show participants how the system operates and how to empty the trap of mosquitoes and clean it on a weekly basis. Contact information for project technicians and community liaison officer was provided so that any technical faults in the systems could be reported and resolved promptly. At the end of each community workshop session, representatives of homesteads had a chance to ask questions and seek clarifications.

Deployment and maintenance of SMoTS: A few weeks after SMoTS were installed in two metaclusters, I concurrently carried out semi-structured interviews and observations to investigate immediate community response to the innovation, especially the deployment and maintenance of SMoTS.

CAB meetings: During the first year of the project, researchers worked with project stakeholders to constitute a 16-member CAB. This group provided advice and acted as a resource for project staff on matters of community engagement. Considerations for membership into the board recognised expertise of the members' knowledge of the community of Rusinga. Members were either nominated or elected to represent a section of the community. Membership of the CAB was broad-based including representatives drawn from both national and county governments, Ministry of Health, churches, beach workers, women, the youth, the education sector, non-governmental organisations, community-based organisations and lay community members. During the first meeting of the CAB, project staff oriented CAB members on their role and protocol-related awareness. The CAB was scheduled to hold a joint meeting with representatives of the project (mainly project management team and community liaison officer) every three months. The schedule was flexible to allow additional meetings if the need arose, such as whenever a community event that required intensive brainstorming and preparations was planned.

Community meetings: From 2012-2015, several formal and semi-formal SolarMal-related meetings took place in the trial community and I participated in most of them. These included meetings to launch the project, to select a roll-out sequence, to launch the installation of SMoTS, to celebrate the installation of the final SMoTS, to release the results of SolarMal and several smaller meetings with both local and foreign visitors to the research area. The meetings typically involved discussions between community members, other participants (such as county and national government health and energy staff, project donors, visiting scientists, journalists, etc.) and the researchers.

Project meetings: The on-site based SolarMal team held bi-weekly meetings to share field work experiences. Each project component presented its work progress including achievements, challenges met and plans for the following two weeks. The progress updates incorporated data collection activities. Team members shared information and brainstormed solutions to challenges during these meetings. During each meeting, two participants volunteered to moderate and record meeting minutes which were circulated to all team members after the meetings.

SolarMal also held an annual project workshop at the field research station every June. This followed the schedule of the bi-weekly meetings but included progress updates from the previous one year period. Workshop reports were generated and shared shortly after the workshop.

b) Interviews

Qualitative interviewing refers to in-depth, semi-structured or loosely structured forms of interviewing. Most qualitative research operates from the perspective that knowledge is situated and contextual, and therefore the role of the interviewer is to ensure that the relevant contexts are brought into focus so that situated knowledge can be produced (Mason 2002). The more open-ended the questioning, the better, as the researcher listens carefully to what people say or do in their life setting (Creswell 2013).

Informal interviews in the community: I mostly employed this method with community opinion leaders in the different community sectors during the initial phase of the research when I was entering the trial community. It therefore served to provide me with an orientation to the trial community and topic. I also used this time to grasp the complexity of the research area as far as possible and to develop more concrete research questions and lines of vision. The approach involved visiting the research site and conducting interviews in which the individual was allowed to talk openly about the SolarMal project without the use of specific questions. The intent was to assess the participants' perceptions of the project. At this point, information had been shared that a new project to control malaria would soon be launched in the community but many details had not been shared. A more strategic awareness campaign followed this initial rapid appraisal phase.

Semi-structured interviews: To investigate immediate community responses to the innovation and the implications for on-going implementation, I purposively sampled early recipients of SMoTS in two metaclusters for interviewing a few weeks after their houses were installed. I mainly collected information on adherence to recommended behaviours for proper deployment of SMoTS. I concurrently carried out observations.

In another use of semi-structured interviews, I sampled homesteads in two metaclusters that had received SMoTS to assess outcomes of house lighting as a result of the SolarMal technical intervention. I used multi-stage purposive sampling based on electrification status at metacluster and homestead levels. I carried out in-depth interviews and focus group discussions with community members.

Key informant interviews: To examine preferences of project stakeholders towards SMoTS sustainability components and assess if they related to social dilemma factors, I carried out key-informant interviews with CAB members and opinion leaders. I combined the data from this approach with those from focus group discussions from community members and observation notes from CAB meetings. I collected data from residents of six metaclusters that had received SMoTS at the time.

Focus group discussions: A group discussion stimulates a discussion and uses its dynamic of developing conversation in the discussion as the central source of knowledge (Flick 2006). I combined focus group discussions with semi-structured interviews to assess participants' perceptions of the outcomes of house lighting. I also combined focus group discussions with key informant interviews to examine participant preferences towards organising SMoTS sustainability components.

c) Content analysis

To assess adherence to recommended behaviours for maintenance of SMoTS (specifically reporting any breakdowns or malfunctions of SMoTS), I quantitatively analysed the subject of community calls for technical maintenance of SMoTS. Throughout the course of the SolarMal project, community members could contact the SolarMal technicians and community liaison officer by telephone in order to report technical faults in the SMoTS for prompt resolution. A detailed record of calls was maintained by the on-site project manager and it was used to schedule maintenance activities and monitor how well the systems were performing over time.

I also used project progress reports to qualitatively track the development of the mosquito trap.

d) Baseline and end line cross-sectional surveys

Prior to the roll-out of SMoTS, I administered a structured questionnaire to a randomly selected sample of 5% of homesteads in Rusinga Island as enumerated by the HDSS component of SolarMal. This was to analyse the effectiveness of the educational and awareness interventions that were part of SolarMal project to enhance the knowledge, perceptions and practices of malaria control among trial participants. I administered a slightly modified version of the same questionnaire with a new random sample of 5% of homesteads following the completion of installation of SMoTS. I interviewed the head of household and his/her spouse in each installed household. The questionnaire included questions on knowledge, attitudes and practices related to malaria, malaria control and the SolarMal project.

Cross-sectional surveys, such as the two I conducted, uses questionnaires for data collection with the intent of generalising from a sample to a population (Babbie and Babbie 1990). The surveys were carried out after explorative qualitative data were collected, and expanded the findings with a larger sample so as to generalise the results to the whole population (Creswell 2013).

Additional information on the research design is found in the individual empirical chapters.

Figure 5 summarises the data collection methods and sources used.

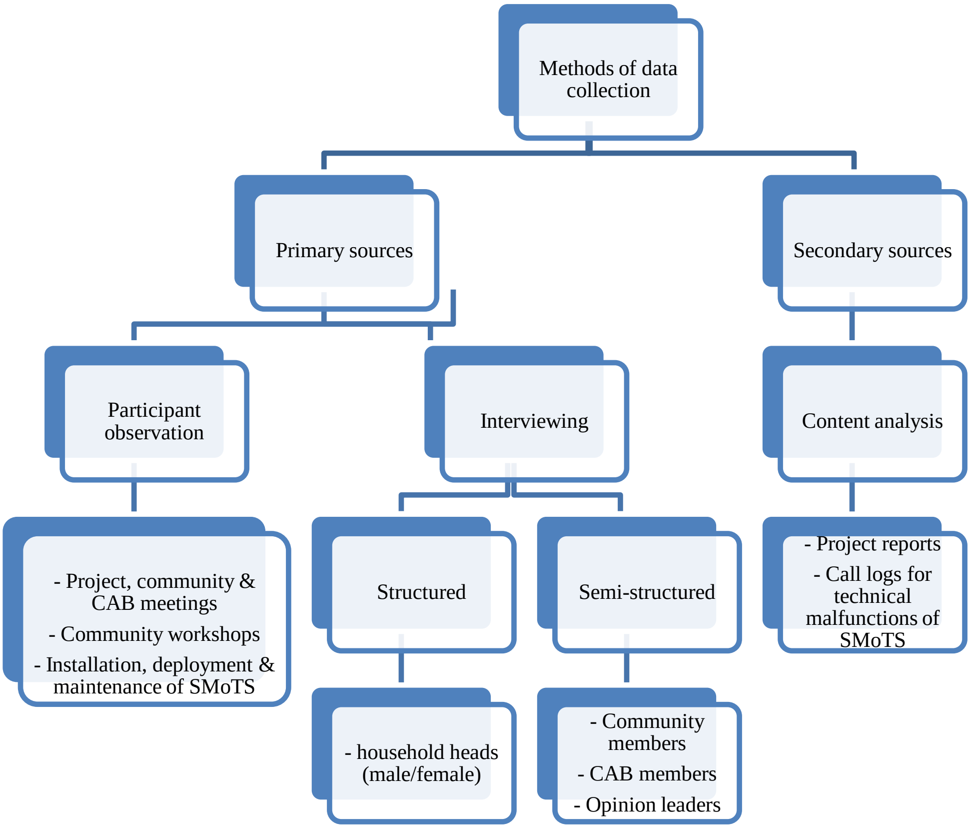

Figure 5. Data collection methods and data sources

Thesis outline

This section highlights the contents of each chapter of this thesis which unfolds across seven chapters. The empirical chapters (2-6) in this thesis have been written in the form of research articles. Each of these chapters addresses the research question in section 1.6.2.

Chapter 2 describes how the mosquito trapping technology and related social contexts mutually shaped each other and how this mutual shaping impacted design and re-design of the SolarMal project.

Chapter 3 explored behaviours and motivations for proper deployment and care of SMoTs with the aim of identifying immediate community response to SolarMal project and the implications for on-going implementation and supportive community communication outreach.

Chapter 4 documented the perceived impact of SMoTs on family dynamics, social and economic status, and the community as a whole.

Chapter 5 evaluated the knowledge, perceptions and practices related to malaria control before and after the roll-out of solar-powered mosquito trapping systems.

Chapter 6 investigated whether the community preferred individual or cooperative solutions for organising sustainability components, and whether and how known social dilemma factors could be recognised in the reasoning of actors.

Chapter 7 synthesises the main findings. Subsequently, this results in the overall conclusions of the thesis that are discussed within the broader debates on research and policy.

Table 1.1 shows a summary of the thesis chapters and the research methods used to inform them.

Table 1.1 Summary of thesis chapters and the research methods used to inform them

Methods	*Design and re-design of SolarMal (Chapter 2)*	*Initial responses to SMoTS (Chapter 3)*	*Socio-economic and perceived health outcomes (Chapter 4)*	*Perceptions of malaria, malaria control and SolarMal project (Chapter 5)*	*Sustainability (Chapter 6)*
Informal interviews (carried out throughout the research phase)	Yes	Yes	Yes	Yes	Yes
Pre- post SMoTS roll-out survey	-	-	-	Yes (N=638: household heads and spouses)	-
Participant observation	Yes – Project and community meetings	Yes – Trial community deployment and maintenance of SMoTS	-	-	Yes - CAB meetings on sustainability
Semi-structured interviews	-	Yes (N=24: male and female adults in households in which a SMoTS is installed)	Yes (N=25: heads of households in which a SMoTS is installed; 13 females and 12 males)	-	Yes (N=16: 9 CAB members; 6 males and 3 female and 7 Opinion leaders; 4 males and 3 females)
Observations	-	Yes (N=24 installed SMoTS)		-	-
Focus group discussions	-	-	Yes (N=54: male and female community members from households in which a SMoTS is installed)	-	Yes (N=35: community members living in beaches and villages)
Content analysis	Yes - Project progress	Yes - Call logs for technical	-	-	-

	reports	maintenance of SMoTS			

**N is the number of participants*

CHAPTER 2

Tracking the mutual shaping of the technical and social dimensions of solar-powered mosquito trapping systems (SMoTS) for malaria control on Rusinga Island, western Kenya

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Parasites and Vectors (2014) 7(1): 523

Abstract

There has been increasing effort in recent years to incorporate user needs in technology design and re-design. This project employed a bottom-up approach that engaged end users from the outset. Bottom-up approaches have the potential to bolster novel interventions and move them towards adaptive and evidence-based strategies. The present study concerns an innovative use of solar-powered mosquito trapping systems (SMoTS) to control malaria in western Kenya. Our paper highlights the co-dependence of research associated with the development of the SMoTS technology on one hand and research for enhancing the sustainable uptake of that very same intervention within the community on the other. During the pre-intervention year, we examined the design, re-design and piloting of a novel technology to generate lessons for malaria elimination on Rusinga Island. Initial ideas about many technological necessities were evaluated and re-designed following feedback from various sources, including technical and social research as well as broader interactions with the social environment. We documented the interlocking of the multiple processes and activities that took place through process observation and document reviews. We analysed the data within the conceptual framework of system innovation by identifying mutual shaping between technical and social factors. Our findings illustrate how various project stakeholders including project staff, collaborators, donor, and community members simultaneously pursued interdependent technological transformations and social interests. In the ongoing process, we observed how partial outcomes in the technological domain influenced social events at a later phase and vice versa. Looking at malaria intervention projects employing novel technologies as niches that may evolve towards system innovation helps to reveal interrelations between the various technical and social aspects. Revealing these interrelations requires a different role for research and different perspective on innovation where innovation is more than the technical aspects. This approach therefore requires that research is designed in a way that enables obtaining feedback from both aspects.

Introduction

Technology is affected at a fundamental level by the social context in which it develops (MacKenzie 1999; Schot and Geels 2008). Adopters of technology may be signing up for far more – politically, economically, even culturally, as well as technically – than appears at first sight (MacKenzie 1999; Geels 2005).

While social scientists working in public health have devoted much attention to the effects of technology on society, they tended to ignore the more fundamental question of what shapes the technology in the first place (Coreil and Genece 1988; Reis, Goepp et al. 1994; MacKenzie 1999). Some progress to change this has been made over the years (Green 1986; Brieger, Ekanem et al. 1996). In relation to malaria control, while researchers rarely investigate the social processes that shape malaria control innovations before implementation, there is increasing focus on making improvements to progressive forms of the interventions based on implementation research insights on human responses to predecessor innovations (Ansah, Gyapong et al. 2001; Mbonye, Neema et al. 2006) or on the bio-physical conditions that determine their effectiveness (van der Hoek, Amerasinghe et al. 1998; Ellis and Wilcox 2009). In the past, it has been shown that challenges of community engagement can undermine research, even in studies where ethical issues have been addressed, as was the case with the abandoned trials in Cameroon and Cambodia of tenofovir as pre-exposure prophylaxis against HIV infection (Singh and Mills 2005). Learning from these experiences, public health technology developers strive to anticipate public acceptance actively by including social contexts in the design and development of their innovations. An innovation, then, is the effective combination of new technology (hardware) and the novel forms of social organisation (orgware). This emphasises the interdependence of the social and technical aspects of an innovation because the hardware does not fulfil societal functions on its own but in association with human agency, social structures and organisations (Hofman 2004; Geels 2005; Geels 2005). Despite advances in the technology assessment field in general, the social issues associated with new technologies are still not fully considered (Birn 2005; Wendy, Vanclay et al. 2010). For understanding the efficacy of an innovation in context it is necessary to understand the interaction between the technical and social phenomena.

The key research and development goal in malaria control is to define an agenda to sustain and improve the effectiveness of currently available tools and to develop new vector control tools that can be used to interrupt transmission in environments or at intensities that existing tools cannot reach (2011). Studies have shown that during the design phase, technology actors usually focus on developing, testing and optimising technology but often neglect embedding the technology in broader societal goals, or leave it to a later pilot stage (Allotey, Reidpath et al. 2008; Schot and Geels 2008). However, embracing bottom-up approaches that engage end users from the outset in research and development have the potential to bolster vector control and move it towards adaptive and evidence-based strategies that vary in space and time depending on local conditions (Thomas, Godfray et al. 2012). Sustainable innovations development therefore requires interrelated social and technical change (Schot and Geels 2008). This is necessitated by the recognition that social impacts are not side effects but core dimensions of new technology and technological development, they are a function of the co-production of technology and society (Wendy, Vanclay et al. 2010). In this way, an innovation project is best advanced by engaging the end users and working in partnerships to generate shared knowledge and solutions relevant to the local context, in addition to optimising the physical functioning of the hardware. Interventions become embedded through the manipulation of these contextual factors that enhance the uptake, performance and sustainability of the intervention (Molyneux 2004; Allotey, Reidpath et al. 2008).

In 2012, we launched a community-based malaria control intervention project using Solar-Powered Mosquito Trapping Systems (SMoTS) on Rusinga Island, western Kenya – the SolarMal Project. The use of novel technology underpinned all areas of the project; from the optimisation of chemical baits to attract mosquitoes, to the design of a new mosquito trap and the installation of solar panel systems to provide power to run the traps (Hiscox, Maire et al. 2012). A SMoTS was distributed to each homestead on Rusinga Island. A homestead is a single fenced-in house or group of houses occupied by one nuclear or extended family respectively. An installed SMoTS consists of a solar panel mounted on the roof of a house, a battery, a battery box with a USB mobile phone charging port, two Light-Emitting Diode (LED) light bulbs and a mosquito trap hung outside the house (Figure 2). The original concept of a SMoTS included house lighting as an additional benefit but the inclusion of a USB mobile telephone charging capacity was incorporated at a later stage of development. Each homestead received one SMoTS. In a homestead with more than one house, members agreed through consensus on which house to install the SMoTS.

The project roll-out used a variation on the stepped wedge trial design, termed the hierarchical design. The intervention implementation began at one randomly selected homestead and expanded randomly until a cluster (defined in this study as a composition of 50-60 homesteads) with the intervention was created. Neighbouring clusters then received the intervention until a metacluster (defined in this study as a composition of nine clusters) was intervened. The intervention implementation then progressed into clusters and metaclusters in a second geographically distinct location, then a third, fourth, fifth, etc., and this will continue until the whole island is covered (Hiscox, Maire et al. 2012).

The main objective in developing the study design was to ensure that the roll-out of the intervention proceeded in such a way that the project was able to maximise the possibility of detecting an effect of the intervention on malaria clinical incidence and parasite prevalence. A step-wise approach was needed due to logistics of installing the systems and to enable measurement of the time taken for the intervention to be effective in any area. Randomisation at the homestead level could create contamination of effectiveness measures by mosquitoes entering the intervention area or by extending the effect of the intervention to neighbouring houses, thus protecting houses beyond the homestead in which the SMoTS was installed and effectively reaching a situation where the entire study area is intervened with no remaining control area for comparison. The roll-out commenced in June 2013 and it was estimated to take two years to reach complete coverage. Boundaries of intervention areas were not the same as village boundaries due to variation in village sizes and the need to create intervention areas of the same number of homesteads. This therefore meant that parts of villages on the island received SMoTS ahead of others.

Our analysis focused on the design, re-design and piloting of the innovative approach to controlling malaria largely before its implementation had started. We systematically documented and analysed how the mosquito trapping technology and related social contexts mutually shaped each other and how this mutual shaping impacted design and re-design of the intervention. This paper highlights the co-dependence of the research associated with the development of the SMoTS technology on one hand and the research for enhancing the sustainable uptake of that very same intervention within the community on the other. In our analysis we demonstrate how system innovation theory helps to provide insights into how a promising malaria control intervention evolves and matures through an interaction between technical and social phenomena.

System innovation and the co-evolution of technology and society

System innovation theory suggests that system innovation happens through experimentation in socio-technical niches which compete with other niches and the existing regimes. New technologies require the adaptation of socio-technical regimes (Geels 2002; Geels and Raven 2006). The experimentation that occurs is a mechanism to adapt to a broader system and must take place in a protected environment that enhances the chances of the new technology prospering even when faced with competition from other technology and associated actors and social interests.

In working towards system innovation, an innovative idea such as this project needs not only to involve technological substitutions, but also changes in social elements (Rip and Kemp 1998; Elzen, Geels et al. 2004; Geels 2005). The end result is that mature incumbent technologies and the existing technological regime are well attuned to each other as a result of a long process of incremental co-evolution (2006).

When talking about societal change it is important to acknowledge that human agency, strategic behaviour, and social struggles are important but situated in the context of wider structures (Geels 2005). Actors interact within the constraints and opportunities of existing structures, while simultaneously acting upon and restructuring these systems. Structures not only constrain but also enable action, making action possible by providing coordination and stability. However, socio-technical reconfigurations do not occur easily because the elements in the configuration are aligned to each other. Radically new technologies have a hard time in breaking through because the various networks are aligned to the existing technology (Geels 2002).

Co-evolution takes place when two or more variables of the system affect and essentially create each other, although their different variables may operate at different scales. Social systems thus adapt themselves to changing technical systems, as well as the converse (Geels 2005). Social shaping of technology is accompanied by technical shaping of society.

Using the above perspective, we regarded the SolarMal project as a niche level activity, aimed to enhance the success of the intervention in both the health and energy regimes. The challenge for the project was to create social and technical novelties and learn how they could be made to work in practice by involving real life stakeholders in their specific context. Thus, in order to effectively combat malaria, the new SMoTS technology needed to become effectively adapted and linked to both a dynamic social and the relevant bio-physical environment, whereby it was relevant to acknowledge that these environments themselves may be influenced deliberately as part of the innovation process. In other words, the SMoTS would eventually have to 'work' socially, for instance, in the sense that it was accepted and supported by behaviours of individuals and organisations, and it would have to 'work' technically, in the sense that it actually captured sufficient mosquitoes in the prevailing geographical and bio-physical conditions of Rusinga Island.

Methods

This social research was carried out within a multidisciplinary team. Research into the interaction between technical and social phenomena in the development of malaria control innovations requires a strategy that is both rich in context and can track developments over time (Geels 2005). The focus was on documenting the interlocking of multiple processes and activities. This article explored the pre-intervention year of the development of a community-based innovative malaria control project which employed the methodology of action research. Beginning April 2012 until April 2013, we examined the design, re-design and piloting of a novel technology to control malaria.

The process of piloting SMoTS in the field took place over a six week period in 2012. The aim of the pilot study was to ensure that the SMoTS functioned from a technical perspective and to assess residents' perceptions of the SMoTS before placing a large order for components. As part of the piloting, the project installed complete SMoTS in the study community to test and evaluate their performance and community perceptions. A total of 18 SMoTS were installed in randomly selected homesteads. Before the piloting, representatives of the selected homesteads were invited to an orientation session, during which they were informed of the reasons for and duration of the pilot, how SMoTS work, and how to care for SMoTS, among others.

During the piloting, the project installed nine 20-Watt and nine 30-Watt solar panels in the selected homesteads. The project piloted four different types of bulbs: in each household we installed two different types of LED bulbs, one brighter than the other. All bulbs were three Watts and white but their brightness and physical size differed. The piloting was to determine whether a 20-Watt panel would provide sufficient energy to run the SMoTS, or if a 30-Watt system was required. The performance and compatibility of the battery and bulbs within the households was also assessed. Technical assessments included checking the voltage of the batteries after a night of use and checking that the lights and trap functioned during all nights. Project staff also held informal conversations in houses that received a pilot SMoTS in order to capture occupants' perceptions of the installed SMoTS. Essentially, the project wanted to ensure cost-effectiveness without compromising the research i.e. to ensure sufficient power supply for operating the mosquito trap yet cognizant of the practical immediate interests to households, such as lighting and phone charging. The findings formed the basis for the larger procurement order.

During this piloting period, the project community engagement mechanisms were also being refined and implemented. The research employed document reviews and ethnographic methods of process observation.

Study site and population

The trial targeted all residents of Rusinga Island, an island in Lake Victoria, western Kenya. The island is extensively deforested and generally rocky with limited vegetation cover (Opiyo, Mukabana et al. 2007). Rusinga has a diverse topography, ranging from flat areas near the shoreline to a central hill. Although malaria is transmitted throughout the year, intensity can vary greatly according to seasons. The area experiences long rains between March and June and short rains between October and November, although the interval of the rains has become unstable in recent years (Opiyo, Mukabana et al. 2007).

As per a census implemented at the end of 2006 during the establishment of a demographic surveillance system, Rusinga Island had 24, 000 inhabitants (Kaneko, Mushinzimana et al. 2007). Residents are primarily engaged in fishing in Lake Victoria, small-scale trading and subsistence agriculture (Opiyo, Mukabana et al. 2007). The local language is *Dholuo*. Most houses on the island have walls made from mud or corrugated iron, with corrugated iron roofs. Lake Victoria is the main source of water for the islanders. The lake is used for fishing, washing clothing and dishes, and bathing. Latrine usage is low. Except for a few businesses, guest houses, and NGO offices, running water and mains electricity are largely untapped. Generators are occasionally used to pump water, operate flour mills, and run mobile phone charging businesses or power speaker systems for events such as church services and religious meetings. Prior to 2012, most Rusinga inhabitants used kerosene lamps as light source and had their mobile phones charged at commercial centres.

Data collection and analysis

The concept for the SolarMal intervention arose following the discovery of synthetic odours that attract malaria mosquitoes by mimicking human odour (Mukabana, Mweresa et al. 2012). After the discovery, researchers started thinking about how to implement the technology in an actual field setting. This led to the development of ideas about whether it would be possible to use traps baited with the synthetic odour and carbon dioxide to lure and capture mosquitoes. Electricity would be required to power fans which could suck mosquitoes into the traps and the power could be generated through solar energy. During the pre-intervention year initial ideas about many of these necessities had been developed but it was during this time that they were evaluated and re-designed following feedback gained from various sources, including technical and social research as well as broader interactions with the social environment. The main aim of the re-design was to customize the intervention to the local setting of the trial community.

The mosquito traps (*Suna* traps) operate according to a counter flow mechanism and are designed to collect mosquitoes outdoors prior to house entry (Hiscox, Maire et al. 2012). Chemical odours placed on nylon strips attract mosquitoes to the trap. A mosquito nearing the trap is sucked through a ventilator into a bag inside the trap. Trapped mosquitoes cannot escape and they eventually die due to lack of water and food. The *Suna* trap has been described elsewhere (Hiscox, Otieno et al. 2014). Figure 6 shows a cross-sectional diagram of a *Suna* trap.

Data presented here were collected in an action research mode. Over a period of one year we convened several project meetings with community members, three meetings with members of the project community advisory board (CAB), and several meetings with members of a community-based organisation (CBO). The aim was to understand the research subject wholly within its social context.

We collected field notes during meetings and expanded these on an MS Word 2007 (Microsoft, Washington, USA) file afterwards. Observational notes and reflexive dialogues were also hand written and expanded on an MS Word 2007 file. The progression from data collection to interpretation was intended to be reflexive. We analysed the data within the conceptual framework of system innovation by identifying mutual shaping between technical and social factors. We noted changes in technical and social designs of the intervention, put them on a timeline and reconstructed the rationale for the changes, and related them to technical or social considerations. We also monitored the effect of the changes on the technical and social refinements on the design and re-design of the intervention.

Ethical considerations

The SolarMal study was approved by the Kenya Medical Research Institute Ethical Review Committee (KEMRI-ERC NON-SSC No. 350). After the study was explained to the households in the local language, written informed consent was obtained from them prior to enrolment.

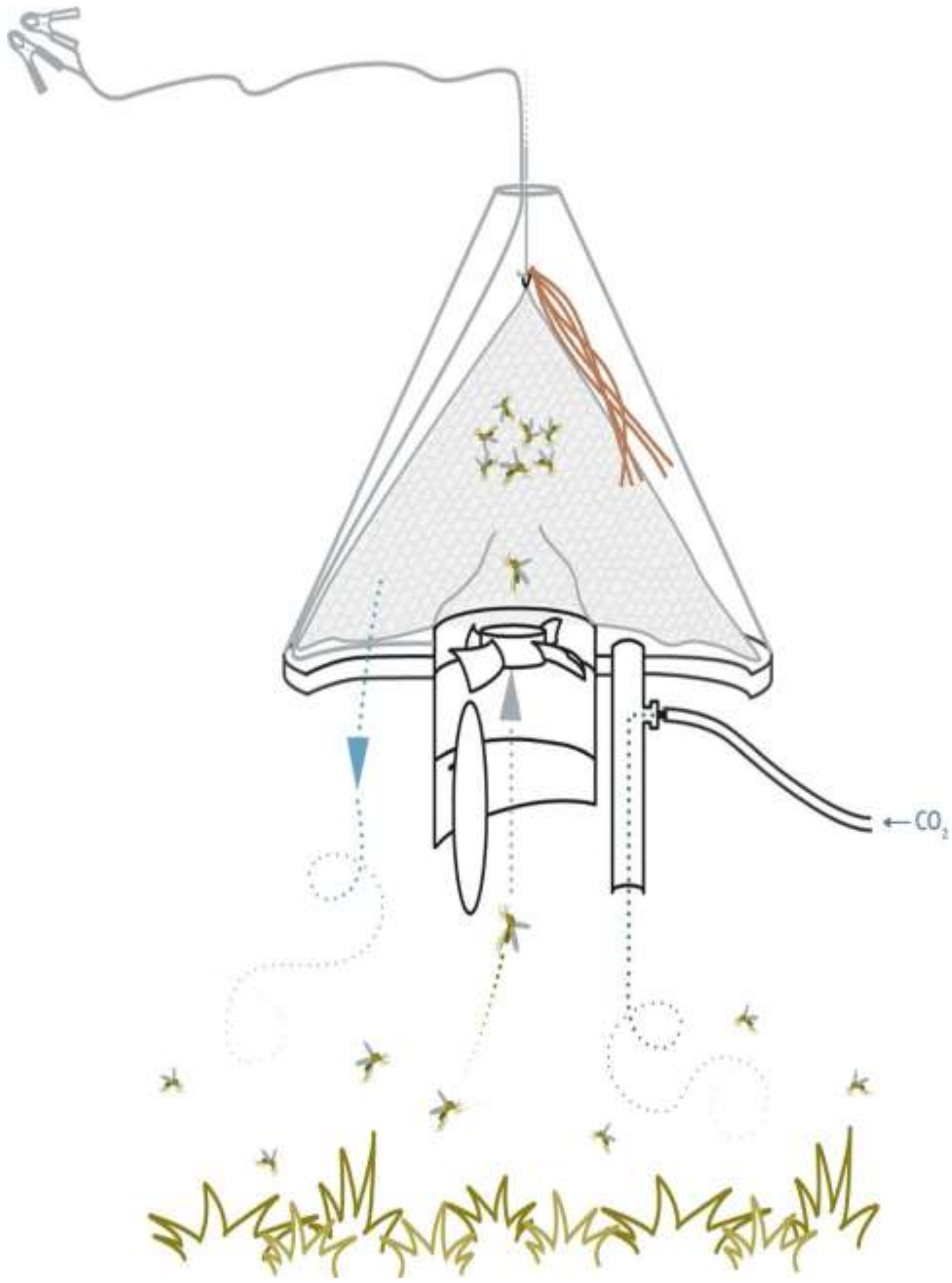

Figure 6. Cross-sectional diagram of the Suna mosquito trap (source: Hiscox et al. Malaria Journal 2014 13:257 doi:10.1186/1475-2875-13-257).

Results

Changes to technology design

Changes to the technology design included removal of carbon dioxide from the blend, trap improvements and re-design of the electricity provision system. Table 2.1 summarises these changes, provides a timeline of when they occurred, feedback that necessitated them and their consequences.

Table 2.1 Mutual shaping of technology and social contexts of the intervention

Period	*Event/decisions*	*Feedback*	*Consequences of feedback*
Jan-March 2012	Commenced trap development with the introduction of Mosquitito™ trap.		
April-June 2012	Continued trap development with the first *Suna* trap.	Solid metal cone introduced because fabric absorbed the odours and consequently reduced trap efficacy. Fabric base replaced with flexible plastic mesh base.	More durable.
July-September 2012	Continued *Suna* trap development with the replacement of metal cones with plastic ones and plastic mesh base with a rigid one.	Metal cones are potentially attractive to thieves who could sell them to scrap metal dealers. Plastic cones are cheaper than metal cones.	Lower unit cost for SMoTS. Rigid plastic base to increase durability but found to reduce airflow and performance.
July-September 2012	Complete SMoTS installed in 18 households for piloting. In nine households 20-Watt systems were provided and in the other nine, 30-Watt systems were provided. Also, four different types of bulb	Performance of various components and community perceptions of SMoTS. Estimates of lengths of electrical cable	Decision on final SMoTS components: 20-Watt systems and brighter bulbs selected for the intervention.

	were provided.	needed per house.	
July-September 2012	Removal of carbon dioxide from the blend.	Logistical challenges with procuring and distributing molasses to households. Time constraints with regard to project timelines. Need for more intensive training to households on replacing molasses on a daily basis and concerns about adherence. Cost of procuring molasses.	Discontinued mobilisation of women's groups that were being mobilised to distribute molasses for fermentation.
October-December 2012	Finalised trap development with the modification of plastic base with fine grid of holes to increase airflow (Figure 3).	Rigid plastic base with fine grid of holes.	Increased airflow and performance with greater durability than a fabric base.

Re-design of the mosquito trap

The components of the SMoTS were designed and developed through a collaboration of a network of actors and institutions. Trap development began with the Mosquitito™ Trap which was already produced and sold by Biogents AG (Regensburg, Germany). The Mosquitito™ Trap is used to capture *Aedes* mosquitoes that are potential vectors of diseases such as Chikungunya and dengue viruses, among others. The Mosquitito™ Trap was modified to create the final *Suna* trap which was used for the SolarMal intervention.

From April to June 2012, the first prototype *Suna* trap was developed. *Suna* is the *Dholuo* word for mosquito. In this prototype the fabric base and fabric cone of the Mosquitito™ trap were replaced with flexible plastic mesh base and metal cone because experiments with the fabric Mosquitito™ trap showed that *An. gambiae* catch sizes decreased by around 20% over time under semi-field conditions and there were concerns about the durability of a fabric trap. The fabric was suspected to absorb odours from the bait, thus leading mosquitoes to approach the trap not only from the lower side where they would be sucked inside, but also from the upper side where there was no trap entry point.

Between July and September 2012, the second *Suna* trap prototype was developed using a more durable rigid plastic base with large air holes and a metal cone. Under semi-field conditions, comparisons of this trap against the first prototype associated the solid plastic base with a 60% reduction in *An. gambiae* catch size. From October-December 2012, the *Suna* trap was modified with a plastic base with a fine grid of holes (Figure 7) to increase air flow to a rate similar to that of the flexible plastic mesh base. The cone was also re-designed so that it could be made from plastic rather than metal to reduce cost and risk of theft. Community members were concerned that metals are more attractive to thieves because there is a ready market for scrap metal. The *Suna* trap in its final form is now sold by Biogents AG[3].

Figure 7. Suna trap with a plastic base with fine holes

[3] Biogents AG
http://www.biogents.com/cms/website.php?id=/en/traps/biogents-trap-systems/bg_suna.htm

Re-design of the electricity provision system

Findings of the piloting with regard to the solar panel, battery and bulb performances suggested that a 20-Watt solar panel provided sufficient energy to simultaneously run a *Suna* trap, charge a mobile phone and light the two LED bulbs. Thus, the project procured 20-Watt solar panels for the intervention. In addition, we noticed dead insects inside some of the bulbs. Ultimately one brand of bulbs was preferred because it gave the brightest light and insects could not get inside.

Cost limitations also shaped many decisions taken in the development of the SMoTS. The cost of components, particularly the solar panels and battery, were important determinants of the end functions of the system.

A report compiled from routine informal conversations with household members during the period they had a SMoTS for piloting revealed that households expressed relief with regard to reduced expenses on kerosene for lighting houses; they either did not need kerosene at all or only needed to buy small quantities for lighting houses that did not have SMoTS. Even though the pilot group could use the systems to charge their mobile phones if they bought a USB cable, only four households bought a USB cable and used the system to charge their phones. During this period, in contrast with the present situation, USB cables were not sold in the vicinity of Rusinga Island. People who charged their phones were excited about having battery time on their phones all the time and saving money they would have otherwise spent on charging their phones at commercial centres.

Removal of carbon dioxide from the odour blend

Carbon dioxide plays an important role in the host-seeking behaviour of blood-feeding mosquitoes. The project initially planned to use a mixture of organic volatiles (ammonia, lactic acid, tetradecanoic acid, 3-methyl-1-butanol, butan-1-amine), impregnated on to strips of nylon, supplied in combination with yeast and molasses-generated carbon dioxide (Menger, van Loon et al. 2014). The yeast and molasses mixture would need to be replenished every day in order to provide carbon dioxide to the trap during every night of trapping. The project therefore needed to develop a molasses procurement and distribution system to ensure all 4000 plus homesteads on the island had a supply of molasses every day. The project started engaging women's groups which were based all over the island to brainstorm on a mechanism for distributing molasses to all homesteads. The project would need to build a central store for molasses on the island from where women from different groups would on a weekly basis collect and distribute it to homesteads for daily replenishment.

Due to increased awareness of financial and logistical challenges related to continuously procuring and distributing molasses in quantities large enough to supply all homesteads on the island on a daily basis, and the unsustainable aspects of molasses provision, the decision was taken to remove carbon dioxide from the blend and replace it with a synthetic mimic (Turner, Li et al. 2011). Because the 5-component odour bait and carbon dioxide mimic was expected to attract and remove a constant fraction of the malaria vector each day, it was considered that the continuous presence of the odour-baited traps was more important in controlling malaria than maximum daily efficacy. The new odour combination was released from small nylon strips suspended inside the cone of the *Suna* trap (Hiscox, Otieno et al. 2014).

Delivery of the odour-bait from nylon strips was the most effective way of producing odour baits at the time (Mukabana, Mweresa et al. 2012). In addition, nylon was locally available and relatively cheap. During the research phase, the odour bait was replaced every three months, but it was expected that research and development work would lead to the creation of odour baits which last longer (Mweresa 2014).

Changes to the social organisational design of the intervention

In order to gain and maintain the support of communities and organisations on the island the project had to carefully operate and adapt its implementation strategies on several occasions. While in the early stages the islanders easily showed enthusiasm for the project, the electrification aspects in particular, later on a number of sensitivities occurred. These related, for example, to issues about who should represent the community in the project organising team and about whom should receive SMoTS and in which order the systems should be rolled out.

Community engagement: From a community-based organisation (CBO) to community advisory board (CAB)

During the initial stages the project worked with members of an already existing community-based organisation (CBO) as a link between the project and the community. However, the project’s engagement with the CBO was characterized by challenges and tensions related to differences in priorities between the CBO and project, the extent to which community members perceived the CBO to represent and reflect community aspirations, and competition between the CBO and other community groups. This hampered initial efforts to foster effective relationships between researchers and the research community.

Based on feedback from meetings with community leaders and members, the project realised that while the CBO’s liaison role may fit other on-going community-based research in Rusinga, this synergy did not necessarily cut across projects. This led to conceptualisation of a community advisory board (CAB). This group would provide advice and act as a resource for the project team on issues of community engagement. Considerations for membership into the board recognised the expertise of the members’ knowledge of the community of Rusinga. The board would interpret the community responses to the project staff and interpret the project to the community. The project team worked with project stakeholders including healthcare workers, church representatives, government administrators, representatives of the fishing community, women and youth representatives, non-governmental and community based organisations to identify key sectors of the community to be represented. The people included in the list were either nominated or elected by community members to represent a section of the community. The above mentioned CBO was invited to join the CAB, in recognition of their role representing a specific group of the island community. The process led to the development of a list of 16 persons who constituted the project CAB. Membership of the CAB was broad-based with representatives drawn from government administration, Ministry of Health, churches, beach workers, women, the youth, the education sector, non-governmental organisations, community-based organisations, political sector, and lay community members. The overriding objective was to have a group that is representative of all sectors of the community so that whenever the project obtained the viewpoints of the board, ideas which are representative of the residents of the island are heard. During their first meeting the CAB members elected an executive committee comprising of a chairperson, vice-chairperson, secretary, and treasurer.

The project then organised a workshop to orient and train the board members to provide them with a broadened understanding of the project. During this event CAB members were trained regarding their functions and protocol-related awareness. Active CAB participation in the intervention process was encouraged.

The CAB immediately became critical when the project engaged it in discussions on how to select a house to install a SMoTS in homesteads with more than one house (see selection of house to install the SMoTS). Members of the CAB were also instrumental in devising a strategy to pick a sequence to follow in rolling-out SMoTS to different clusters and metaclusters. They provided feedback during simulation of a roll-out ballot and participated during the actual community ballot exercise (see community roll-out sequence ballot below).

Community roll-out sequence ballot

Especially within the project team, a lot of deliberation occurred regarding the order in which SMoTS would be rolled out. Scientific concerns, particularly about the randomness of the intervention process, were of overriding importance in this realm, but at the same time it was critical that the community would agree that the roll-out strategy was reasonable and fair.

Therefore, although drawing a sequence which would maximise the ability to measure an effect of the intervention was of utmost importance for the study project, it was also necessary to develop a formula for selecting a sequence that was acceptable to community members. During discussions with various project stakeholders, among them project staff, members of the CBO and CAB, various approaches to balloting were introduced, discussed and simulated. Most of them were later dismissed because they were seen as unfair since they gave a perceived advantage to either some of those involved in the ballot process or some parts of the island. This was perceived to have the potential to reduce the credibility of the project and negatively impact acceptability with community members particularly those who would receive SMoTS later than the others.

Ultimately, based on insight from stakeholders, the project used a blind ballot approach where many possible roll-out sequences were computer-generated. Nine complete sequences (one starting in each metacluster) were presented to community members for selection according to a blind ballot. During the ballot, nine community members – one from each of the nine metaclusters – first picked a sealed number from numbers 1-9. The person who picked number one then picked a sealed envelope from nine unmarked envelopes each containing a different roll-out sequence. The sequence this person picked was the one the project followed. This approach was participatory for community residents and was perceived as a fair process. The ballot was conducted in a community forum. Community members who did not attend the balloting event were initially confused about the procedure but later on, following discussions with other community members and project staff, considered it fair and transparent.

Selection of houses to install the SMoTS

Once the project-initiated baseline demographic surveillance census of the island was completed, the number of houses was discovered to be much higher than earlier research had shown (Kaneko, Mushinzimana et al. 2007). This meant that the project could only provide a SMoTS to each homestead rather than to each individual house. This led to a scenario where the project needed a system to determine the one house to install the SMoTS in cases where a homestead had more than one house.

Initially, the project anticipated using a balloting approach to select houses because this system would ensure a variety of houses were selected in different homesteads which would be representative of the mixture of houses on the island. However, it was important to choose a method that would show transparency of the selection process to residents. Therefore, based on insights from discussions with a section of project stakeholders and with the project CAB members, it was agreed that consensus among the members of the homestead would be the more socially acceptable method by the community. Table 2.2 shows a synthesis of the influences to the social and technical design of the intervention.

Table 2.2 A synthesis of influences to the technical and social aspects of the SolarMal intervention

	Technical influences	**Social influences**
Technical design features 1. Removal of carbon dioxide from the blend.	Need for daily replenishment of molasses mixture in all houses to ensure the same blend of odours in all houses. Cost of procuring molasses. Disposal of by-products of fermentation.	Mobilisation of women to distribute molasses.
2. Change from fabric to metal trap cone.	The textile used absorbed the odorant cues.	
3. Change to trap with rigid plastic base with fine mesh that allowed passage of odorant cues.	Need to increase airflow into the mosquito trap.	More appealing to end users.
4. Change of metal trap cones to plastic.		Researchers' and residents' concerns over theft of metallic SMoTS parts. Plastic cones cheaper than metal ones.
5. Inclusion of a port for mobile telephone charging.		Researchers wishes to provide an additional benefit to research participants.
Social design features 1. Community roll-out sequence ballot	Need to maximise possibility of detecting effect of the intervention in complex island geography.	Scientists need for the roll-out to be legitimate and transparent in the eyes of the community. Community wishes to have an input in decision making.

2.	Creation of CAB	Channel of communication for development of project and problem solving.	Scientists' need to keep community involved and interested.
3.	Choice of consensus method to select house to install with SMoTS in homesteads with multiple houses.		Community wishes to have a say and scientists wish to involve community members in decision making. Number of houses in a homestead.

Discussion

Numerous studies have shown that successful innovations are usually based on an integration of technological and other ideas and insights from not only scientists, but also from users, intermediaries, and other societal agents. This shows the crucial role of empirical evidence in tailoring interventions to local settings. Typically, technological designs are negotiated achievements involving many parties (Feenberg 1995). The design process is the place where the various actors interested in a technology first share their ideas about the technology. Their diversity guarantees that the design represents many interests.

We looked at the intervention through the mutual shaping approach and this provided a more encompassing account of the impact of the joint processes of technical and social contexts. Our findings show how the various project stakeholders, including project staff, collaborators and community members, simultaneously pursued interdependent technological transformations and social interests. We see how in the on-going process, partial outcomes in the technological domain influenced social events at a later phase and vice versa.

Social shaping of technology is the way in which objects are changed because of their circumstances. Some technologies may require particular social relations to accompany them. In this project, considerations of a social nature also fed into the processes of deciding on the most practical odour bait for attracting malaria mosquitoes and during the re-design of the mosquito trap. Working with a blend without carbon dioxide provided much convenience in use and distribution for the researchers and residents. The cones of the mosquito traps were initially made of metal but were later changed to plastic since metal, although durable, would increase risk of theft. An additional advantage was that the use of a plastic cone made the trap more affordable without compromising its durability.

It has been argued that system innovation projects must enable the challenging and change of presumptions, current practices, and the underlying institutions, either in the design of a project or in its management (van Mierlo, Arkesteijn et al. 2010). In these reflexive undertakings institutions and their relations are not conceived as givens, but as objects of scrutiny and change. Initially during this intervention, community engagement was mainly channelled through a CBO operating in the community and that already carried out malaria-related work. This approach seemed appropriate but the project later on realised that the approach was not sufficient in representation of all community segments. Findings of other studies have shown that collaborations which are not representative of community-wide interests are a potential problem for participatory research (Macaulay, Commanda et al. 1999; Wallerstein and Duran 2006). The project consequently devised a CAB that was more deliberately representative in its nomination of members, guidelines and constitution. While there are strong philosophical reasons to involve diverse people and organisations in collaborative research efforts, broad engagement is also needed to strengthen the capacity of the community to identify, understand, and solve complex problems (McKnight 1985). Partnerships with many different kinds of participants have a greater variety of nonfinancial resources to create synergy than those with few homogenous partners. This approach to creating and structuring sets of principles for community engagement is recommended as it recognises the specific local context and project (Wallerstein and Duran 2006).

Collaboration between researchers, the research community and the development of CAB have been identified as important issues in public health (Israel, Schulz et al. 1998; MacQueen, McLellan et al. 2001). Involving the research community in decision making through a range of social research methods has been important in our research. We designed and simulated the community ballot with engagement of the CAB and input their ideas into the final approach to balloting. CABs are one strategy for establishing partnerships between researchers and host communities to promote community consultation in socially sensitive research (Melton, Levine et al. 1988; Morin, Morfit et al. 2008). In our study, the participation and input of community representatives helped to solidify the partnership between the researchers and the research community.

Choosing a sequence for rolling out SMoTS involved a process of social and statistical cost and benefit analysis of sorts. We considered a method that would provide statistical power for measuring effects of the intervention and issues of social acceptability to accommodate the wishes of the residents. The method used also had to be practical as far as the geography of the island is concerned and was based on metaclusters earlier on defined by the project. Informed by insights from consultations with project stakeholders, we used a method that enabled participation of a community member from each of the metaclusters. In addition to involving community members in the ballot, we drew nine different possible sequences with each beginning installation of SMoTS at a different metacluster. This ensured each of the nine metaclusters had an equal chance of coming first and at the same time met the requirements of the scientific aspects of the intervention, namely to measure the impact on malaria in the community.

Social acceptability also played important roles in the method chosen to select the house in a homestead to install the SMoTS. While the project had initially considered randomisation at the homestead level because this would ensure all sorts of houses were included in the sample, it was important to use a formula whose outcome would not be contested by members of the homestead. We therefore selected a consensus approach among homestead members to select the house to install in homesteads with multiple houses.

Conclusion

Our analysis has shown that the process of arriving at a more mature and better adapted technical and social design of the malaria control intervention involved a range of interactions, in which feedback from the technical and social environment were incorporated in the design and re-design and implementation strategy during the initial phases of the intervention. In generating this feedback, social science and natural science research were mutually useful and instrumental. To look at interventions this way requires a different role for research and a different perspective on innovation where innovation is more than the technical aspect. Feedback obtained from action research was used to not only see the workings of, but to also re-design the intervention. This approach therefore requires that research is designed in such a way that enables obtaining feedback from both aspects.

We argue that a mutual shaping perspective is well suited to capture the complexity and unpredictability of the interactions between technological features and social issues. Looking at intervention projects as niches that may evolve towards system innovation helps to reveal interrelations between the various technical and social aspects. The insights gained from this can be used to strengthen the designs of both the social and technical aspects of the intervention. This evidence-based re-design contributes towards aligning the innovation and therefore improves the survival chances of the innovation.

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CHAPTER 3

Combining malaria control with house electrification: adherence to recommended behaviours for proper deployment of solar-powered mosquito trapping systems, Rusinga Island, western Kenya

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Abstract

The objective of this study was to investigate community adherence to recommended behaviours for proper deployment of solar-powered mosquito trapping systems (SMoTS) after 3-10 weeks use. SMoTS, which also provided power for room lighting and charging mobile phones, were installed in houses in Rusinga Island, western Kenya. We used a structured checklist for observations and a semi-structured questionnaire for interviews in 24 homesteads. We also analysed the subject of 224 community calls to the project team for technical maintenance of SMoTS. Most respondents cared for SMoTS by fencing, emptying and cleaning the trap. Our observations revealed that most traps were fenced, clean and in good working condition. A significantly higher proportion of community calls was lighting-related. Lighting was the main reason respondents liked SMoTS because it reduced or eliminated expenditure on kerosene. However, some respondents observed they no longer heard sounds of mosquitoes inside their houses. All respondents reportedly slept under insecticide-treated nets (ITNs) before receiving SMoTS. After receiving SMoTS most respondents reportedly continued to use ITNs citing that the project advised them to do so. Some beach residents stopped using ITNs because they no longer heard mosquitoes or due to heat discomfort caused by lights. This study demonstrated that the electricity related incentives played a greater role in encouraging adherence to recommended behaviours for proper deployment of SMoTS than the potential health benefits in the early stages of the intervention. Although energy-related financial incentives may play a role they are insufficient to ensure adherence to health advice, even in the short term. Ongoing community engagement and research monitored and addressed adherence to recommended behaviours including continuation of pre-existing malaria control strategies.

Introduction

Success of vector control interventions as a public health measure for infectious disease control depend on their acceptability and perceived value to affected communities (Agyepong and Manderson 1999; Atkinson, Bobogare et al. 2009; Montgomery, Munguambe et al. 2010). Drawing from experiences with studies of insecticide-treated nets (ITNs) use for malaria prevention, understanding facilitators and barriers to increased adherence is necessary to encourage and maintain long-term use (Okrah, Traore et al. 2002; Toe, Skovmand et al. 2009).

In 2012, Wageningen University and International Centre for Insect Physiology and Ecology (icipe) launched a proof of principle study to reduce malaria transmission using the nation-wide adopted strategies augmented with mass mosquito trapping (Hiscox, Maire et al. 2012). As part of the intervention, a solar-powered mosquito trapping system (SMoTS) was given to each homestead (a single fenced-in house or group of houses occupied by one nuclear or extended family respectively). A SMoTS consisted of an odour-baited mosquito trap, a solar panel to provide power to run the trap, a battery, a battery box with a USB telephone charging port and two LED light bulbs (Figure 3). The roll-out commenced in June 2013 and it was estimated it would take two years to reach complete coverage. The main objective of the project was to control malaria, thus lighting and mobile telephone charging facilities were provided as additional benefits (Oria, Hiscox et al. 2014).

Before distributing SMoTS, the project invited a representative of each homestead to an orientation session. During the session, participants were reminded of the project objective to control malaria, the process of selecting a house to install SMoTS in each homestead, and provided with practical advice to operate and care for SMoTS. While the mosquito trap automatically turned on at dusk and off at dawn, participants were to ensure the optimum operation of SMoTS by practicing recommended behaviours which included continuing use of ITN (to protect users from mosquitoes that might not enter the trap), fencing mosquito trap (against damage by animals), emptying mosquito trap on a weekly basis, cleaning the trap, switching off lights when they were not in use and informing the project about malfunctions of SMoTS parts. The project designated three mobile telephone numbers, which were printed and pasted on to each battery box during installation, for reports of technical malfunctions of SMoTS. Residents could call or, if it was more convenient, send a free text message or flash and the project staff called back. SMoTS were allocated free of charge, but they would have little impact on the burden of malaria unless households deployed and cared for them while continuing to follow the existing national malaria control strategies.

The objective of this study was to investigate immediate community response to the innovation and the implications for ongoing implementation. We used the Health Belief Model as framework of the study. The direct health impact of the intervention was being investigated in a separate study.

Theoretical and conceptual framework

The Health Belief Model (HBM) (Rosenstock, Strecher et al. 1988) suggests that a person's belief in a personal threat of a disease together with a person's belief in the effectiveness of the recommended health behaviour or action will predict the likelihood that the person will adopt the preventive behaviour. According to the HBM, adherence to prescribed practices related to SMoTS was most likely to occur when residents (1) perceived that they were at risk of malaria infection (perceived vulnerability), (2) perceived that exposure to malaria could do them harm (perceived severity), (3) believed that the benefits of adopting the recommended behaviour outweighed obstacles to change (perceived benefits versus perceived losses), (4) noticed a reduction in mosquito bites and/or malaria with SMoTS use (stimulus to action).

Data on perceived susceptibility and severity of malaria were readily available because studies from the area (Opiyo, Mukabana et al. 2007; Minakawa, Dida et al. 2008; Wanyua, Ndemwa et al. 2013) showed that residents regarded malaria as a major threat to life, especially for children. We therefore concentrated on perceived benefits and barriers of adhering to recommended behaviours to ensure proper deployment of SMoTS.

Solar-powered mosquito trapping systems offered benefits of electrification and malaria control. Electrification was private and immediate while malaria control could protect the community at large and would be realised after some time. We were therefore interested in comparing the perceptions of private (house lighting) and public (malaria control) benefits and assessed the adherence to various recommended behaviours specific to malaria control and electricity provision. We also documented community calls for maintenance of SMoTS and compared the frequency of calls related to electrification and mosquito control. Figure 8 shows the conceptualisation of users' initial experiences within the HBM.

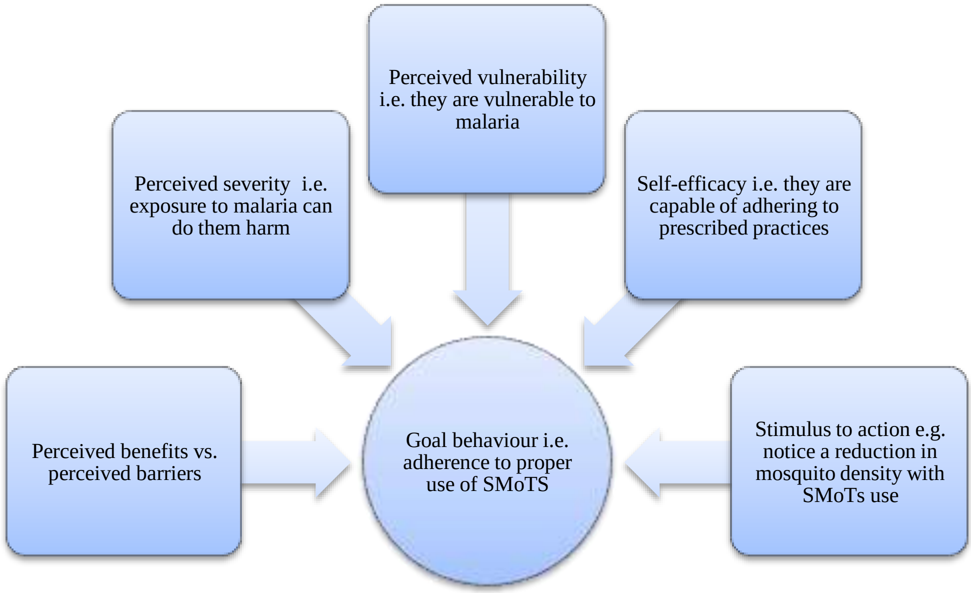

Figure 8. Conceptualisation of users' experiences with SMoTS within the Health Belief Model

Methods

Study area and population

Rusinga Island, western Kenya, occupies an area of 44 km^2. A census implemented by this project at the end of 2014 put the population of Rusinga Island at 25, 110 inhabitants which formed 4, 918 households. The main economic activities practiced by residents include fishing, small scale trade and traditional subsistence farming. Two rainy seasons occur annually from March to June and October to November, but their duration and intensity vary considerably between years (Minakawa, Dida et al. 2008).

Most houses have walls made of a mixture of mud and cow dung and a tin roof. Most residents are of the Luo ethnic group and *Dholuo* is the main language spoken on the island. Some residents who depend on fishing, especially of *omena (silver cyprinid)*, reside on the island only temporarily before relocating to other areas due to declining catches or the seasonal government-imposed closed fishing season (Geheb and Binns 1997). While fishing is almost entirely practiced by men, fish trading is monopolized by women. Prior to 2012, most Rusinga inhabitants used kerosene lamps for room lighting and charged their mobile telephones at commercial centres.

Sampling procedure

The project segmented the island into 81 clusters (each consisting of 50-60 homesteads) and nine meta-clusters (each consisting of nine clusters). For this study, we purposively sampled residents of ten clusters in which SMoTS had been installed because we targeted residents' experiences with installed SMoTS; eight in villages and two on the beaches of Lake Victoria. In each village cluster we conveniently (based on their availability and willingness to be interviewed) picked two homesteads and interviewed a male or female adult (17+ years old) in the house where a SMoTS was installed. In each beach cluster we picked four homesteads. We included persons who were 17 years and above in our sample because many households head or their spouses were under 18.

In reference to technical maintenance of SMoTS we sampled calls made to the project from January through June 2014. We excluded the first six months following beginning of SMoTS roll-out to allow familiarity with the reporting system.

Data collection

The study generated descriptive data using observations and interviews. We used a structured checklist for observations, and a semi-structured questionnaire for interviews. The questionnaire included questions regarding the respondent, emerging perceived benefits and barriers to use of SMoTS, interaction of SMoTS with other malaria control strategies and ways of caring for SMoTS. We carried out interviews in homesteads in which SMoTS had been in place for a minimum of three and maximum of 10 weeks. We also compared the frequency of calls related to electrification and mosquito control. We interviewed five males and 19 females in 24 homesteads. Sixteen respondents lived in villages and eight in beaches. Beginning January through June 2014, the project received 224 calls reporting technical malfunctions of SMoTS. At that time, 2492 SMoTS had been installed.

Semi-structured interviews and observations

Two research assistants experienced in conducting field interviews conducted interviews and observations from August through October 2013. They interviewed one adult in each homestead and carried out observations of the condition of SMoTS and availability of ITNs. If a house did not have an ITN, the interviewer asked why. Prior to the pilot testing, the standard forward-backward procedure was applied to translate the questionnaire from English to *Dholuo* by two bi-lingual researchers. Interviews were carried out in *Dholuo*. Interviewers took detailed notes during the interviews and expanded upon their notes on a computer within 24 hours following interviews. They immediately shared the transcript with a social scientist that carried out an analytical review of content for consistency with expectations, to trouble shoot areas that needed further probing and to inform decisions of when to stop further interviews, that is when additional interviews do not yield new ideas. We collected data until additional respondents were not generating new ideas.

Community calls for technical maintenance of SMoTS

We logged all calls made about maintenance of SMoTS into a database. The database therefore included calls made through project-designated telephone lines and those reported by word of mouth. We analysed calls made from January through June 2014.

Data analysis

The text data from interviews and observations were analysed as follows: 1) Scrutinised transcripts were coded into broad themes and sub-categories, 2) Identified dominant themes through the systematic sorting of data and labelling emerging ideas, 3) Re-examined categories for internal consistency and developed fresh categories until saturation. We coded and analysed data by hand.

We included all calls in our analysis (regardless of the cause of the reported malfunction) because our objective was only to determine the kinds of malfunctions that triggered calls to the project. We categorised calls as either relating to electrification or mosquito control, or to the general functioning of SMoTS.

We carried out the test of association to compare reports related to electrification and mosquito control using the Pearson chi-square test in Stata version 13.0 (StataCorp. 2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP). We excluded reports relating to the general working of SMoTS because we could not categorise their motivating factor.

Ethics

This study was approved by the Kenya Medical Research Institute Ethical Review Committee (KEMRI-ERC NON-SSC No. 350). After the study was explained to the households in the local language, written informed consent was obtained from them before enrolment. To guarantee confidentiality, study tools did not include respondent identifiers.

Results

We carried out 24 interviews with respondents whose ages ranged from 17 to 75.

Adherence to recommended behaviours

Respondents reportedly cared for SMoTS by fencing the trap (14) and emptying (9) and cleaning it weekly (9). Respondents also reportedly washed the trap net (4), cleaned the battery box (4), placed the battery box on a raised stool to ensure it did not get damp (1), ensured no one opened the battery box (3), cleaned the light bulbs (3) and ensured no one touched them (1). One respondent did not care for the SMoTS in any way besides switching the lights on and off.

When we observed SMoTS, we noticed that at least two thirds of traps were fenced (15) and in good working condition (16), but only one third (8) were clean. In some cases the trap was not fenced (8), was dusty (8), had cobwebs (1) or was suspended lower than recommended (2). Light bulbs and batteries were generally clean (17) and in good working condition although two battery boxes were dusty. Most of the unfenced traps were located in beaches.

Benefits and behaviours related to electricity provision

All respondents said lighting was the main reason they liked SMoTS because it reduced or eliminated expenditure on kerosene. Other reasons were that children could study for longer durations (5), they charged their telephones for free in their houses (5), it was easier to locate items in the house (2), families could sleep later (1), and they made savings because they bought fewer matchboxes (1). Perceptions of the benefits of house lighting are summed up by the following statements:

"I like the light so much since I no longer buy kerosene and I can now charge my phone at any time." 86-year-old male

"I like the lighting of my house because the children can now do their homework without me spending money on kerosene and the light has brightened my house so much that I don't strain to find anything in the house." 52-year-old female

Some (6) respondents said they no longer heard sounds of mosquitoes inside their houses with some four of these suggesting there were no mosquitoes. Two respondents said mosquitoes did not bite in their houses anymore.

"I like the trap most because I don't hear mosquitoes anymore. I also like the lighting because I can now read easily and I don't have to bother with the tin lamp or kerosene." 22-year-old female

Barriers to adherence with recommended behaviours

Sixteen respondents had no dislikes for SMoTS. However, others cited dislikes such as the system sometimes going off apparently due to the rains (1), faulty USB socket (1), the light on the battery box being too bright and interfering with sleep (1), or their system going on later than those of neighbours (2). Another respondent said the light bulb was too bright she considered putting a carton beside it to block some light. One respondent worried that her children continued to suffer from malaria even after a SMoTS was installed in her house.

Interactions between SMoTS and other malaria control strategies

All respondents reportedly slept under ITNs before receiving SMoTS. In addition, two respondents had indoor residual spraying (IRS) the previous year. Other measures were burning mosquito coils (1), draining stagnant water (1), and clearing bushes around their house to control mosquitoes (1). After receiving SMoTS, some (12) respondents reportedly continued to sleep under ITNs mainly because the project had advised them to do so, as some mosquitoes might not enter the trap. Additionally, respondents rationalized that the trap only caught mosquitoes outside the house (1), trap could not catch all mosquitoes (1), mosquitoes became very active once lights were switched off (1) and a net stops other crawling insects (1). Statements below relate to continued use of ITNs:

"I have continued to sleep under a bed net because when lights are switched off mosquitoes become very active and that is the time they start biting. You also said that we should not stop using nets*."* 56-year-old female

"I still use the net to protect myself from mosquitoes that may have entered the house because the trap only works outside." 45-year-old female

Four of eight beach residents stopped using ITNs; three said they no longer heard mosquitoes and the fourth said lights heated the house and made it uncomfortable to use an ITN. Another respondent stopped burning mosquito repellent coils. Discontinued use of nets is captured in the statements below:

"These days I don't hear mosquitoes anymore and that's why I stopped using mosquito nets." 38-year-old female

"I don't hear mosquitoes anymore and I don't like using a net because it makes me suffocate." 75-year-old female

During observations of sleeping areas in houses with SMoTS, we noticed that there was no ITN hung over the bed in a third of observed houses. In one of these houses the interviewers were told the ITN had been washed.

Calls about technical malfunctions of SMoTS

Fifteen of 36 (41.7%) trap-related malfunctions attended to by the project were not reported through telephone calls. Of 128 lighting-related malfunctions attended to, 30 (23.4%) were not reported through telephone calls. Of 105 telephone calls made for general SMoTS malfunctions, mostly about SMoTS switching off before dawn, only 56 (53.3%) appeared to require project action because in the remaining 49 (46.7%) cases, SMoTS had resumed normal operations when project technicians arrived. Systems spontaneously switched off before dawn due to faulty charge controllers, low voltage batteries or depleted energy stores. Some faulty charge controllers later on worked without intervention while the rest were replaced. The project recharged batteries with low voltage. In cases where energy stores had been depleted, SMoTS resumed normal operations after a day of sufficient sunshine. The nature of calls about technical malfunctions of SMoTS, malfunctions attended by project and the discrepancy are summarised in table 3.1.

Table 3.1 Calls made by residents about SMoTS malfunctions, malfunctions attended to by the project and the discrepancy from January through June 2014

Nature of malfunction		**Community reported malfunctions (N=224)**	**Project attended malfunctions (N=220)**	**Discrepancy**
a.	***Lighting-related reports***	**98**	**128**	**30 (23.4%)**
	Faulty USB sockets	52	71	19
	Faulty light switches	42	55	13
	Faulty light bulb	4	2	2
b.	***General SMoTS reports***	**105**	**56**	**49 (46.7%)**
	System switched off before dawn	93	54	39
	System not working	5	1	4
	Panel was loose on roof	5	1	4
	System working during the day	2	0	2
c.	***Trap-related reports***	**21**	**36**	**15 (41.7%)**
	Damaged trap cable	11	25	14
	Damaged trap fan	1	8	7
	Broken funnel	4	3	1
	Damaged trap	4	0	4
	Missing bait	1	0	1

A significantly higher proportion of malfunctions were light-related (76.6%) than trap-related (58.3%) (Table 2). The odds of reporting for light-related malfunctions were 2.3 times higher compared to trap-related malfunctions (P=0.033).

Table 3.2 A comparison of calls for lighting and trap-related technical malfunctions

	Community reported malfunctions		
Nature of malfunction	**Yes**	**No**	**Total**
Lighting-related reports	98 (76.6%)	30 (23.4%)	128
Trap-related reports	21 (58.3%)	15 (41.7%)	36
Total	119 (72.6)	45 (27.4%)	164

Discussion

The aim of this study was to analyse the benefits and risks of combining malaria control with house electrification, which is likely to be popular in a community that does not have access to this utility. Respondents strongly liked SMoTS, mainly citing immediate benefits of lighting and reduced or eliminated expenditure on kerosene. Protection from malaria was not often mentioned as a benefit despite reported reduction in mosquitoes. A similar observation was made when mothers did not associate an ITN trial with child health despite the emphasis placed on the link and actual population level improvements in child health (Alaii, van den Borne et al. 2003). This may be because the main purpose of protection from mosquitoes seems to be to avoid nuisance biting rather than to prevent malaria (Aikins, Pickering et al. 1994; Van Bortel, Barutwanayo et al. 1996; Okrah, Traore et al. 2002; Alaii, van den Borne et al. 2003; Atkinson, Bobogare et al. 2009). Savings which could be re-directed to other pressing expenses was of utmost importance; this is consistent with findings that people tend to look for practical benefits personally experienced than more strategic benefits such as malaria control (Winch, Makemba et al. 1994; Minja 2001; Alaii, van den Borne et al. 2003). This evidence paints a clear picture of the discrepancy between rational public health beliefs and health behaviour within the context of daily life and may support observations that health is often overlooked in everyday life and only comes into focus when illness emerges. While people appreciated that they could charge their mobile telephones at no cost and at their discretion, the instances people mentioned this benefit were noticeably fewer compared to the compounded benefit of house lighting which was associated with reduced expenditure on kerosene, ability for children to study at night, ease with finding things in the house, and families could stay up later.

Although respondents understood that the intervention was complementary to malaria control strategies deployed by the government which included use of ITNs and effective and prompt management of clinical malaria cases (Hiscox, Maire et al. 2012), there was some evidence of risk compensation. Risk compensation is the psychological phenomenon of an increase in risky behaviour due to a decrease in perceived risk (Cassell, Halperin et al. 2006) such as when men circumcised for HIV prevention engaged in higher risk behaviours than uncircumcised men (Seed, Allen et al. 1995; Bailey, Neema et al. 1999; Auvert, Taljaard et al. 2005). Some respondents, particularly those living in the beach areas, stopped using ITNs after receiving SMoTS. Only two beach clusters had SMoTS at the time of this study and yet most residents who stopped using ITNs or did not fence traps lived on beaches. This neglect may be because beach houses were mainly rented out to fishermen who frequently moved beaches depending on abundance of fish and seasonal government-imposed closed fishing season (Geheb and Binns 1997). Perceived seasonal reduction of mosquitoes has been cited as a reason for stoppage of ITN use (Binka and Adongo 1997; Alaii, Hawley et al. 2003; Baume, Reithinger et al. 2009; Iwashita, Dida et al. 2010), however, the problem is compounded for this project by possible perceived reduction of vulnerability to malaria when residents see mosquitoes successfully trapped. During this study, a respondent wondered why her child still suffered from malaria although she had a SMoTS, revealing that some residents may falsely think they are fully protected from malaria with SMoTS alone. The project monitored malaria indices at health facilities and epidemiological data for sustained evidence based communications outreach to encourage continued use of existing malaria control strategies.

This study also revealed gaps in reporting trap-related malfunctions. In some cases, maintenance technicians responded to calls related to electrification components only to find that the trap also needed repairs. Additionally, project staff occasionally came across unreported damaged trap parts when conducting other activities in the study area. Residents, especially of beaches, sometimes informed technicians of malfunctions of their traps only when technicians responded to calls for maintenance at a neighbour's home. The findings of this initial assessment do not support the assumption that the benefit of electrification would encourage adherence to recommended behaviours for proper deployment of SMoTS, especially reporting trap malfunctions. Rather, electrification in fact seemed to distract from behaviours to ensure effective malaria control such as keeping the mosquito trap in optimum working conditions or when some respondents claimed that electric lighting made the house too hot to use ITNs. This raises the need to carefully evaluate adherence barriers within the specific life-circumstances and to adopt a collaborative approach that demonstrates respect and that goes beyond merely providing information (Simoni, Amico et al. 2008).

While the immediate benefits of SMoTS may encourage adherence in the short-term, strategies to ensure adherence to long-term use and maintenance of all components of SMoTS are needed. Studies in Burkina Faso showed the population used ITNs at high rates for the first few months and then gave it up (Okrah, Traore et al. 2002; Toe, Skovmand et al. 2009) even following an intense sensitization campaign that initially led to a high acceptance and use (Toe, Skovmand et al. 2009). Although there is good adherence to cleaning and securing SMoTS, there are gaps in continued use of ITNs and reporting breakdowns of trap-related components. To ensure long-term adherence to SMoTS use, the challenge for the project is to create awareness about the benefits of SMoTS while also explaining that SMoTS do not offer full protection from malaria. SMoTS will be most effective if they are perceived as one component of malaria control, including ITNs, IRS and malaria case management. Therefore, the project should aggressively pursue strategies to mitigate perceptions of lower risk to malaria among people with SMoTS as lapses in adherence may render SMoTS ineffective.

The barriers to proper deployment of SMoTS were related more to the technical issues around the operations of SMoTS especially that SMoTS went off before dawn. Given that this study distributed SMoTS for free, it is possible the issue of cost, which has been reported (Okrah, Traore et al. 2002; Barat, Palmer et al. 2004; Chuma, Okungu et al. 2010) as a major barrier to the uptake of malaria control interventions was eliminated. It is also possible that because SMoTS were distributed for free and had immediate practical benefits, respondents perceived that they should give socially desirable answers.

This study suggests that the main reason that people adhered to recommended behaviours for SMoTS deployment was to provide lighting at night, rather than reducing mosquito biting or malaria risk. It will be interesting to see to what extent a reduction in malaria and associated cost reductions become noticeable and an incentive for adherence in the later phase of the intervention. Community engagement and further research will monitor and encourage adherence to recommended behaviours including continuation of current malaria control strategies.

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CHAPTER 4

Controlling malaria with solar-powered mosquito trapping systems (SMoTS): Socio-economic and perceived health outcomes of house lighting in Rusinga Island, western Kenya

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To be submitted

Abstract

In 2012, a proof of principle study was launched to eradicate malaria from Rusinga Island using solar-powered mosquito trapping systems (SMoTS). In addition to the mosquito trap, two light bulbs and a mobile telephone charging port were provided for use in each homestead in which a SMoTS was installed. Prior to receiving SMoTS, residents mainly used kerosene tin lamps for lighting. The effectiveness of new preventive health interventions is enhanced if, in addition to clinical efficacy, they are socially and culturally acceptable, and are widely adhered to in the longer-term. Social science studies on the project aim to understand socio-cultural and behavioural aspects of adherence to use and maintenance of SMoTS. We assessed socio-economic and perceived health outcomes of house lighting using in-depth interviews and focus group discussions with selected early recipients of SMoTS. The main economic benefit of solar lighting was reduced or eliminated expenditure on kerosene. Additionally, some residents charged mobile telephones for neighbours without SMoTS for pay. Kerosene traders, however, attracted fewer customers which led some to abandon the trade. Electricity reportedly reduced risks of respiratory infections, fire outbreaks from tin lamps, and physical accidents prone to poor house lighting. However, bright lights reportedly attracted mosquitoes into houses. Social outcomes included improvements in spousal relations due to reduced squabbles over expenditure on kerosene, while extended lighting periods facilitated unhurried social networking in the evenings, and night-time studying. Respondents also perceived improved social status as a result of owning a SMoTS. Negative social outcomes were strained relationships among women in polygamous households and envy from households that did not receive SMoTS. Before data on malaria prevention was complete, there was evidence of enhanced socio-economic and emotional well-being of study participants which could increase the desire of community members to sustain the intervention beyond the research period.

Introduction

In 2012, International Centre for Insect Physiology and Ecology (Icipe), Kenya and Wageningen University, the Netherlands launched a proof of principle study to eradicate malaria from Rusinga Island using solar-powered mosquito trapping systems (SMoTS). As part of the intervention, a SMoTS was given to each homestead (a single fenced-in house or group of houses occupied by one nuclear or extended family, respectively). In a homestead with more than one house, members agree through consensus on a house to install the SMoTS. The mosquito traps are powered by electricity and SMoTS parts included a 20W solar panel and a 12V/12Ah battery. As a benefit to homesteads participating in the study, two 3W LED light bulbs and a universal serial bus (USB) mobile telephone charging port were also provided for use in the house in which a SMoTS was installed. Due to the low power output of the installed solar panels beneficiaries are restricted to the project authorised uses of electricity mentioned above. The system is regulated by a solar charge controller which manages the charging current for the battery and ensures that the system only operates in the evening and at night when mosquitoes are active. The intervention has been described elsewhere (Oria, Hiscox et al. 2014).

Electrification enhances quality of life at the household level and stimulates economic growth at a broader level (Khandker, Barnes et al. 2009) and the immediate benefit of electrification is improved lighting. Access to modern energy such as electricity can contribute in addressing the multiple dimensions of poverty such as the economy, education and health (Kanagawa and Nakata 2008). Although the availability of electricity by itself is not a panacea to Africa's socio-economic problems, the importance of electrifying rural areas which continue to be home to the majority of the population cannot be overemphasised (Karekezi and Kithyoma 2002; Wolde-Rufael 2006). In rural areas of developing countries many families depend on kerosene for household lighting. But use of traditional lighting devices has an adverse effect on the quality of life of the people because these devices are inefficient, emit smoke and give poor quality light. Therefore, it is important to estimate the impacts of energy access improvements on socio-economic situations in areas that are newly electrified.

Creating value for the end user in disease control is important for project acceptance and sustainability once its handed over to the community (Hirmer and Cruickshank 2014). This is especially the case for a research project such as this. During the four-year research period, residents reported SMoTS malfunctions to project technicians who attended to them free of charge. When the research ends in December 2015, there will be no more funding from the project and SMoTS parts and repairs will no longer be available free of charge to residents. This fact combined with the uncertainty of anticipated benefits with regards to malaria control led to the inclusion of the incentive of house lighting. Because of the rural and isolated nature of the study site, the electrification component seemed promising in producing community-wide impacts. The SMoTS were easy to install and maintain which further facilitates sustainability.

This study assessed the relationship between access to electricity on the one hand and perceived health benefits and advancement in socio-economic conditions of the study community on the other.

Theoretical and empirical approach: value as experience

The notion of user value is important to designers adopting a user-centred approach because it guides their efforts to better understand users and deliver products which are of value to them (Boztepe 2007). The value a user assigns to a product is created at the interface of the product and the user (Frondizi 1971; Cockton 2006). Value resides not in the product but in the user's experiences (Holbrook 2002; Jordan 2002) and what people actually desire is the experiences products provide (Pine and Gilmore 1999). Since products enable an experience for the user, the better the experience, the greater the value of the product to the consumer (Cagan and Vogel 2002).

Experience has both operative and reflexive dimensions; the operative dimension refers to the way we make use of an object while the reflexive dimension addresses the way we think about a product and give it meaning (Margolin 2002). In other words, experiences with products relate not only to the activities but also to the meanings they add to people's lives. Users interact with products within the contexts of their needs, goals, expectations, physical contexts, and emotions. And products, with their tangible and intangible qualities, can influence the way users interact with them(Boztepe 2007) . User value is thus created as a result of the interaction between what the product provides and what the users bring in terms of their needs, goals, limitations, etc.

We used three categories of user value as put forward by Boztepe (Boztepe 2007) i.e. utility, social significance and emotional. Utility refers to the fact that a product might enable the accomplishment of a physical or cognitive task and encompasses the values of convenience, economy and quality. Social significance refers to the socially oriented benefits such as social prestige and construction and maintenance of one's identity. Emotional value refers to the affective benefits of a product for the people who interact with it, benefits such as pleasure and nostalgia.

Methods

This piece of social research was carried out within a multidisciplinary team. Social science studies on the project assessed socio-cultural and behavioural aspects of design, adherence to use and maintenance of SMoTS. For the current study, the information gathered related mainly to the secondary utility of the intervention for providing house lighting.

Study site and population

The proof of principle study for the elimination of malaria was carried out in Rusinga Island in Lake Victoria, western Kenya. Rusinga Island lies on longitude 34 10'E and latitude 0 25'S at an altitude of 1,100m above sea level. There is one dirt road encircling the $44km^2$ island and the primary modes of transport are by foot, bicycle, or motorcycle taxi. Rusinga Island is connected to the mainland by a causeway because the island was in close proximity to the mainland. Most houses are made from wooden frames smeared with mud or corrugated iron, with corrugated iron roofs. All residents of Rusinga Island, as enumerated in a Health and Demographic Surveillance System (HDSS) were eligible to participate in the study (Homan, Di Pasquale et al. 2015). The census at the end of 2014 put the population of Rusinga Island at 25, 110 inhabitants which formed 4, 918 homesteads.

The island is mainly inhabited by two ethnic groups, the Luo and Abasuba. Through generations of intermarriage with Luo clans who came to populate the mainland to the East, the vast majority of the Abasuba speak fluent *Dholuo* and assume inherited Luo beliefs and customs hence referred to by historians and anthropologists as a Luo sub-group, the Luo-Abasuba (Ogot 1967). The mother tongue spoken on Rusinga Island is *Dholuo*. The main economic activities practiced by island residents are fishing, petty trade and traditional subsistence agriculture. Lake Victoria is the main source of water for drinking, cooking, washing dishes and clothes and bathing. Prior to the installation of SMoTS most residents of Rusinga relied on kerosene for domestic lighting and charged their mobile phones at commercial centres with electricity.

Study design and sampling

We used an explorative cross-sectional design to mainly collect qualitative data. Ethnographic research focussing in-depth on value assignment builds a fuller understanding of the complexities of the contextual nature of value assignment (Boztepe 2007).

The project divided the island into 81 clusters (each consisting of 50-60 households) and nine metaclusters (each consisting of 9 clusters). The project in collaboration with community stakeholders designed a roll-out sequence for SMoTS installation which begun at a cluster and continued within that metacluster until every cluster was installed and then moved to another. It took approximately one week to install one cluster.

We used multi-stage non-random sampling based on electrification status at metacluster and homestead levels. The two metaclusters which had SMoTS installed by the time this study was carried out were sampled purposively and selected for data collection in order to assess outcomes of house lighting. The two metaclusters consisted of approximately 1080 homesteads. We included respondents from each installed cluster to make the sample inclusive. Within the clusters, homesteads were selected based on availability of respondents and willingness to be interviewed (individually or as part of a group). We interviewed a household head or their spouse in each selected homestead.

Data collection

We first pre-tested data collection instruments and made necessary adjustments. Between March and April 2014, we conducted 25 (12 with males and 13 with females) in-depth interviews with heads of households and six focus group discussions (three with males and three with females) with 54 community members. Two researchers; the third author who is an Anthropologist, and a Development Economics student, collected the data in *Dholuo*, the local language. Both data collectors are bilingual *Dholuo* and English speakers. In-depth interviews were conducted first, and the findings explored further in focus group discussions. Both data sets of interviews were audio recorded after obtaining verbal consent of the participants.

Data analysis

Audio recordings were transcribed verbatim and translated into English by the data collectors. A codebook with indicators of socio-economic and health outcomes based on the research themes was developed by the data collectors and the first author. Outcome indicators were categorised under three broad categories; social, economic and perceived health impacts. Text data were coded and analysed manually.

Ethical considerations

The SolarMal study was approved by the Kenya Medical Research Institute Ethical Review Committee (KEMRI-ERC NON-SSC No. 350). After the study was explained to the households in the local language, written informed consent was obtained from them prior to enrolment.

Results

House lighting prior to installation of SMoTS

Residents mainly used *nyangile* (kerosene tin lamps) (Figure 9) for lighting before receiving SMoTS. Others used kerosene lanterns (Figure 10) while pressure lamps were used in a few business premises. Two lamps were mainly used; one in the main living quarters and the other the kitchen. Respondents complained that one lamp could, however, not illuminate all corners of a house.

Figure 9. Kerosene tin lamp

Figure 10. Kerosene lantern

''When they (school children) are still busy then you have to forfeit it (access to the lamp) ... if you want to write, you get closer to the table where they are using the lamp." 42-year-old male, IDI

"We ate supper as early as 8pm so as to allow children study with the lamp because before the meal the lamp was used by the person cooking." 40-year-old female, IDI

Prior to receiving SMoTS, residents spent Kshs 25-315 (0.27-3.46 USD) per household per week on kerosene (Table 4.1). Households with school-going children purchased more kerosene for study time. Women were generally responsible for lighting the lamps while men provided the money.

Table 4.1 Expenditure on kerosene per household per week prior to installation of SMoTS (N=25)

Amount per week (Kshs)	Frequency	Percent
25.00	1	4.0
50.00	3	12.0
60.00	2	8.0
70.00	2	8.0
80.00	1	4.0
85.00	1	4.0
100.00	2	8.0
105.00	1	4.0
140.00	2	8.0
175.00	3	12.0
200.00	1	4.0
210.00	2	8.0
280.00	2	8.0
315.00	2	8.0
Total	**25**	**100.0**

Utility value: Economic and perceived health outcomes of solar lighting

Economic benefits

Lighting reduced or eliminated expenditure on kerosene. As a result of increases in available money, households increased expenditures on food, house items (especially kitchenware) and clothing. Some residents saved the money they would have otherwise spent on kerosene and ploughed it into their businesses.

"I can now buy basins, plates, salt and sugar in larger quantities than before. This is only possible because I no longer buy kerosene and I can use the money meant for kerosene to purchase these things." 27-year-old female, IDI

"When I don't spend anything on kerosene that means I save a lot. On average I save about Kshs 50 a day. That means almost Kshs 1,500 per month. That is a lot of savings." 58-year-old male, IDI

Additionally, some residents used their systems to charge mobile telephones for neighbours without SMoTS at a fee.

"There are people who did not get solar ... so sometimes when they want to charge their mobile phones ... they bring them to my house and I charge them for Kshs 10 instead of the usual Kshs 20. Sometimes you get Kshs 60-70 in this way." 32-year-old female, IDI

Kerosene traders, however, recorded fewer customers as more residents eliminated or reduced purchase of kerosene. This led some traders to discontinue kerosene business.

Health Benefits

Respondents also said electricity led to reduced vulnerability to respiratory infections. Lighting with kerosene tin lamp which produces smoke was perceived to cause respiratory infections. Respondents mentioned that family members had suffered from chest problems in the past and attributed these to inhaling smoke.

"The smoke from the kerosene lamps when inhaled might cause respiratory complications ... kerosene lighting is just bad for health ... it may be difficult for me to explain but I know it is bad in many ways." 40-year-old female, IDI

Reduced risk of fire outbreaks was perceived to preserve health and life. Respondents said the brightness of the house had improved safety from physical accidents that often occurred in darkness.

"One day I went to the lake at night and instructed my children to put off the lamp when they go to sleep. When I returned I found the fire had almost reached their bed nets. Luckily, I put it off." 40-year-old female, IDI

"With the efficient solar lighting we can easily see moving things, fallen things and avoid associated dangers in the house." 58-year-old male, IDI

Respondents also observed that bright light attracted insects, including mosquitoes, into their houses. This reportedly encouraged use of mosquito nets.

"The lights attract many insects ... I know they are mosquitoes and maybe other insects as well. Since the system was installed we have experienced an increase in the number of mosquitoes coming into our home. Maybe your trap attracts the mosquitoes but fails to trap them." 23-year-old female, IDI

"The system has attracted many mosquitoes such that we cannot sleep without bed nets. The numbers of mosquitoes have especially increased during the rainy seasons." 39-year-old female, IDI

Social significance

Reported social significance included improved relations between household members, between spouses who often squabbled over purchasing kerosene. There was reportedly also an improved atmosphere in which to relax in the evenings.

"When she asked for money and I did not have she felt offended and talked bitterly about why I could not provide. Our women can never believe that a man cannot have money ... you see they insist that you provide the money and failure to do this results in wrangles. Since we received solar, our wives no longer ask for money on a daily basis." 55-year-old male, IDI

Household members, especially school-going children, also benefitted from improved environment for night-time studying or reading.

"*I am longer irritated by the smell of kerosene and my children study well without complaining of itchy eyes caused by smoke from the tin lamp."* 27-year-old female, IDI

Respondents reportedly had longer days during which they could spread out tasks and complete them at their own convenience.

"*I can now decide to do some duties at night if I do not have time for them during the day. I can also wake up as early as 5 am to clean dishes and my house. This reduces my burden during the day.*" 32-year-old female, IDI

Respondents also felt that their social status had improved as a result of owning a SMoTS.

"Those who do not have solar electricity perceive me as a rich man because I have substantial property (solar) in my home. I feel that my status has been uplifted because I no longer carry bottles to go buy kerosene. In fact, as a man buying kerosene is a challenge ... sometimes reducing my status because I do not stay with my wife." 34-year-old male, IDI

"The people around perceive me as a blessed person ... there is no jealousy since most people have the same lighting system. The people visiting from places outside Rusinga feel that we are on different levels from them ... they see us as people who live an advanced and happy life." 45-year-old male, IDI

A negative social outcome included strenuous relationships among women in polygamous households and envy from households that did not receive SMoTS. The project provided only one SMoTS in each homestead and in polygamous households this meant some houses were not installed. Similarly, in homesteads with multiple households, only one received a SMoTS.

"Things are fine between me and other people outside our homestead. But the fact that my house was installed has completely destroyed the relationship between me and my co-wife. She no longer talks with me since installation." 27-year-old female, IDI

"Those who do not have solar in their houses are disgruntled. They have the project sticker on their door but no solar … they continue buying kerosene and we don't. They feel bad towards the project." 70-year-old male, IDI

Emotional value attached to solar lighting

Respondents said lighting had aesthetic effect on their houses. They had reportedly become used to electricity and would have a difficult time reverting to use of kerosene tin lamps if the need arose.

"My house appears brighter at night ... it looks beautiful. I, however, do not feel that I am on top of the world ... or arrogant ... the lighting system makes us happy but we don't have to show the rest that we are better than them." 45-year-old male, IDI

"Our house looks good. My wife does not admire things from the neighbours. She does not long to relocate to a town because we now have town life right here at home." 70-year-old male, IDI

"*The house looks bright and beautiful. It is like we live in a town ... it is like Nairobi. Our people who live in Nairobi marvel when they come here. They wonder about the town in the village."* 39-year-old female, IDI

Discussion

This study assessed the socio-economic and perceived health outcomes of house lighting as an incentive of malaria control with SMoTS. Even with the limited application of the solar systems, respondents reported direct and indirect benefits. Solar lighting increased welfare levels and reduced the need for, and, embarrassment of frequently purchasing small quantities of kerosene.

Although relatively costly, kerosene is the most widely used modern energy source for lighting and fuel in rural areas (Karekezi and Kithyoma 2002). As with other studies (Acker and Kammen 1996; Wamukonya and Davis 2001) , improved lighting was the main benefit of the SMoTS. A study on household welfare impacts following electrification via grid or via solar in Namibia found that either forms of electrification improved household welfare but almost exclusively as a result of lighting (Wamukonya and Davis 2001). This may point to the high value placed on lighting. In this study, lighting led to a perception of increased safety in the house as all corners were illuminated, the ability to do housework for longer hours (including at dawn and night), spend time relaxing and opportunity to read and study at night. Home electrification was also reported to have created more time especially for women who are more responsible for housework. Women started their day earlier and ended it later thus being able to spread out tasks during the day instead of fitting all activities between sunrise and dusk. Interestingly, the women viewed this as a positive development although it could also be argued that house lighting increased opportunities for domestic drudgery for women. Similar to observations by Acker and Kammen (Acker and Kammen 1996), with light in two rooms the family now had more sources of light allowing different people to carry out various activities in each room instead of having to crowd around the family's one or two lanterns. The quality of light from solar bulbs was also a significant improvement over kerosene lamps and more conducive for studying.

Similar to (Acker and Kammen 1996; Wamukonya and Davis 2001), respondents were satisfied with the ease of turning lights on and off with a simple switch instead of having to refill or light a kerosene lamp. Electrification also led to profound changes in how residents viewed their circumstances; beneficiaries felt that their social status had been elevated.

Benefits included financial savings. House lighting led to financial savings on regular expenses on kerosene for lighting. Prior to receiving SMoTS, many families purchased kerosene on a daily basis which encouraged spousal squabbles over expenditure on kerosene. Families with school going children purchased more kerosene to enable the children study at night. The money saved from expenditure on kerosene was re-directed to other household commodities that improve general welfare such as more food, utensils, clothes, and even school fees. A few families also ploughed their savings into business.

Respondents perceived electricity as safer than kerosene lamps which can cause fires and emit fumes that irritate the eyes. However, significant changes in energy use can only be expected for lighting because the project-provided electricity cannot entirely substitute traditional energy sources. Use of biomass cooking fuels such as wood and charcoal with negative health impacts on women and children continued for the majority of electrified households. Studies have shown that there are links between biomass combustion and respiratory illnesses in women and children (Mishra 2003; Rinne, Rodas et al. 2006; Rumchev, Spickett et al. 2007; Po, FitzGerald et al. 2011). Due to the limited capacity of the PV provided for this study, the impact on exposure to indoor air pollution was probably minimal although exposure to dangerous kerosene fumes may have been reduced. As was observed in another study (Acker and Kammen 1996), it was not surprising that respondents did not mention any environmental benefits of PV lighting as the systems were not powerful enough to replace fuel wood for cooking. Cooking accounts for between 90% and 100% of energy consumption in households (Karekezi and Kithyoma 2002). Provision of improved biomass technologies such as more efficient stoves can reduce respiratory problems associated with smoke emission from fuel wood (Karekezi and Kithyoma 2002; Po, FitzGerald et al. 2011).

While bright lights improved the appearance of houses, residents said the lights attracted mosquitoes into their houses. This observation may, on the one hand, have a negative effect on adherence to use of SMoTS, specifically the trap, if residents perceive that SMoTS are ineffective in trapping mosquitoes. Users have an essential role in value realization as their attitudes and actions determine if the system is accepted and used effectively (Kujala and Väänänen-Vainio-Mattila 2009). On the other hand, it may encourage the continued use of bed nets, as was mentioned by some respondents, as sighting of mosquitoes becomes a motivation for protection against mosquitoes. An assessment of initial user impressions of SMoTS that was carried out 3-10 weeks after residents received SMoTS revealed that some residents no longer saw mosquitoes in their houses since they received SMoTS leading some to abandon use of bed nets (Oria, Alaii et al. 2015). To the users, the fact that bright lights are perceived to attract mosquitoes into the house raises the issue of the value of

SMoTS as a balance of benefits over costs, and particularly in a setting with other malaria control strategies. The resulting perceived value depends also on what is important and valuable to the user (Kujala and Väänänen-Vainio-Mattila 2009). The earlier assessment (Oria, Alaii et al. 2015) on user experiences also showed that residents were more likely to report malfunctions of the lighting component as compared with trap component, raising the question of the perceived value of SMoTS beyond lighting. This value assignment, coupled with results of the entomological and parasitological surveys, have direct implications for the sustainability of SMoTS beyond the research period.

In polygamous families in which only one house was installed, the other wives sometimes expressed feelings of disappointment towards the project. This happened despite the explanation of the criterion (Oria, Hiscox et al. 2014) and involvement of household members in the selection of the house to install. Homesteads that did not receive SMoTS also sometimes held negative feelings about the project. Some did not understand why they still needed to be part of the project without themselves receiving SMoTS. These facts may have negative implications for the smooth running of the project since the research participants includes both those who did and did not receive SMoTS. As the project nears completion, the community liaison function is focussing on the community-wide outcomes of malaria prevention. This will hopefully encourage all Rusinga Island residents to participate in and/or support sustainability efforts geared towards ensuring SMoTS are maintained in optimum working conditions beyond the research period.

Unlike other countries in Africa, the Kenya solar market developed with minimal direct government support and only very moderate inputs from the international donor aid groups (Jacobson 2007). The bulk of installations in Kenya are private and largely driven by unsubsidized over-the-counter cash purchases of household solar systems (Acker and Kammen 1996; Hankins and Bess 1996; Hankins 2000). This means that the majority of the systems are owned by affluent rural households (Acker and Kammen 1996; Cloin 1998; van der Plas and Hankins 1998; Mulugetta, Nhete et al. 2000; Karekezi and Kithyoma 2002) because even after price decreases over the years, solar systems are still mostly unaffordable to the rural masses. Cost is one of the most important barriers to greater dissemination of PV technology and research has shown that as incomes increase, the use of modern energy becomes more prevalent in rural households (Karekezi and Kithyoma 2002). Our respondents, on the other hand, received SMoTS free of charge and our sample can be expected to include a bigger representation of poor households who could have never afforded to purchase a solar panel on their own. In any case, the bulk of rural inhabitants are poor with irregular income flows and cannot afford even low-end solar systems (Karekezi and Kithyoma 2002).

Even though beneficiaries of SMoTS have expressed a willingness to continue using SMoTS, particularly lighting, beyond the research period which ends in December 2015, the reality that some households may not afford (even if they were willing) to pay for the maintenance of SMoTS has critical implications for the sustainability of SMoTS. The project funding for installation and maintenance of the systems will end when the four year research period ends. The challenge therefore is on facilitating the creation, training and launch of a community-driven sustainability system before the project ends. The main challenges with sustainability of solar PV-based rural electrification include adequate means of providing regular and proper maintenance, supplying spare parts, and viable choices to suit consumers' affordability (Cloin 1998; Ahammed and Taufiq 2008). The project is working with project stakeholders to facilitate a two pronged system that will enable community members save money upfront to repair or replace SMoTS parts and ensure parts are accessible to the community members. Another important drawback of PV technology is its high reliance on imported components (Karekezi and Kithyoma 2002). In order to improve chances for sustainability, the SMoTS has been designed such that it is easy to install and maintain. For instance, it is possible to replace the maintenance-free battery after five years with any 12V battery. To address lack of maintenance and reliable technical support which is one of the major causes of failure for PV (Nicklas 1998) this project has trained and employed two solar technicians in each metacluster to provide technical support to SMoTS owners during the research period. Because the trainees are residents of the island, the project's aim is to make the expertise available locally.

Additional lessons on sustainability can be learned from previous government and donor supported PV programmes. While initial dissemination has been successful, the long-term functioning of built-up structures has been poor. Due to this, although in previous projects attempts were made to promote local suppliers and service capacity, most of the subsidies went to large entrepreneurs without sustainable operation once external financing ended (Mulugetta, Nhete et al. 2000; Gustavsson and Ellegård 2004). This project is working on a business model which involves partnering with the many women's groups that are active all over Rusinga. Women dominate rural energy use at the household level (Wamukonya and Davis 2001; Karekezi and Kithyoma 2002), and women's groups have successfully implemented energy efficient cooking stoves in Kenya (Karekezi and Kithyoma 2002), and may therefore provide the commitment and networking required to spearhead sustainability of SMoTS.

Even when the use of energy is restricted, electricity can enhance the value of life. Although data on malaria prevention was yet to be fully collected and analysed, there was evidence of enhanced socio-economic and emotional well-being of study participants which may enhance the desire to sustain the intervention. In the end, this may be a double-edged intervention that delivers health benefits and contributes to improved welfare. The utility, social significance and emotional benefits experienced with the lighting component of SMoTS may create the desire to sustain the intervention. However, the motivation to sustain the whole SMoTS will also depend on the results of the entomological and parasitological components of this intervention.

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CHAPTER 5

Knowledge, perceptions and practices related to malaria control before and after the roll-out of solar-powered mosquito trapping systems in Rusinga Island, western Kenya

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To be submitted

Abstract

As part of a proof of principle trial of the effectiveness of odour-baited mosquito traps for malaria control, solar-powered mosquito trapping systems were installed in Rusinga Island. The project was backed by continuous social mobilisation. As SolarMal was an additional strategy to the existing malaria control strategies, continued use of long-lasting insecticidal nets (LLINs) and prompt malaria care seeking was a key message during the SolarMal project's social mobilisation activities. The SolarMal project used an innovative way to control malaria and there was some concern that excitement over it could have a negative impact on deployment of the existing malaria control strategies, mainly use of LLIN s and prompt malaria care seeking. This study explored how the SolarMal project affected use of LLINs and malaria care seeking. It used a pre- and post-intervention representative quantitative sample survey to assess the effects of the SolarMal intervention on the malaria control knowledge, perceptions and practices of participants. In the short term, the SolarMal project did not document a negative effect of the innovation on existing malaria strategies. Instead, there was an improvement on the already high levels of knowledge and positive perceptions and practices towards malaria control. This improvement could have contributed to the effectiveness of the SolarMal intervention. To ensure the maintenance of the health educational gains, the malaria control program should explore best practices for longer and persistent social mobilisation efforts. Future studies should monitor the long-term maintenance of the gains from the social mobilisation efforts.

Introduction

As part of a proof of principle trial of the effectiveness of odour-baited mosquito traps for malaria control (Hiscox, Maire et al. 2012), solar-powered mosquito trapping systems (SMoTS) were installed in Rusinga Island (Homan et al. 2015). The study was designed to be participatory (Oria, Hiscox et al. 2014) and involved formal and informal community feedback sessions to inform project planning, implementation and monitoring. The project was backed by continuous social mobilisation. The intervention also incorporated a capacity building approach to enable residents properly deploy the installed SMoTS. Incorporating community participation is expected to promote self-awareness and confidence and causes people to examine the problem and think positively about solutions (Smith, Jones et al. 2009; Bamidele, Ntaji et al. 2012). Community participation is also a necessary imperative for sustainable interventions. Effective malaria control can only happen at the local level when people own the approach. The sense of ownership is enhanced when the people have been provided with adequate information through appropriate channels to make an informed choice. As SolarMal was an additional strategy to the existing malaria control strategies, continued use of long-lasting insecticidal nets (LLINs) and prompt malaria case management was a key message during the SolarMal project's social mobilisation activities.

The social mobilisation activities focused at the interpersonal, group and community levels. During the initial phase of the project, project staff held informal discussions with community opinion leaders in their homes to introduce the project. This was followed by meetings with various community groups including women, men, youth, and fisher folk. The central messages for discussion during these meetings were the project objective, design and components. Specifically, the activity aimed to assess; 1) what the communities knew about the project, and, 2) how best to address emerging issues including information gaps and concerns. The informal discussions ran concurrently with team support of community outreach activities and baseline activities by other project components. Afterwards, community-wide meetings were held to introduce the project. The project segmented the island into 81 clusters (each consisting of 50–60 homesteads) and nine meta-clusters (each consisting of nine clusters). The project convened a community workshop with representatives of all homesteads in a cluster, prior to the installation of SMoTS. During community workshop sessions, project staff reminded participants of the project objective to control malaria, the process of selecting a house to install SMoTS in each homestead and provided practical advice to operate and care for SMoTS. Demonstration SMoTS were used to show participants how the system operated and how to empty the trap of mosquitoes and clean it on a weekly basis.

In addition to the social mobilisation activities, home visits by project staff for entomological, parasitological, demographic, and sociological data collection (Oria, Hiscox et al. 2014; Homan, Di Pasquale et al. 2015; Oria, Alaii et al. 2015; Homan, Maire et al. 2016), also provided an opportunity for the multi-disciplinary teams within SolarMal to talk with participants about malaria control. A community advisory board (CAB) that evolved through the feedback sessions and activities (Oria, Hiscox et al. 2014) provided on-going opportunities to ensure the involvement of the research community and key stakeholders in guiding the implementation of SolarMal. In addition to the activities of the SolarMal project, a mass LLIN distribution took place in August 2014, 10 months before the end line survey commenced.

This paper explores how the SolarMal project affected use of LLINs and malaria care seeking. The implication of the findings for malaria control is discussed.

Methods

Study site and population

This study was carried out in Rusinga Island, an island in Lake Victoria, western Kenya. The island is located between 0°20′51.53″–0°26′33.73″ South, and 34°13′43.19″–34°07′23.78″ East) (Homan, Maire et al. 2016). Administratively, Rusinga Island is part of Homabay County in western Kenya. It is a rural community located on a 44 square km island which depends economically on fishing, trade and traditional subsistence agriculture. Due to the island's close proximity to the mainland, the waterway separating Rusinga Island from the mainland was filled in 1985 and a road to Rusinga Island was constructed to facilitate the transportation of people, goods and services (Opiyo, Mukabana et al. 2007; Nagi, Chadeka et al. 2014). A project-initiated census carried out in 2012 revealed the community consisted roughly of 4,063 homesteads and 23,337 inhabitants(Homan, Maire et al. 2016). Most of the residential areas were situated between 1100 and 1200 metres above sea level around the lakeshore of the island (Homan, Maire et al. 2016). The predominant language spoken is *Dholuo*.

Rusinga has a diverse topography, ranging from flat areas near the shoreline to a central hill and from low to medium density vegetation cover. The island has suffered enormous environmental degradation, soil erosion and extended drought conditions in recent years leaving little productive land and few opportunities to make money other than through fishing (Opiyo, Mukabana et al. 2007). Furthermore, construction activities, deforestation, vegetation clearance, and poorly planned infrastructure development has led to an increased abundance of mosquito larval habitats (Fillinger, Sonye et al. 2004). The long rainfall season is generally expected between March and May and the short rains from October to December, but the seasons are usually not well defined with some years of more or less regular rains and others with prolonged dry periods (Fillinger, Sonye et al. 2004; Okech, Gouagna et al. 2007). Average temperatures range from 20 to 29 °C in the rainy season and from 25 to 34 °C in the dry season (Homan, Maire et al. 2016). Although malaria is transmitted throughout the year, intensity varies greatly according to seasons (Minakawa, Mutero et al. 1999; Shililu, Mbogo et al. 2003; Fillinger, Sonye et al. 2004; Fillinger and Lindsay 2006).

Study design

This study used a pre- and post-intervention representative quantitative sample survey. This pre-post design was intended to assess the effects of the SolarMal intervention on the malaria control knowledge, perceptions and practices (KPP) of participants. The baseline survey was conducted between March and June 2013 and end line survey between June and August 2015. The study proceeded in the following stages:

1. A baseline survey
2. SMoTS roll-out (24 months)
3. End line survey, which repeated the pre-intervention questionnaire with one additional message about concerns related to project closure.

Sampling and data collection

Respondents were randomly selected. Respondents for the baseline survey were drawn from the project-initiated demographic surveillance database of island residents while those for the post-survey were drawn from the list of homesteads installed with SMoTS. A sample size of 204 and 214 representing 5% of the homesteads was selected for the pre- and post-intervention studies respectively. We interviewed 321 individuals for the baseline and 317 individuals for the end line survey.

Interviewers were given pre-allocated lists of survey homesteads, by clusters. A household head and their spouse or only the female in female-headed households was interviewed. At end line, as only one house was installed with SMoTS in each homestead, we interviewed members of the installed house. The questionnaires were administered by two experienced research assistants trained on the study protocol, research ethics and confidentiality. Respondents were asked during both surveys specific questions on their KPP related to: malaria, mosquitoes, LLINs, pregnancy and intermittent preventive treatment in pregnancy, malaria case management, and existing household protection from malaria. The end line survey included questions about perceived benefits of SolarMal and concerns about project closure.

Data analysis

The data collected from both males and females was analysed for the individual-level variables. Only the data from females was analysed for the household-level variables, as a female was interviewed in each household. Bi-variate analysis of the differences between pre-and post-intervention in knowledge, perceptions and practices related to malaria control were performed using Chi-square test or Fisher's exact test. The multiple variable analysis, that adjusted for the effect of the differences in the demographic characteristics, were performed using logistic regression models on variables that were found to be different between pre- and post-intervention at $p<0.1$ in the bi-variate analysis. For the individual level analysis, the multivariable models were adjusted for age, highest level of education attained and occupation. For the household responses, the models were adjusted for age and highest level of education attained. Statistical significance was considered if the p-value was <0.05 in the multivariable models. Statistical analysis was performed with SPSS version 23.0 (SPSS Inc., Chicago, IL) and Stata version 13.0 (StataCorp. 2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP).

Results

Demographic characteristics of respondents

Demographic characteristics of the study respondents are reported in Table 5.1. A total of 321 and 317 respondents were interviewed during the baseline and end line surveys, respectively. More than half of the respondents of both surveys obtained some primary schooling and were either fishermen or traders. There were significant differences between the age groups, highest level of education attained and occupation of the pre and post-SMoTS roll-out study participants. Demographic characteristics of respondents to the household level questions (women) are reported in table 5.2. Pre-SMoTS roll-out respondents were drawn from 204 households and those of post-SMoTS roll-out were from 214 households. There were significant differences between age groups and highest level of education attained by pre and post-SMoTS respondents to the household questions (women).

Table 5.1 Comparison of demographic characteristics between pre- and post-SMoTs study participants

Variable	Pre-SMoTS roll-out (N=321)	Post-SMoTS roll-out (N=317)	p-value
Age group			**<0.001**
20-24 yrs	38(11.8)	22(6.9)	
25-29 yrs	66(20.6)	30(9.5)	
30-34 yrs	55(17.1)	47(14.8)	
35-39 yrs	51(15.9)	40(12.6)	
40-44 yrs	16(5.0)	33(10.4)	
45-49 yrs	25(7.8)	15(4.7)	
50-54 yrs	15(4.7)	28(8.8)	
55-59 yrs	19(5.9)	11(3.5)	
60-64 yrs	10(3.1)	25(7.9)	
65+ yrs	26(8.1)	66(20.8)	
Sex			**0.293**
Male	117(36.4)	103(32.5)	
Female	204(63.6)	214(67.5)	
Did you ever attend school?			**0.009**
No	16(5.0)	33(10.4)	
Yes	305(95.0)	284(89.6)	
Highest level of education attained			**0.021**
None	16(5.0)	33(10.4)	
Primary not completed	99(30.8)	128(40.4)	
Primary completed	109(34.0)	70(22.1)	
Secondary+	97(30.2)	86(27.1)	
Occupation			**0.010**
Subsistence farmer	22(6.9)	30(9.5)	
Fisherman	75(23.4)	47(14.8)	
Market trader	144(44.9)	133(42.0)	
Unemployed	34(10.6)	54(17.0)	
Other occupation	46(14.3)	53(16.7)	

Table 5.2 Comparison of demographic characteristics between pre- and post-SMoTs study respondents to the household level questions

Variable	**Pre-SMoTS roll-out (N=204)**	**Post-SMoTS roll-out (N=214)**	**p-value**
Age group			**<0.001**
20-24 yrs	32(15.7)	22(10.3)	
25-29 yrs	46(22.5)	26(12.1)	
30-34 yrs	33(16.2)	29(13.6)	
35-39 yrs	27(13.2)	22(10.3)	
40-44 yrs	10(4.9)	18(8.4)	
45-49 yrs	12(5.9)	9(4.2)	
50-54 yrs	8(3.9)	18(8.4)	
55-59 yrs	14(6.9)	9(4.2)	
60-64 yrs	3(1.5)	17(7.9)	
65+ yrs	19(9.3)	44(20.6)	
Did you ever attend school?			**0.042**
No	16(7.8)	30(14.0)	
Yes	188(92.2)	184(86.0)	
Highest level of education attained			**0.001**
None	16(7.8)	30(14.0)	
Primary not completed	69(33.8)	94(43.9)	
Primary completed	74(36.3)	43(20.1)	
Secondary+	45(22.1)	47(22.0)	
Occupation			**0.194**
Subsistence farmer	14(6.9)	20(9.3)	
Fisherman	4(2.0)	1(0.5)	
Market trader	134(65.7)	124(57.9)	
Unemployed	29(14.2)	43(20.1)	
Other occupation	23(11.3)	26(12.1)	

Comparing the pre and post-intervention malaria control KPP

Knowledge and perceptions of malaria, mosquitoes and bed nets

Even at baseline, many respondents correctly identified mosquito bite as the main cause of malaria (91.1%), fever as the main symptom of malaria (63.1%), and sleeping under a mosquito net as the most effective way to prevent malaria (92.8%) as shown in Table 5.3. While more than half of the respondents correctly identified children under five years old (52.6%) as the group most vulnerable to malaria, fishermen (13.7%) were also mentioned. A few others mentioned a combined group of children and pregnant women (9.7%).

Fewer respondents reported that they were troubled by mosquitoes at end line compared to baseline (50.8% versus 85.4%; P<0.001). Respondents who were troubled by mosquitoes at end line were less troubled about bites causing malaria (41.6% versus 60.9%; P<0.001) and more about just being bitten (42.2% versus 22.6%; P<0.001) compared to at the beginning.

Table 5.3 Bi-variate analysis of the knowledge and perceptions related to Malaria among Rusinga Island residents 2013-2015

Variable	**Pre-SMoTS roll-out** N (%)	**Post-SMoTS roll-out** N (%)	**p-value**
Which people most often suffer from malaria in Rusinga Island?	N=321	N=317	0.0012
Children < 5 years	169 (52.6)	172 (54.3)	
Fishermen	44 (13.7)	14 (4.4)	
Children < 5 years and pregnant women	31 (9.7)	46 (14.5)	
People living along the lake	15 (4.7)	11 (3.5)	
Elderly people	0 (0.0)	6 (1.9)	
Other	10 (3.1)	11 (3.5)	
Don't know	52 (16.2)	57 (18.0)	
What is the main cause of malaria?	N=321	N=317	0.932
Mosquito bite	246 (76.6)	251 (79.2)	
Bite by malaria infected mosquito	49 (15.3)	43 (13.6)	
Being cold	7 (2.2)	7 (2.2)	
Other	7 (2.2)	7 (2.2)	
Don't know	12 (3.7)	9 (2.8)	
What is the main symptom of malaria?	N=320	N=317	0.013
Fever	202 (63.1)	179 (56.5)	
Headache	56 (17.5)	82 (25.9)	
General body weakness	19 (6.0)	25 (7.9)	
Body/joint pain	16 (5.0)	11 (3.5)	
Vomiting	16 (5.0)	10 (3.1)	
Other	11 (3.4)	10 (3.1)	
What is the most effective way to prevent malaria?	N=319	N=317	0.046
Sleeping under a mosquito net	296 (92.8)	298 (94.0)	

Clearing bushes/draining stagnant water	7 (2.2)	0 (0.0)	
Taking preventive medicine	6 (1.9)	5 (1.6)	
Other	4 (1.2)	9 (2.7)	
Don't know	6 (1.9)	5 (1.6)	
Would you personally say mosquitoes trouble you?	N=321	N=317	<0.001
Yes	274 (85.4)	161 (50.8)	
No	47 (14.6)	156 (49.2)	
What is it about mosquitoes that mainly trouble you?	N=274	N=161	<0.001
Their bite causes malaria	167 (60.9)	67 (41.6)	
They bite	62 (22.6)	68 (42.2)	
They disturb my sleep	31 (11.3)	6 (3.7)	
Their bites are itchy/painful	14 (5.1)	19 (11.8)	
Other	0 (0.0)	1 (0.6)	
What is the main reason nets are ever used in this house?	N=195	N=213	0.3908
To prevent malaria	109 (55.9)	128 (60.1)	
To prevent mosquito biting	86 (44.1)	85 (39.9)	
What is the main reason this house does not have or never use nets?	N=24	N=3	0.387
Cannot afford nets for every space	21 (87.5)	2 (66.7)	
Other	3 (12.5)	1 (33.3)	

Some changes seen at end line were still significant, even after adjusting for respondent age, highest level of education attained and occupation (Table 5.4). Respondents less frequently mentioned fishermen as the group that most often suffer from malaria at end line compared with at the start (4.4% versus 13.7%; P<0.001). Similarly, fewer respondents reported that they were troubled by mosquitoes at end line compared to at baseline (50.8% versus 85.4%; P<0.001). Fewer respondents were also troubled by mosquitoes disturbing their sleep (3.7% versus 11.3%; P<0.001) and mosquito bites causing malaria (41.6% versus 60.9%; P<0.001) at end line compared to at baseline.

Table 5.4 Multivariate analysis of individual level questions on perceptions of malaria and mosquitoes

Variable	Pre-SMoTS roll-out	Post-SMoTS roll-out	Odds ratio (95% CI)	p-value	Adjusted* Odds ratio (95% CI)	p-value
Which people most often suffer from malaria in Rusinga Island?	N=321 N (%)	N=317 N (%)		0.0012		
Children<5	169 (52.6)	172 (54.3)	Ref		Ref	
Children<5 & Pregnant women	31 (9.7)	46 (14.5)	1.5(0.9-2.4)	0.141	1.7(0.9-2.9)	0.084
Elderly	0 (0.0)	6 (1.9)	-		-	
Fishermen	44 (13.7)	14 (4.4)	0.3(0.2-0.6)	<0.001	0.3(0.1-0.6)	<0.001
People living along the lake	15 (4.7)	11 (3.5)	0.7(0.3-1.6)	0.426	0.8(0.3-2.2)	0.731
Don't Know	52 (16.2)	57 (18.0)	1.1(0.7-1.7)	0.736	0.7(0.4-1.1)	0.123
Others	10 (3.1)	11 (3.5)	1.1(0.4-2.6)	0.863	1.3(0.5-3.6)	0.567
Would you personally say mosquitoes trouble you?	N=321	N=317		<0.001		
No	47 (14.6)	156 (49.2)	Ref		Ref	
Yes	274 (85.4)	161 (50.8)	0.2(0.1-0.3)	<0.001	0.2(0.1-0.3)	<0.001
What is it about mosquitoes that mainly trouble you?	N=274	N=161		<0.001		
They bite	62 (22.6)	68 (42.2)	Ref		Ref	
Bites are painful/itchy	14 (5.1)	19 (11.8)	1.2(0.6-2.7)	0.588	0.9(0.4-2.1)	0.795
Bite causes malaria	167 (60.9)	67 (41.6)	0.4(0.2-0.6)	<0.001	0.4(0.2-0.6)	<0.001
Disturb my sleep	31 (11.3)	6 (3.7)	0.2(0.1-0.5)	<0.001	0.1(0.1-0.4)	<0.001
Other	0 (0.0)	1 (0.6)	-		-	

*Adjusted for age, highest level of education attained, and occupation

Practices related to bed nets and use of health services for children

There was an improvement in bed net use among some groups during the night preceding the interview at the end of the trial compared to at the start as presented in Table 5.5. Improvements were reported for: children under five (98.3% versus 92.6%; P=0.008) and children between the ages of 5-17 (96.7% versus 89.7%; P=0.020). For pregnant women, there was no change at the end of the trial (90.9% versus 100%; P=1.000).

Table 5.5 Bed net use the night before the interview among Rusinga Island residents 2013-2015 (women only)

Did any of these people sleep under a bed net last night?	**Pre-SMoTS roll-out (N=204)**				**Post-SMoTS roll-out (N=214)**				**p-value**
	Yes	No	Don't Know	Not Applicable	Yes	No	Don't Know	Not Applicable	
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	
Child < 5 years	125 (61.3)	10 (5.0)	0 (0.0)	69 (33.8)	113 (52.8)	1 (0.5)	1 (0.5)	99 (46.3)	0.008
Child 5-17 years	148 (72.5)	16 (7.8)	1 (0.5)	39 (19.1)	174 (81.3)	6 (2.8)	0 (0.0)	34 (15.9)	0.020
Pregnant woman	8 (3.9)	0 (0.0)	0 (0.0)	196 (96.1)	10 (4.7)	1 (0.5)	0 (0.0)	203 (94.8)	1.000

As shown in Table 5.6, fewer children under the age of five years had an episode of malaria in the 12 months preceding the end of the trial compared with at the start (21.0% versus 33.0%; P=0.009). While the proportion of children under the age of five years who were taken to a health facility within 24 hours of fever onset did not change much at end line (63.4% versus 65.5%); there were reductions in purchasing medicines over the counter (4.9% versus 24.1%), using left over medicine from health facility (2.4% versus 3.5%), and using left over medicine from a previous over the counter purchase (0% versus 3.5%).

More respondents cited being bitten by mosquitoes as the cause of the most recent malaria episode in a child less than five years of age from a list of responses at the end of the project (46.3% versus 27.6%), although the difference between the two lists was not significant. However, the proportion of respondents who said they did not know the cause of the most recent episode from the same list did not change much at the end of the trial (46.3% versus 44.8%).

After controlling for age and highest level of education attained as shown in Table 5.7, more households had enough nets to cover every sleeping space (94.4% versus 83.4%; P=0.003).

Table 5.6 Bi-variate analysis of the practices related to bed nets, pregnancy and IPTp, and malaria case management among Rusinga Island residents 2013-2015 (women only)

Variable	**Pre-SMoTS roll-out** N (%)	**Post-SMoTS roll-out** N (%)	**p-value**
What is the main method used to prevent malaria in this house?	**N=204**	**N=214**	**0.340**
Sleeping under a mosquito net	193 (94.6)	207 (96.7)	
Other	11 (5.4)	7 (3.3)	
Does your household have any mosquito nets that can be used while sleeping?	**N=204**	**N=214**	**0.027**
Yes	199 (97.5)	214 (100.0)	
No	5 (2.5)	0 (0.0)	
How many nets that can be used for sleeping does this household have?	**N=199**	**N=214**	**0.776**
1	21 (10.6)	18 (8.4)	
2	94 (47.2)	91 (42.5)	
3	50 (25.1)	60 (28.0)	
4	25 (12.6)	31 (14.5)	
5	6 (3.0)	8 (3.7)	
6+	3 (1.5)	6 (2.8)	
Are there enough nets to cover every sleeping space in this household every night?	**N=199**	**N=214**	**<0.001**
Yes	166 (83.4)	202 (94.4)	
No	33 (16.6)	12 (5.6)	
Have you ever been pregnant in the last 2 year period?	**N=204**	**N=214**	**0.001**
Yes	66 (32.4)	39 (18.2)	
No	138 (67.6)	175 (81.8)	
How many years back was your last pregnancy?	**N=66**	**N=39**	**0.127**
Currently pregnant	7 (10.6)	10 (25.6)	
1	40 (60.6)	19 (48.7)	
2	19 (28.8)	10 (25.6)	
During your last pregnancy (or this pregnancy), did you visit a health facility for pregnancy care before the baby was born?	**N=66**	**N=39**	**1.000**
Yes	62 (93.9)	37 (94.9)	
No	4 (6.1)	2 (5.1)	
During your last pregnancy (or this pregnancy), how many times did you visit a health facility for antenatal care?	**N= 63**	**N=37**	**0.356**
1	2 (3.2)	3 (8.1)	
2	61 (96.8)	34 (91.9)	
During your last pregnancy (or this pregnancy), did you receive medicines at a health facility to prevent you from getting malaria?	**N=63**	**N=37**	**0.563**
Yes	52 (82.5)	33 (89.2)	
No	11 (17.5)	4 (10.8)	
During your last pregnancy (or this pregnancy), how many times did you receive medicines at a health facility to prevent malaria?	**N=51**	**N=34**	**0.370**

Only once	12 (23.5)	11 (32.4)	
More than once	39 (76.5)	23 (67.6)	
Did you deliver your last child at a health facility?	**N=66**	**N=39**	**0.028**
Yes	52 (78.8)	37 (94.9)	
No	14 (21.2)	2 (5.1)	
What is the main reason for delivering your child at a health facility?	**N=52**	**N=37**	**0.010**
We always seek health facility care	29 (55.8)	20 (54.1)	0.873
To be helped especially with complications	11 (21.2)	1 (2.7)	0.012
To receive proper care	7 (13.5)	13 (35.1)	0.016
I was advised to deliver in a health facility	5 (9.6)	2 (5.4)	0.695
We live near a health facility	0 (0.0)	1 (2.7)	0.416
What is the main reason for not delivering your child at a health facility?	**N=13**	**N=2**	**0.429**
Sudden delivery	7 (53.9)	1 (50.0)	
I was alone	2 (15.4)	1 (50.0)	
Other	4 (30.8)	0 (0.0)	
Has any member of this house had fever/malaria in the last 12 months?	**N=204**	**N=214**	**0.278**
Yes	176 (86.3)	192 (89.7)	
No	28 (13.7)	22 (10.3)	
Was the family member who most recently had fever/malaria 5 years of age or younger?	**N=176**	**N=195**	**0.009**
Yes	58 (33.0)	41 (21.0)	
No	118 (67.0)	154 (79.0)	
When was s/he last sick?	**N=176**	**N=192**	**0.293**
1-2 weeks ago	85 (48.3)	106 (55.2)	
3-4 weeks ago	50 (28.4)	51 (26.6)	
2-3 months ago	27 (15.3)	18 (9.4)	
>3 months ago	14 (8.0)	17 (8.8)	
What do you think caused the child to have fever/malaria?	**N=58**	**N=41**	**0.076**
Child was bitten by mosquitoes	16 (27.6)	19 (46.3)	
Child was exposed to cold	9 (15.5)	3 (7.3)	
Child did not sleep under a net	3 (5.2)	0 (0.0)	
Don't know	26 (44.8)	19 (46.3)	
Other	4 (6.9)	0 (0.0)	
What actions did the family take to manage case of fever/malaria? (Multiple response)	N=58	N=41	
Took child to health facility within 24 hours of fever	38 (65.5)	26 (63.4)	
Took child to health facility more than 24 hours of fever onset	15 (25.9)	10 (24.4)	
Purchased over the counter medicine	14 (24.1)	2 (4.9)	
Used left over medicine from health facility	2 (3.5)	1 (2.4)	
Used left over medicine from over the counter purchase	2 (3.5)	0 (0.0)	
Other	0 (0.0)	2 (4.9)	
What was your main reason to seek medical care in a health facility for the last fever/malaria case in your household?	**N=53**	**N=36**	**0.015**
We always seek care at a health facility	25 (47.2)	14 (38.9)	
The episode was severe	19 (35.9)	6 (16.7)	
To receive proper care	9 (17.0)	12 (33.3)	
Child had fever	0 (0.0)	2 (5.6)	
Other	0 (0.0)	2 (5.6)	

What is the main reason this family did not seek medical care in a health facility for the last fever/malaria case in your household?	**N=21**	**N=22**	**0.130**
The episode was not severe	15 (71.4)	19 (86.4)	
We had no money to seek medical care	4 (19.1)	0 (0.0)	
Other	2 (9.5)	3 (13.6)	

Table 5.7 Multivariate analysis of household level questions on net cover, pregnancy and malaria case management (women only)

Variable	**Pre-SMoTS roll-out**	**Post-SMoTS roll-out**	**Odds ratio (95% CI)**	**p-value**	**Adjusted* Odds ratio (95% CI)**	**p-value**
Are the nets enough to cover every sleeping space in this house every night?	N=199 N (%)	N=214 N (%)		0.0003		
No	33(16.6)	12(5.6)	Ref			
Yes	166(83.4)	202(94.4)	3.3(1.7-6.7)	0.001	3.0(1.4-6.2)	0.003
Did you deliver your last child at a health facility?	N=66	N=39		0.0175		
No	14(21.2)	2(5.1)	Ref			
Yes	52(78.8)	37(94.9)	5.0(1.1-23.2)	0.041	5.6(1.1-28.9)	0.039
What is the main reason for delivering your child at a health facility?	N=52	N=37		0.0087		
Always seek care	29(55.8)	20(54.1)	Ref		Ref	
Live near a health facility	0(0.0)	1(2.7)	-		-	
To be helped with complications	11(21.2)	1(2.7)	0.1(0.0-1.1)	0.062	0.2(0.0-1.4)	0.102
I was advised to deliver in a health facility	5(9.6)	2(5.4)	0.6(0.1-3.3)	0.539	0.6(0.1-3.9)	0.629
To receive proper care	7(13.5)	13(35.1)	2.7(0.9-7.9)	0.073	2.4(0.7-8.3)	0.182
What was your main reason to seek medical care at a health facility for the last child fever/malaria case in your household?	N=52	N=37		0.066		
Always seek care	25(47.2)	14(38.9)	Ref		Ref	
Episode was severe	19(35.8)	6(16.7)	0.6(0.2-1.7)	0.319	0.8(0.2-3.0)	0.786
Receive proper care	9(17.0)	12(33.3)	2.4(0.8-7.0)	0.117	1.3(0.3-4.8)	0.721
Child had fever	0(0.0)	2(5.6)	-		-	
Other	0(0.0)	2(5.6)	-		-	

*Adjusted for age, and highest level of education attained

As shown in Table 5.8, more than half the respondents agreed with the following statements on LLIN use at baseline: I would not sleep under a bed net if I had a choice, I sleep under net for good sleep, and the sleeping space determines net use. At end line more respondents disagreed with the following statements (P<0.001): I would not sleep under a net if I had a choice, I fail to sleep under net even though has own net, I prefer malaria treatment over nets, I prefer IRS over nets, the sleeping space determines net use.

Table 5.8 Practices related to bed net and health services use for children among Rusinga Island residents 2013-2015

	Pre-SMoTS roll-out			**Post-SMoTS roll-out**			**p-value**
	Likert scores						
	Agree	Sometimes	Disagree	Agree	Sometimes	Disagree	
How would you describe your use of bed nets?	N=313			N=317			
1. Sleeps under nets when sees mosquitoes	37	3	273	17	1	299	0.004
2. Sleeps under nets on cold nights	35	1	277	20	3	294	0.048
3. Would not sleep under net if had a choice	196	9	109	80	19	218	<0.001
4. Likely to not sleep under net during hot season	49	5	259	24	7	286	0.006
5. I am more likely to sleep under net when sick	54	0	259	100	13	204	<0.001
6. Encourage net use in pregnancy	308	0	5	314	2	1	0.076
7. Sleeps under net for good sleep	276	2	35	286	0	31	0.376
8. Sleeps under net for malaria prevention	312	0	1	315	2	0	0.372
9. Sleeps under net all year round	266	9	38	289	1	27	0.008
10. Fails to sleep under net even though has own net	35	36	242	7	32	278	<0.001
11. Prefers malaria treatment over nets	74	0	239	31	2	284	<0.001

12. I fish at night so cannot use net	44	14	255	6	29	282	<0.001
13. Prefers IRS over nets	69	0	244	14	0	303	<0.001
14. The sleeping space determines net use	211	3	99	9	3	305	<0.001
How would you describe your use of health services (HS) for child health in your household?	N=204			N=214			
1. Visits health service (HS) after home therapy fails	96	15	93	75	29	110	0.016
2. Starts home therapy then HS immediately	96	15	93	63	42	109	<0.001
3. Goes to HS right away	96	95	13	108	92	14	0.759
4. Some childhood diseases cannot be treated at HS	49	2	153	88	6	120	<0.001
5. Encourages HS during pregnancy	203	0	1	213	1	0	0.738
6. HS use depends on whether we have money for it	137	2	65	155	15	44	<0.001
7. HS use is determined by distance	42	2	160	8	2	204	<0.001

Perceptions of the SolarMal project post-intervention

The information on perceptions of the SolarMal project after the roll-out of SMoTS is presented in Table 5.9. Respondents were knowledgeable about the project with the majority frequently mentioning; lighting houses (88.3%), killing mosquitoes (63.1%) and charging telephones (36.6%). House lighting (97.8%) was reportedly the most important aspect of SolarMal, followed by killing mosquitoes (56.8%), and then charging telephones (36.0%). When considering sustaining SMoTS, respondents were mainly concerned about who would repair parts of SMoTS and replace baits (38.5%) and where to buy parts (37.9%).

Table 5.9 Perceptions of Rusinga Island residents towards SolarMal project 2015

What do you know about SolarMal project?	
Category	**Frequency (Per cent) (N=317)**
Brought solar power to light up our homes	280 (88.3)
Used solar malaria kit to kill mosquitoes	200 (63.1)
Brought solar power to charge our phones	116 (36.6)
Reduced malaria in Rusinga Island	44 (13.9)
Tested and treated malaria	16 (5.1)
Eliminated malaria from Rusinga	9 (2.8)
No information	5 (1.6)
Other	12 (3.8)
What has been important to you on SolarMal?	
Lighting up our houses	310 (97.8)
Killing mosquitoes	180 (56.8)
Charging our phones	114 (36.0)
Reducing malaria in Rusinga	56 (17.7)
Testing and treating malaria	8 (2.5)
Other	3 (1.0)
What concerns might you have about the closure of SolarMal project?	
How and by whom SMoTS will be maintained	122 (38.5)
Where to buy parts of SMoTS	120 (37.9)
I have no worries	96 (30.3)
Lack of money to maintain SMoTS	19 (6.0)
That some residents don’t have SMoTS	16 (5.1)
Security of SMoTS in my house	9 (2.8)
Other	29 (9.2)

Discussion

This study assessed the KPP related to malaria control prior to and following the roll-out of the SolarMal project to compare any changes that may have taken place during the implementation of the project. As mosquito trapping was an additional strategy to use of LLINs and malaria care-seeking, these topics were central to this assessment. The SolarMal project used an innovative way to control malaria and there was some concern that excitement over it could have a negative impact on deployment of the existing malaria control strategies, mainly use of LLIN s and prompt malaria care seeking.

The findings from this study show that Rusinga Island residents were fairly knowledgeable about malaria and the government recommended preventive measures, even before the roll-out of SolarMal project. High levels of correct biomedical knowledge of malaria among populations living in endemic areas have been reported by other studies in Kenya (Mwenesi, Harpham et al. 1995; Winch, Makemba et al. 1996; Adera 2003). Despite being knowledgeable, some responses still pointed to the limitation of LLINs such as when respondents said: they would not sleep under an LLIN if they had a choice, they sleep under an LLIN for good sleep and that sleeping space determines LLIN use. These reasons point to inconveniences associated with using nets and lack of congruency between using LLINs to prevent malaria versus to ensure good sleep. Sleeping space and good sleep have been documented as determinants of seasonal and/or inconsistent LLIN use by other studies (Alaii, Hawley et al. 2003; Alaii, Van den Borne et al. 2003; Iwashita, Dida et al. 2010; Koenker, Loll et al. 2013).

The end line survey revealed significant improvements in knowledge, perceptions and reported practices related to LLINs even though these were already high at baseline. Unlike at baseline, fewer respondents preferred malaria treatment or IRS over sleeping under an LLIN. Fewer respondents also said they failed to sleep under an LLIN although they have one. Similarly, fewer respondents said that sleeping space determines net use. In addition, more children under five years and older children slept under LLINs the night preceding the end line survey. These improvements are likely to have been encouraged by the education and awareness campaign that stressed the complementary nature of SolarMal, as other studies of effects on educational interventions on malaria control have shown happens in the short term (Kroeger, Meyer et al. 1996; Amoran 2013). The improvements are also likely to have been further enabled by the availability of more LLINs at end line following a mass distribution campaign in August of 2014, 10 months before the end line survey commenced. The mass distribution is reflected in more houses reporting having enough LLINs to cover every sleeping space at end line. Studies have reported mass distribution campaigns, especially when coupled with an awareness campaign of the benefits of using LLINs, as improving LLIN usage (Atieli, Zhou et al. 2011; Zhou, Li et al. 2014). While this positive improvement supports efforts towards malaria control, sustaining the changes may require a longer and persistent effort with educational programmes and cues to action. As sustained behaviour change, the ultimate goal of health education, is a complex process that cannot be accomplished over the short-term, follow-up studies should assess how KPP change two years after closure of the research phase of SolarMal.

Not only did fewer respondents report being less troubled by mosquitoes at the end of the trial, but respondents were also less worried about catching malaria from mosquito bites and mosquitoes disturbing their sleep. These perceptions may be validated by mosquito surveillance findings (Homan et. al. In Press) that showed that the mosquito traps led to a significant reduction in the density of *An. funestus* mosquitoes, the main malaria vector on the island. However, this change may also lead to risk compensation as residents feel less at risk of malaria with reduced exposure to mosquito bites. This is especially the case in Rusinga Island where the main motivation for using bed nets is to avoid malaria and more than half of respondents had indicated at baseline that they would not sleep under an LLIN if they had a choice. Although these changes seem to indicate that SolarMal may have been not only effective in controlling mosquitoes but also in influencing perceptions of residents on mosquito density, the changes have the potential to lead to complacency in deploying additional malaria prevention strategies. In an assessment carried shortly after SMoTS were rolled out, some residents had reportedly stopped using LLINs after receiving SMoTS because they no longer heard mosquitoes (Oria, Alaii et al. 2015), pointing to the potential challenge of reduced risk perception. The challenge of risk compensation – increases in risky behaviour sparked by decreases in perceived risk – has long been associated with disease prevention strategies that prove effective (Richens, Imrie et al. 2000; Blower, Ma et al. 2003; Cassell, Halperin et al. 2006; Eaton and Kalichman 2007).

This study had two limitations. The first limitation is that there was a mass net distribution exercise approximately a year before the end line interviews. The awareness campaign that accompanied net distribution exercise could have contributed to the improvements in the perceptions of malaria control reported at end line. The second limitation is the significant differences in the demographic characteristics of study respondents at pre- and post-intervention, which may have contributed to differences in responses. The respondents in the post-intervention survey were older and had less education. This difference is attributed to the fact that interviews were conducted in households with a SMoTS installed, and members of many homesteads had agreed to install the system in the house of the most senior woman in the homestead. We addressed this limitation in analyses by controlling for the significantly different demographic variables in multivariate analyses of the pre and post-intervention samples.

Conclusion

In the short term, the SolarMal project did not document a negative effect of the innovation on existing malaria strategies. Instead, there was an improvement on the already high levels of knowledge and positive perceptions and practices towards malaria control. This improvement could have contributed to the effectiveness of the SolarMal intervention. In view of the limitations, the introduction of this innovation should be accompanied by targeted follow-up behavioural and epidemiological surveillance to troubleshoot and address any emerging challenges with deployment of existing malaria strategies, and introduce targeted appropriate risk reduction measures; since OBTS is deemed as one part of a collection of complementary interventions. To ensure the maintenance of the health educational gains, the malaria control program should explore best practices for longer and persistent social mobilisation efforts. Future studies should monitor the long-term maintenance of the gains from the social mobilisation efforts.

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CHAPTER 6

Options for sustaining solar-powered mosquito trapping systems on Rusinga Island, western Kenya: a social dilemma analysis

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To be submitted

Abstract

In 2012, a donor-supported proof of principle study was launched to eliminate malaria from Rusinga Island, western Kenya, using solar-powered mosquito trapping systems (SMoTS). SMoTS, which also provided power for room lighting and charging mobile telephones, were installed in houses. In view of the involvement of individual and collective benefits, as well as individual and collective maintenance solutions, this study examined preferences of project stakeholders towards SMoTS sustainability components to see if and how they related to social dilemma factors. The data were collected through participant observation, semi-structured interviews and focus group discussions. The results show that respondents largely preferred individual solutions to various aspects of maintenance, and there seemed to be linkages between preferences towards organising various components of SMoTS sustainability and known hindrances to addressing social dilemmas. Sustaining SMoTS presents a social dilemma for residents.

Introduction

In 2012, the International Centre for Insect Physiology and Ecology in collaboration with Wageningen University launched a four-year proof of principle study to eliminate malaria from Rusinga Island using solar-powered mosquito trapping systems (SMoTS). SMoTS, which also provided power for room lighting and charging mobile telephones, were installed in houses (Oria, Alaii et al. 2015). The project was launched with core support from donor funding and the research phase ended in December 2015. From January 2016 there is no more funding from the project and SMoTS parts and repairs are no longer be available to residents free of charge. However, the community can come up with a sustainability plan and a project-initiated community advisory board (CAB) (Oria, Hiscox et al. 2014) is spearheading this process.

Demonstration programmes, such as the SMoTS intervention, are usually deployed in real life conditions but with immense project human and financial resource support to ensure conditions required to demonstrate proof of principle to enable learning on the side about long term feasibility. However, when sustainability is not assessed, it remains questionable whether community efforts can be sustained long enough to have a lasting effect (Heintze, Garrido et al. 2007). While not all research projects need to be sustained, the current project was unique in that although its main aim is malaria elimination, it provided an immediate benefit through the provision of electricity for house lighting and telephone charging. While the benefits of electricity provision are mainly at the level of individual households, the benefits of malaria control accrue to the wider public.

Substantial time and resources are often invested in programme development, adaptation and implementation. It is important, as an integral part of the programme planning process, to identify factors that promote the integration and maintenance of new programmes into community setting (Goodman and Steckler 1989; Lefebvre 1990; Goodman, McLeroy et al. 1993). This study examined preferences of project stakeholders towards SMoTS' sustainability components and assessed if they related to social dilemma factors.

Social dilemma theory: public goods dilemma

Social dilemmas are situations in which the rational pursuit of self-interest can lead to collective disaster (Kerr 1983). A public good can be provided only if group members contribute something towards its provision; however, both contributors and non-contributors may use it (Komorita and Parks 1995). Public goods confront the individual with the temptation to defect i.e. to take advantage of the public good without contributing to it (Hauert, De Monte et al. 2002). The SMoTS project benefits, particularly the malaria control component, resemble public goods and may have dilemma characteristics. Unlike electrification which is private and enjoyed exclusively at the individual household level, malaria control is a public benefit realised beyond the installed house and homestead. For instance, to sustain the malaria control component of SMoTS, individuals need to give up some of their own resources to maintain a public good everybody enjoys. Each installed household essentially oversees that the mosquito trap is always in optimum working condition to assure adequate coverage of traps in the area. Reaching the collective target requires individual sacrifice, with benefits to all but no guarantee that others will also contribute (Milinski, Sommerfeld et al. 2008).

While in a classic public goods dilemma maximum benefits are usually accrued when things are organised collectively, SMoTS has distinguishing characteristic features; (a) some sustainability components can be organised individually and others collectively, (b) provides double incentives of malaria control and electrification which are enjoyed at public and individual levels, respectively, and (c) presents an immediate and a long-term incentive. Critical sustainability components for SMoTS include: ownership, repair of installed SMoTS, stocking and selling parts and financing SMoTS repairs and spare parts. Each of these factors can be arranged individually and/or collectively.

Research has shown that a number of factors influence whether people choose short-term individual benefit or longer term collective benefit (Dawes 1980). Factors that facilitate group cooperation in social dilemmas include; trust in partners, smaller group size, enhanced in-group identity, effective leadership, and possibility of sanctioning. Trust is the willingness of a party to be vulnerable to the actions of another party based on the expectations that the other party will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party (Mayer, Davis et al. 1995); and strong perceptions of trust positively influences cooperation (Dawes 1980; Messick, Wilke et al. 1983; De Cremer 1999; De Cremer and Van Vugt 1999; Rothstein 2000). Cooperation decreases in large groups mainly because people feel less efficacious, are less identifiable and may feel negligible responsibility to pursue the group's welfare (Brewer and Kramer 1986; Yamagishi 1992; Seijts and Latham 2000). In-group identity is the sense to which people feel they belong to and identify with the group, and those with strong group identification have been found to invest more in public goods dilemmas (Kramer and Brewer 1984; De Cremer and Van Vugt 1999), because their trust in others to do the same is high. Sanctioning is an effective factor in promoting cooperative behaviour (Ostrom, Walker et al. 1992; Gächter and Fehr 2000; Sefton, Shupp et al. 2007). Effective leadership can have a positive impact on how much group members contribute to collective efforts (Van Vugt and De Cremer 1999; De Cremer and Van Knippenberg 2002).

In this study we explored community aspirations for sustainability, and investigated whether the community preferred individual or cooperative solutions for organising sustainability components, and whether and how known social dilemma factors can be recognised in the reasoning of actors.

Methods

The data reported here were collected as part of a multidisciplinary trial on which the social science studies assessed socio-cultural and behavioural aspects of design, adherence to use and maintenance of SMoTS.

Study site and population

This study was carried out in Rusinga Island, western Kenya. The island covers an area of 44 km^2. A project-initiated census estimated the population of the island at 25,110 individuals living in 4,918 homesteads at the end of 2014. The trial targeted the whole island and each eligible homestead received a SMoTS. Roll-out of SMoTS begun in June 2013 and was completed in June 2015 after 4, 358 houses were installed with SMoTS.

Two rainy seasons occur annually, from March to June and October to November, but their duration and intensity vary considerably between the years (Minakawa, Dida et al. 2008). The island is extensively deforested and generally rocky with limited vegetation (Opiyo, Mukabana et al. 2007). Rusinga has a diverse topography, ranging from flat areas near the shoreline to a central hill. Although malaria is transmitted throughout the year, intensity can vary greatly according to seasons. Most houses have walls made of a mixture of mud and cow dung and a tin roof. Lake Victoria is the main source of water for the islanders. The lake is used for fishing, washing clothing and dishes, and bathing.

Most residents are of the Luo ethnic group and *Dholuo* is the main language spoken on the island. The main economic activities are fishing, small-scale trade and traditional subsistence agriculture. Some residents who depend on fishing especially of *omena* (*Silver cyprinid*), live on the island only temporarily before relocating to other areas due to declining catches or the seasonal government-imposed closed fishing season (Geheb and Binns 1997). While fishing is almost entirely practiced by men, women dominate fish trading. As most Rusinga residents lacked electricity supply before the roll-out of the current project in 2012, the majority used kerosene tin lamps for room lighting and charged their mobile telephones at commercial centres.

Sampling and data collection

The study team developed questionnaires in English. The questionnaires were translated into *Dholuo* by the first author and research assistants and corrections were made during fieldworker training and piloting. We carried out participant observation, semi-structured interviews and focus group discussions (FGDs), in that sequence, with each preceding process informing questions for the next. The data were collected in two phases. The first phase was by the first author through participant observation of routine CAB meetings to plan for the sustainability of SMoTS. A total of six meetings took place between August 2014 and June 2015. Discussions were audio recorded.

During the second phase, which assessed preferences for sustainability options, we conducted 16 semi-structured interviews, comprising nine CAB members (6 males, 3 females) and seven community opinion leaders (4 males, 3 females). The nine CAB members purposively selected out of 16 were residents of the island and eligible to receive SMoTS. A variant of snow-ball sampling was used to select opinion leaders. After interviewing a CAB member, they were asked to provide names of community members they perceived as opinion leaders on sustaining SMoTS. This list mostly resulted in names of males and informal questioning of community members elicited names of female opinion leaders that were added to balance gender representation on the list. Each interview was audio recorded after obtaining verbal consent from the interviewee. Participants could choose to end the interview at any time or not respond to particular questions. The interviews were conducted from 25 November through 8 December 2014. All interviews took place in a setting of the respondent's choice, most often in their home. The questionnaire included questions on respondent's understanding of sustainability of SMoTS, measures that would improve prospects for sustainability of SMoTS, their preferences towards organizing each sustainability component, and their experiences participating in collective community initiatives.

The data obtained from the interviews were used to suggest four preliminary sustainability models which were presented to community members for evaluation during FGDs conducted from 8 through 15 January 2015. Community members explored the potential advantages and disadvantages of each model. Six FGDs were conducted: four with residents of villages and two with residents of beaches (35 participants in total). The distinction between villages and beaches was made because an earlier study (Oria, Alaii et al. 2015) showed a difference in perceptions and behaviours of residents of the two settings. Half of the FGDs in each location were with males. FGD participants had to be over 18 years old and have a SMoTS. Participants were randomly selected from the project SMoTS' installation list. FGD sessions were held with 4-10 participants and discussions were audio-recorded.

Experienced bilingual research assistants conducted the interviews and moderated the group discussions in *Dholuo*, the local language. Verbal informed consent to participate was obtained from the participants after an introduction and explanation of the study purpose. In addition, verbal consent was obtained to audio-record sessions. The first author trained the research assistants in the administration of the questionnaires. Data collection was supervised by the first author.

Data analysis

The research assistants transcribed verbatim narrative interviews directly from *Dholuo* into English, discussing any interpretation issues with the first two authors. To decrease investigator bias in the data analysis, we employed coding triangulation (Miles and Huberman 1994; Yin 2013). Together PAO, MW and CL developed a thematic framework based on the interview topic guides, which was updated with new themes emerging from the data. Following the construction of the coding framework, PAO and MW independently analysed the transcripts of the CAB meeting notes, interviews and focus groups into themes concerning ways of organising each aspect of sustaining SMoTS. Data analysis was manually.

Ethical considerations

Ethical approval for the study was obtained from the Kenya Medical Research Institute Ethical Review Committee (KEMRI-ERC NON-SSC No. 350). After the study was explained to the households in the local language, written informed consent was obtained from them before enrolment. To guarantee confidentiality, study tools did not include respondent identifiers.

Results

In the first part of this section, we present the results of the interviews with CAB members and opinion leaders on different sustainability components. In the second part, we present additional findings based largely on FGDs with residents on the four sustainability models that were constructed based on information from the earlier interviews.

Exploring views on sustaining SMoTS

Findings are presented according to four sustainability components that can either be organised more individually or collectively: (1) Ownership of SMoTS; (2) Repair of installed SMoTS; (3) Stocking and selling of SMoTS' parts; and (4) Financing spare parts.

Ownership of SMoTS

Mosquito trapping was the mainly mentioned benefit of SMoTS, alongside lighting and telephone charging. Respondents portrayed preference that households should own SMoTS after the research phase ends because they were motivated to maintain the system and trained on how to care for them.

A CAB member said, *"It is not easy for someone who is not staying in an installed house to be assigned ownership as he may not be concerned and things may not proceed well. He may even take away the cables!"*

However, there were also concerns that individual ownership may allow residents to migrate from Rusinga with SMoTS. SMoTS were deemed to be the property of Rusinga Island.

"Some people received SMoTS even though they are not natives of Rusinga and if we allow individual ownership when the research ends, they will definitely leave with the system. These things should remain with us," said a CAB member.

Although collective ownership was deemed to offer a better environment for proper maintenance of SMoTS, the idea did not receive much prominence in discussions. Participants cited potential for non-cooperation by group members, but equally remarked that such challenges could be managed effectively through proper group regulations.

"There should be a board that makes sure this thing (SMoTS) is sustained … not the beneficiary. The beneficiary should use it as a result of paying a small fee. Similar to Kenya Power where users pay a monthly fee to access electricity. I am a beneficiary but the project is not mine," said a CAB member.

"As long as a person has a SMoTS installed in their house they must join a group. And as long as you are a member of a group, you must abide by the rules and regulations governing the group and every member of the group must abide by these rules and regulations," said an opinion leader.

Repair of installed SMoTS

Respondents mainly indicated repairs should be done by project trained technicians or other local technicians, citing the importance of familiarity with the equipment.

"Project technicians should be the only people allowed to repair SMoTS. You are very likely to find an error if you use random experts to repair this equipment," said an opinion leader.

Three ways of paying repair technicians were proposed; per service by the household in need of repairs, monthly fee to a governing body, or through group savings. CAB members were reluctant to save in groups for repair costs mainly preferring to pay for repairs individually. Some opinion leaders, however, said they would save in groups for repairs.

"The households will pay the technicians and it will be very cheap for each household because the technicians reside around here .... They are our sons and we know them," said a CAB member.

None of the interviewees thought it was a good idea to employ technicians full time for repairs. Technicians would still make a living out of being paid per service because some were also fishermen and others businessmen.

"We cannot employ them because we cannot sustain them. After they have done their job, we pay and finish with them," said an opinion leader.

Stocking and selling of SMoTS' parts

The majority of the interviewees said a shop in Mbita would be the most convenient place to obtain spare parts. The rest preferred the project donor or project management to stock parts for sale to the community. While most respondents preferred a private shop, a few CAB members said this shop could be run by the CAB while others proposed a governing body. Households would pay a monthly fee to the CAB or governing body to purchase stock which community members would afterwards buy from the shop.

Respondents had no preference of the private person to run the shop although they suggested it would be better if the project approached a businessperson than community members who were perceived to have strong personal interests.

"Because the community would talk nonsense ... the project should approach him because I will talk of my benefit, you will talk of yours but the project will approach him without a direct interest," said a CAB member.

Financing spare parts

To improve prospects for sustainability, in addition to paying technicians, money is also needed to buy spare parts of SMoTS. There were three categories of responses in this category; through individual means, through group savings, and through donor support. Saving at the individual level was deemed most reliable but respondents pointed out that some members of the community such as the elderly and poor would require help to have sufficient money for spare parts, hence the need for collective saving.

"We have these old men and women who cannot afford to pay on their own. They can join together in a group and invite their Member of County Assembly (ward representative) to do a harambee (public fundraising) for spare parts," said an opinion leader.

Although group savings was perceived as a good way of generating sufficient resources to purchase spare parts, there was some distrust about group efforts that involve money. Many respondents were wary of group savings and narrated their previous bad experiences with group undertakings that involved money.

"No! I have an experience with things like this being done in groups and they don't succeed. Things don't work in the correct way in groups because you can put money together and then you find the money is not there," said an opinion leader.

Construction and evaluation of sustainability options

Sustainability options

The data from interviews with CAB members and opinion leaders were used to construct preliminary sustainability options in Table 6.1. Sustainability option A leans towards a more individual orientation. In this option households own SMoTS and individually pay for spare parts and repairs. Option B is similar to the former with the distinction that SMoTS' owners may form voluntary savings groups to finance parts and repairs collectively. In options C and D, there is a governing body which owns SMoTS on behalf of households. But while in option C households form compulsory groups in which they save money that the governing body uses to stock the spares parts shop, in option D a donor finances stocking the shop and households only pay a monthly fee to the governing body to cover individual household's spare parts and repair needs.

Table 6.1 Sustainability options derived from interviews with CAB members and opinion leaders

Options	**A (Individual household)**	**B (Household/ voluntary groups)**	**C (Governing body + compulsory groups)**	**D (Governing body + donor)**
Governing body	No	No	Yes	Yes
Ownership	Individual	Individual	Governing body	Governing body
Repairs	Self/technician	Technician	Technician	Technician; paid by governing body
Shop in Mbita	Yes	Yes	Yes	No
Monthly fee to governing body	No	No	Yes; to fund shop stock	Yes; for funding repairs/technicians
Saving in groups	No	Optional	Compulsory	Optional
Donor	No	No	No	Yes; to fund shop stock

Community members' evaluation of sustainability options

The four sustainability options were presented to community members to express their preferences during FGDs. The feedback is summarised in Table 6.2. The feedback suggests that respondents generally preferred sustainability option A followed by option B. In general; respondents would like to own SMoTS and finance spare parts and repairs but would like someone else to procure and stock affordable and accessible spare parts as well as have access to technicians. While option C contained elements that were considered as serious options by the project management and some CAB members and opinion leaders, this option gained little or no support in the community.

Table 6.2 Community members' evaluation of sustainability options

Options	**A (Individual household)**	**B (Household/voluntary group)**	**C (Governing body + compulsory groups)**	**D (Governing body + donor)**
General views	The preferred option	Some participants said this may work	May work for villages and some beach women if some conditions are met	May work for villages and some beach women
Conditions			Sense of ownership and trust in governing body	
			Addressing fear of contributing money	
			Governing body should be composed of people who have SMoTS	
Advantages/Conditions	Households are accountable to themselves on sustainability	Group members will support the poor to maintain SMoTS		Donor provides funds for stock
Disadvantages	Difficulty recovering credit	Free riders	Distrust in governing body	Distrust in governing body
	Good for light but not for malaria elimination	Misappropriation of group resources	Bad previous experiences with group monetary contributions	Lack of trust among people on island
	Untrustworthy technicians	Lack of trust between members	Governing body could favour parts of the island	Failure to pay monthly fee to governing body
	Neglect/sale if maintenance costs are high	Frequent migrations in town areas		
	Clarify who owns SMoTS in beaches; landlord or tenant	Politics		

Views and developments on a governing body and group formation

Besides yielding arguments similar to those discussed in relation to the sustainability components (see section 3.1), the discussions during the focus groups revolved around the axis on which the options presented were different: having a governing body or not, and the appropriateness of having compulsory or voluntary saving groups. In the discussions, the two often appeared interlinked as both were associated with collection of funds. The idea of collective monetary contributions elicited concerns about trust of those handling money. The concern was mostly attributed to previous experiences when leaders failed to account for finances they had been entrusted to safeguard. Such experiences included a long-standing stalemate over Kshs 500 (5USD) presumably contributed to a CBO kitty by individuals in anticipation of household "prequalification" for SMoTS. The project intervened to clarify that the CBO's activity was separate from project plans, that there was no prequalification for SMoTS except as determined by the scientific design of the study and that the CBO was wrong to solicit money using the name of the project. Many unsuccessful efforts have been undertaken to get the CBO to refund the money to the contributors without success.

Whenever the idea of working in groups that would involve monetary contributions arose, participants often mentioned this experience:

"First that word governing body has scared me; we need to know those who will head the body and in most cases the projects have failed on Rusinga because of such bodies. Some time back there was this idea; Kshs 500 that was collected from community and we don't know where the money is, they also have harsh conditions that if you can't meet they will take the systems. Without saying too much I can't support that model. No!"

As indicated in 3.1.4, savings groups were seen as a useful component, especially for financially weaker persons:

"It can work since group work is inclusive of the old who do not have enough knowledge about the system. From the group they will get assistance: those that lack enough money will get assistance from the group savings; group work is also very good since people share ideas; working in a group can enable them face credit as a group thus making it easier; and, group work opens ways for other developments."

"Group members will assist the member who is not able and that's why we are forming the group. Not all the members are able, but the few who are not able are also members of our community and group, so the group will assist them."

However, many respondents narrated negative experiences with groups related to poor group cohesion, misappropriation of funds, and gossip. According to some, these problems were also linked to specific parts of the island:

"There are areas in Rusinga where groups can succeed and areas where they cannot succeed, people might contribute money and when I need some repairs to be done there is no money."

"It might not work in town since people keep on migrating in and out and also forming groups in town is not easy because people vary in opinion and bringing them together is also a very big problem."

Respondents also mentioned several mechanisms through which group problems could be ameliorated. To enhance group cohesion and avoid free riding, respondents suggested that people should join or form groups of their own choice and with people they trust:

"They should identify their own membership and they should be people that live close to one another since if someone comes from far you might not know his or her character i.e. knowing one another better before coming together to form a group."

During a CAB meeting in June 2015, we learned that an existing women's group that was originally formed for table banking (group contributions and immediate loaning) had introduced an aspect of saving money towards sustaining group members' SMoTS. From savings made from kerosene purchases as a result of owning SMoTS, members contributed Kshs100 (1USD) monthly that was saved in a SMoTS maintenance kitty. The plan was that whenever a group member would need repairs, money would be withdrawn from this kitty. At the time of the meeting, the group had already saved for five months but SMoTS had not needed any repairs yet. Further investigation indicated that membership consisted of people who knew and trusted each other, and that the group had rules in place which included expelling those not conforming. The group consisted of 20 members and did not want to grow larger to avoid reduced commitment and responsibility of members.

Based on the outcomes of this study and the women's group experience, the project eventually adopted the group saving approach by seeking to encourage integration of savings for SMoTS into existing table banking groups and encouraging formation of new groups by residents who were not members of an existing savings group. The community champion for table banking was engaged by the project to coordinate this activity. By December 2015, 86 such voluntary savings groups had been sensitised and 48 were actively saving towards sustaining members' SMoTS. As training of new groups continues, monitoring of operations of working groups is on-going and will provide vital lessons going forward.

Discussion

The findings indicate that residents of Rusinga Island leaned towards largely individualistic solutions to the sustainability issue. Specific collective solutions such as table banking groups were considered positively for the purpose of mobilising financial resources necessary for maintenance (e.g. replacing batteries), but residents were hardly willing to contribute financial resources under the custody of a saving group or a governing body. In fact, very few people saw a meaningful role for a collective governing body; people preferred to rely on individual household responsibility and private service delivery when it comes to repairs and stocking spare parts. As summarised in Table 6.3, there seemed to be linkages between preferences towards organising various components of SMoTS sustainability and social dilemma factors.

Table 6.3 The relationship between preferences towards organising Solar-powered Mosquito Trapping Systems' sustainability components and social dilemma factors

	Sustainability components			
Social dilemma factors	*Ownership*	*Repairs*	*Stocking and selling parts*	*Financing parts*
Trust	Yes: Preference for individual ownership due to lack of trust in a collective ownership body	Yes: Preference to organise and pay individually because a collective body and technicians may be untrustworthy	Yes: Preference for a private business person or donor because some community members may display self-interest	Yes: Preference for individual approach because if group savings is adopted there were concerns about unaccountable leaders; concerns about free riding by group members
Group identity	No	No	No	Yes: Preference for individual approach but if group savings is adopted, many preferred joining groups of their own choice
Leadership	Yes: Preference for individual ownership because of concerns about unaccountable group leaders	Yes: Preference for individual pay per service because of concerns about unaccountable group leaders	Yes: Preference for private individual stocking and selling because of concerns about unaccountable group leaders if activity is organised collectively	Yes: Preference for individual financing because of concerns about unaccountable leaders if activity is organised collectively
Group size	Yes: Preference for individual ownership of SMoTS to ensure accountability	Yes: Preference for individual pay per service for technicians because of concerns about lack of accountable group leaders if activity is organised collectively;	No	Yes: Preference for individual approach because of concerns about accountable group leaders if activity is organised collectively; concerns about free-riding by group members; if group saving

		concerns about free-riding by group members		is adopted there were preferences for “manageable” groups with 15-16 members
Possibility of effective sanctions	No	Yes: Preference to pay per service because if technicians were to be on a salary, households would have no control over the technicians	No	Yes: Preference for individual approach but if group saving is adopted many suggested that sanctions should be meted to leaders who misappropriate funds and group members who default

An overriding concern was that people lacked trust in other community members, leaders and/or technicians who would be employed by a governing body. This distrust was based largely on past experiences with free-riding and unaccountable leaders, including a recent experience that related directly to this project. The story of the CBO collecting money on “behalf” of the project demonstrates how efforts to foster sustainability of initiatives from outside may already be undermined before a project starts and develops a sound understanding of the context in which it operates. Based on this and other experiences, residents also had little confidence that a governing body or saving group could effectively impose sanctions to misappropriation of funds, poor leadership, defecting group members or technicians that might abuse a salaried position. The large size of the community, and the diversity on the island in terms of sub-communities, in- and out-migration, and residence patterns (towns versus rural areas) seemed to also complicate the achievement of collective solutions.

Lack of clarity of the collective benefit from malaria control

In interpreting the findings, it is relevant to note that respondents may have been thinking mainly about the benefits of house electrification (electric lights mostly) which accrue to individual households and are relatively cheaper to maintain when expressing preference towards an individual approach to sustainability. Research carried out earlier in the project revealed that residents were more excited about the electrification benefits (Oria, Alaii et al. 2015), raising the question about the overall perceived value of SMoTS and the recognition of the possible public good benefit therein. Research has shown that early evaluation results and perceived effectiveness of an intervention improves prospects for project continuation (Bossert 1990; Shediac-Rizkallah and Bone 1998) and may especially be relevant for the malaria control aspect of this project whose impact had not been analysed when this study was carried out.

Although SMoTS have proved effective in controlling malaria (Homan et. al., submitted), that fact alone may not assure sustainability as the problems and issues outlined above remain. Experiences elsewhere confirm the difficulty of maintaining technically effective vector control strategies. A review of the sustainability of community-based tsetse fly control programmes in Kenya revealed that although the approaches were associated with good reductions in tsetse fly populations and trypanosomosis prevalence during the first few years, a key concern was failure to build new traps and maintain traps. In Lambwe Valley, Kenya, it was reported that insufficient funds were available from the community to maintain the traps. In Busia, it was reported that most of the traps were destroyed by either rats or floods or people had believed the project was for the researchers thus abandoning maintenance after the research period (Barrett and Okali 1998). But while the tsetse fly traps were installed in bushes and therefore vulnerable to wild life interference and extreme weather conditions, SMoTS have been installed in people's houses and that fact alone may enhance a sense of ownership and responsibility. An additional advantage of SMoTS is the more immediate benefit of house electrification which may increase the desire by community members to sustain it.

Learning from embedded social science research in malaria control

This study was part and parcel of the project that was implemented on Rusinga Island hence part of project learning. While the project and CAB had initially considered organizing sustainability through an island-wide body, insights from social science research led to changes. After learning that an island-wide body may not work well, the project initially planned to organise savings groups according to metaclusters before learning that this was also not feasible as residents preferred to come together with people they trusted and not necessarily their immediate neighbours. Through adaptive learning in-built into the action research focus of this study, the project adopted the group savings approach by seeking to encourage integration of savings for SMoTS into existing table banking groups and encouraging formation of new groups by residents who were not members of existing saving group. This led to the involvement of the community champion for table banking as the coordinator for these successful scaling efforts.

Studies have indicated that community champions are pivotal in triggering and sustaining behavioural change (Israel, Krieger et al. 2006; Chambers 2009), including the organisation and formation of new groups with which people can identify (Chen, Chen et al. 1998). However, forming new organisations is rarely a straight-forward process, and it is idealistic to expect community members to form workable organisations without providing the opportunities for them to acquire skills in leadership, decision-making, conflict resolution, developing norms and procedures, and articulating shared visions (Murray and Dunn 1995; Poole 1997). The experience with the table banking groups also demonstrates that some residents in the community (notably women's groups) had already developed more or less effective solutions to some of the problems of trust, identity and leadership that the projects is struggling with in ensuring sustainability. It is important therefore that projects actively look for these and try to build on them.

As a governing body for sustaining SMoTS seems out of reach, a final recommendation to the CAB may be to explore the possibility of converting itself into an island-wide body composed of volunteers that does not receive monetary contributions from residents but which facilitates overarching issues that will not be addressed by individual households and table banking groups. These could include addressing emerging issues around stocking and retailing of spare parts, organising support for savings groups, contributing to conflict resolution, and overseeing availability and access to qualified technicians, etc.

The value of social dilemma theory

In this study, we started from the idea that the sustainability of SMoTS had features of a social dilemma situation. Therefore, we used social dilemma theory to explore and interpret residents' reasoning behind their preferences for organising components of sustainability. Although social dilemma theory provided useful concepts for categorizing and understanding the preferences of individual residents, the theory also has limitations which largely derive from its social psychological origin and individual focus. In this setting with concerns about misuse of funds, decision making also takes into account some structural collective and interactional issues such as politics and financial accountability. The very capacity of social groups to act in their collective interest depends on the quality of the formal institutions under which they reside (Adger 2010). This calls for a broadening of the theoretical framework to incorporate the more structural collective aspects, including political aspects.

Conclusion

This study suggests that residents of Rusinga Island leaned towards largely individualistic and privately organised solutions to maintenance of SMoTS that provide both benefits at the household level (electricity) and a public good (malaria control). This poses considerable challenges to organising the sustainability of this innovative malaria control strategy, which has features of a social dilemma situation. There seemed to be linkages between preferences towards organising various components of SMoTS sustainability and known hindrances to addressing social dilemmas such as lack of trust, large group size, weak group identity, and limitations in leadership and the impossibility of imposing effective sanctions. These conditions are not very conducive to realizing the initial sustainability options that were considered by the project, which included an island-wide governing body, collection of fees, and the formation of savings groups along the lines of project clusters.

Early planning for sustainability by the project focussed on working closely with the community through the CAB and transferring technical skills to locals. Activities directed at realizing sustainability components geared towards savings and the organisation of stocks and repairs started late, and activities directed at addressing important barriers such as saving and mobilising funds were not very popular because of residents' lack of trust in potential leaders and partners, based on previous experiences with working in groups. The community has, however, provided vital lessons on how to organise this strategy to improve success. This learning was possible because the project's action research approach that generated feedback about community views and experiences as part of a reflexive process of research and monitoring. In hindsight, the prospects for sustainability would have improved if planning and research for sustainability had started well before the launch of the project. This might simultaneously have prevented that a CBO could illegitimately collect money from residents in the name of the project before the project even started; an event which complicated later sustainability efforts and has haunted the project from the start.

To further improve prospects for sustainability, there is need for active attempts to improve trust in collective community undertakings. This may be done through showcasing successful group undertakings such as women's groups' table banking, allowing residents to voluntarily join SMoTS' savings groups of their choice or form new ones with people of their choice, and developing linkages with existing programmes and organisations in the community. Although social dilemma theory was useful to examine the sustainability of SMoTS because individual level factors were relevant in shaping preferences towards sustainability of SMoTS, in this setting with experiences of misuse of funds and unaccountability, preferences towards organising sustainability also took into account some structural collective and interactional issues such as politics and financial accountability. This calls for a broadening of the theoretical framework to incorporate the more structural collective aspects, including political aspects. These findings support the need for a deep understanding of the strengths and limitations of distinct forms of community-based planning interpreted within the broader socio-political contexts.

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CHAPTER 7

Discussion and conclusion

Introduction

This thesis is based on data from socio-behavioural research conducted as part of a multidisciplinary trial of an innovative way to control malaria. It analyses factors that influenced the design, implementation, adherence to proper deployment and sustainability of a proof of principle trial for the effectiveness of use solar-powered mosquito trapping systems for malaria control. Furthermore, the process of the complex intervention from the pre-intervention period to the roll-out of the systems and their integration in the community are presented, and factors relevant for the sustained use of the systems beyond the project-funded research phase are explored. In addition to the roll-out of SMoTS, the SolarMal project comprised a community engagement component and various disciplinary research components including Health and Demographic, Parasitology, Entomology and Sociology.

The SolarMal intervention incorporated a socio-behavioural participatory action research component from the pre-intervention to the end of the research phase (Hiscox, Maire et al. 2012; Oria, Hiscox et al. 2014). The participatory aspect was based on the recognition that community involvement was an essential component as the intervention required implementation at the household and community levels. The project therefore considered building community ownership for the intervention, and SMoTS in particular, essential for SolarMal to be successful and impact health behaviours. SolarMal was implemented as an additional strategy to the use of LLINs and prompt health care seeking and continued uptake of the existing malaria strategies was therefore a main focus for the social mobilisation campaign. Because SMoTS' end users required knowledge and skills to properly deploy and maintain the systems, the development and implementation phases took into consideration how knowledge and skills on deployment and maintenance could be effectively learned by end users, as this would make the likelihood of implementation success greater. The challenge for the project was to promote the intervention in a way that took into account the social and cultural context.

The central research question of this study was: How do Rusinga residents perceive SMoTS and malaria control and how did this influence the design, deployment, maintenance and sustainability of SMoTS? This research question encompassed various aspects of the SolarMal project including: design, re-design and roll-out of the SolarMal intervention, perceptions and outcomes of SMoTS and sustainability.

A summary of the research findings

Chapter 2 systematically documented and analysed how the mosquito trapping technology and related social contexts mutually shaped each other and how this mutual shaping impacted the design and re-design of the intervention. Our analysis focused on the design, re-design and piloting of the innovative approach to controlling malaria largely before its field implementation had started. During the pre-intervention year, various aspects of the intervention were re-designed ahead of the project roll-out. Changes to the technology design included removal of carbon dioxide from the blend, trap improvements and re-design of the electricity provision system. In order to gain and maintain the support of the community and organisations on the island, the project adapted its implementation strategies regarding who should represent the community in the project organisation team, who should receive SMoTS, and in which order the systems should be rolled out. This process involved not only the project team and the producers of the different components of SMoTS, but also included feedback from the residents of Rusinga Island. This process of incorporating feedback from a broad range of stakeholders utilized data from the entomological, technical and socio-behavioural researches as well as data from more broad engagements with the social environment of the study population and setting. The analysis demonstrates how system innovation theory helps to provide insights into how a promising malaria control intervention evolves and matures through an interaction between technical and social phenomena. This part of the study demonstrated that SolarMal was not only a technical innovation, but similar to other malaria strategies, required new social organisational arrangements to go with it. Innovation thus involves numerous simultaneous changes.

In chapter 3, this thesis investigated immediate community response to the innovation and the implications for ongoing implementation. The explorations found that the main benefit of SMoTS to study participants was house lighting and suggested that the main reason that people adhered to recommended behaviours for SMoTS deployment was to ensure uninterrupted lighting at night, rather than reducing mosquito biting or malaria risk. The characterisation of house lighting as the most important aspect of the intervention was reported throughout the research period including the pre-intervention, during the roll-out of SMoTS, after initial experiences with SMoTS, and after the completion of the installation of SMoTS. Electrification led to a number of immediate benefits including reduced expenditure on kerosene and telephone charging and conveniences (such as lit early mornings and late nights, increased study hours, etc.). The changes brought about by electric lighting provided conveniences which improved the welfare of residents. Some respondents also reported hearing fewer mosquito sounds when interviewed a few weeks after a SMoTS was installed in their house.

In chapter 5, this thesis assessed the effect of the SolarMal intervention on existing malaria strategies. As a malaria control strategy, SMoTS were installed in Rusinga to complement the existing use of LLINS and malaria care seeking. The findings described in chapter 5 indicate that overall, the SolarMal project did not induce a negative effect of the innovation on the uptake of existing malaria strategies. This is with the exception of findings during spot-checking carried out after a few weeks of use that some residents especially of beaches had temporarily abandoned LLINs use after receiving SMoTS (Chapter 3). The message about the complementariness of SMoTS as a malaria strategy was further stressed in educational messaging to encourage continued use of LLINs. The continuation of LLIN use and recommended malaria treatment seeking was likely contributed to by the social mobilisation component of the SolarMal intervention as well as the mass distribution of LLINs campaign, suggesting the need for a strong continuous demand generation exercise.

The number of respondents who reported that mosquito densities had reduced was much higher at the end of the research phase confirming that the recorded entomological changes (that showed SMoTS had proved effective in controlling mosquitoes) had also been experienced by residents.

On the question of maintenance, this thesis found that residents of Rusinga Island adequately maintained SMoTS during the research period (Chapter 3). They did this by fencing installed SMoTS for protection against domestic animals, cleaning the mosquito trap, deploying the system as recommended, and emptying the trap catch bag of trapped mosquitoes. This adherence to recommended behaviours for proper deployment was facilitated by the project provision of technical support during the research phase of the intervention. Households reported maintenance needs to the project and project technicians carried out repair and maintenance needs. The adherence to recommended deployment and maintenance of SMoTS was also facilitated by the social mobilisation, the benefit of house lighting, the disincentive of withdrawing neglected SMoTS, and perhaps reduction in mosquito density reported by residents, especially towards the end of the trial. However, explorations of sustainability of installed SMoTS beyond the research period did not portray a promising picture (Chapter 6). While residents were unanimous that they would like to continue enjoying the benefits of SMoTS (especially house electrification), it appeared that residents preferred largely individual approaches. Yet the individual approaches suggested by residents for sustaining SMoTS may be realistic for sustaining only the lighting component. This concurs with findings in Chapter 3 that the lighting aspect appeared to be a highly valued immediate benefit of SMoTS. Sustaining the mosquito control component, which is what would impact malaria, requires more resources (than the lighting component) and may be better facilitated by more collective undertakings by residents. Residents expressed concerns about working collectively with others that seemed to suggest that the situation had features of a social dilemma. These insights were used to address the situation and find more creative ways to motivate collective actions for change. During the annual project workshop in June 2015, CAB members shared their experiences from sustainability discussions with community members. Approaches that had seemed effective with each sustainability component were compiled to create an approach that had seemed effective. Such approaches included residents joining savings groups of their own choice or forming savings groups with people of their own choice (not necessarily with their neighbours or people who reside within their cluster); trained technicians telephone numbers shared with community to call for technical service and pay per demand; and a private business person identified to stock SMoTS parts in Mbita from where residents make purchases according to individual household needs. This new model was largely inspired by lessons from women’s savings groups and replaced the earlier project plan to work through a community-wide organisation.

Discussion and implication of the findings

The key lessons learnt from this thesis which may also provide ideas relevant for scaling-up SMoTS to other areas are discussed below.

a. Factors contributing to the effectiveness of a socio-technical intervention

The risk factors for malaria are part of a wider framework of determinants of health which can generally be grouped into biomedical factors, environmental factors and health behaviours. The SolarMal project therefore considered the activities that would bring about the outcomes identified in the programme objectives to control malaria with SMoTS. The project recognised from the onset that this would not only relate to SMoTS but also to social organisation within the study community as well as continued utilisation of existing malaria control strategies. Based on this recognition, SolarMal integrated technical and social mobilisation components into the intervention, in addition to the multi-disciplinary researches. Interventions with multiple components, such as SolarMal, are more complex and act synergistically to yield their intended benefits as each component contributes to the greater whole. Using a systems perspective can help disease control projects reach a more integral and sustainable approach in which the complex nature of the processes is supported (Naaldenberg, Vaandrager et al. 2009).

The SolarMal intervention targeted both biomedical factors and health behaviours with the mosquito traps targeting mosquito control, and the social mobilisation targeting health behaviours. Health behaviours at the community level were targeted by relying on improving selected background determinants of health including knowledge, perceptions and practices related to malaria control strategies. As a range of contextual factors that can be dynamic over time were expected to influence the effectiveness of the intervention, the implementation of the SolarMal project used many forms of existing knowledge and experiential learning to guide the design and implementation. These included efficacy evidence, knowledge of contextual factors and experiences from the local context (Chapter 2). Although the social mobilisation strategies were a critical component of the SolarMal intervention, they additionally contributed to the overall goal of malaria control by continuing to provide cues (reminders) in the effort to maintain/increase uptake of LLINs and malaria care seeking, alongside the innovation (Chapter 5).

The intensive social mobilisation that was part of SolarMal likely contributed to the success of the intervention (Homan et. al. 2015, submitted) by providing a reminder, motivation for, and social support for positive health perceptions and behaviour witnessed during the trial and documented at the end of the trial (Chapter 5). Additionally, the feedback from implementation research that was systematically used to guide the SolarMal implementation process and incorporate new learning likely played a key role in the effectiveness outcome. As others have noted, the estimation of the intervention impact on the outcome of interest alone will usually be insufficient (Kirkwood, Cousens et al. 1997; Power, Langhaug et al. 2004; Wagemakers, Vaandrager et al. 2010), particularly in interventions such as SolarMal, which require the cooperation of people to be effective. Designing and developing an appropriate intervention requires a carefully planned feasibility assessment incorporating both formative and process assessments, with particular attention to the context of the proposed intervention (Power, Langhaug et al. 2004). SolarMal process assessment findings such as on how to order the roll-out process, select the house to install in a homestead and constitute a board to represent the community led to changes to the delivery of the intervention and therefore generated critical lessons for enhancing effectiveness. This role for adaptive learning processes suggests that an exclusive reliance on mass distribution of SMoTS without prior formative research to inform the design, implementation and community mobilisation may prove ineffective.

The SolarMal intervention devised a strategy appropriate to the context to educate the community about the intervention and encourage active participation. Community engagement, mainly directly with participants at household and group levels but also through the CAB, was critical in building trust and fostering acceptance of this community-based intervention. Intersectoral action was also a key process of the project. Intersectoral action refers to engaging and coordinating actors from a variety of relevant sectors in the planning and implementation of interventions. For SolarMal, in addition to the trial community and researchers, other stakeholders included a broad range of actors including the ministries of health and energy, to other sectors such as education, religion and CBOs and NGOs working in the trial area. Because most of the social and environmental determinants of population health exist outside the sphere of influence of the health sector (Glanz, Rimer et al. 2002; Mabry, Olster et al. 2008; Pronk 2013), such intersectoral partnerships are key processes by which changes in the main determinants of health may be harnessed.

Reporting the effectiveness of the SolarMal intervention (to achieve intended outcomes) was largely limited to the effects of the technical component of the intervention. Whereas the main outcomes were on mosquito density and malaria prevalence, the various social organisational activities that went into the intervention are not reported to give the comprehensive picture of the intervention. The publication that presents the effectiveness of the intervention (Homan et. al. In Press), focuses on the health impact of the SMoTS, and renders invisible the process and social organisational components required for effectiveness. This provides only part of the story about the factors that contributed to the levels of effectiveness observed with the intervention. For the SolarMal intervention to be effective SMoTS had to capture sufficient numbers of mosquitoes to impact malaria transmission and households were mobilised to deploy the systems properly to achieve the objective of malaria control. Although other papers present data on these socio-organisational aspects, many readers may not read all the separate papers and may therefore interpret the conclusions of the effectiveness paper without the benefit of a comprehensive picture. Other studies have also reported a gap in information on how interventions bring about change in the social environment in favour of health (Anderson, Scrimshaw et al. 2003; Metzler, Amuyunzu-Nyamongo et al. 2007), and noted that a lot more happens through partnerships than is reported (Wagemakers, Vaandrager et al. 2010).

b. The benefits and challenges of combining malaria control with house lighting

One of the ways through which the SolarMal intervention was adapted to the local context was by recognising the energy resource constraints of the trial community and consequently adding a house lighting and telephone charging component to SMoTS (Chapter 2). The additional benefit of house lighting was commonly popular with trial participants, as access to electricity was initially low (Chapter 3). The perceived opportunity to access electrification created and most likely maintained interest in the project and was the most often mentioned benefit of the intervention. The main attraction was reportedly the economic gains from reduced purchases of kerosene for house lighting. Other reported benefits of house lighting were; they could see all everything in their houses, children could study in the night, women could continue their household chore into the night and start them at dawn, and no smoke causing the eyes to tear up. However, at the same time, the benefits of electrification also seemed to distract interest from focussing on the objective of malaria control. In the earlier phase of the roll-out of SMoTS, participants reported repair needs related to the electrification component more often than to the mosquito trap, despite breakdowns in the mosquito trap (Oria, Alaii et al. 2015). As this apparent neglect of the malaria control component happened during the research period even when there was social mobilisation, it can be expected to deteriorate further after the completion of the research period when there are no scheduled reminders to residents of the benefit of using the mosquito trap. During the research phase, the project also withdrew a system that was not adequately maintained and this provided a disincentive for neglecting installed systems. However, house lighting may not be a sufficient motivation to use and maintain the mosquito trap after the research phase as households can continue to enjoy the benefits of house lighting independently from the malaria control component.

The excitement about electric lighting was mainly related to the immediacy of its benefit, and demonstrates the challenge of promoting a relatively longer-term benefit such as malaria control. This overshadowing of the objective of malaria control raises a question of how effective (for malaria control) it is to combine malaria control with house electrification, which is bound to be hugely popular in such an area of previous low electrification uptake. This unbalanced relationship between malaria control and house lighting was further complicated by the fact that the longer term benefit of malaria control was being implemented in an area where malaria is endemic and people see malaria as a "normal" thing. There is no question, however, on the fact that attraction of house lighting contributed in a big way to make the trial possible by raising and maintaining interest in the intervention. The seeming double-edged sword role of house electrification raises the question of how the intervention process may have unfolded without the additional benefit of house lighting. The enthusiasm witnessed towards the project may have been lower but among those who would have embraced the project, the motivation probably would have been clearer and in line with the objective of malaria control.

Towards the end of the trial, respondents mentioned the free malaria testing and treatment offered by the project to participants who tested positive for malaria during the parasitological surveys as a benefit of the intervention (Chapter 5). Although this shows an appreciation of a benefit related to disease control, it may be more of an indication of concerns about the disease after it has occurred over enthusiasm about preventing the disease in the first place. Offering treatment free of charge at the recipient’s house also eliminated costs associated with treatment seeking including transport, time spent in queues, and money spent in hospital procedures and medicines. Seeking treatment outside the household also requires an investment in time mainly for women and is a distraction from other daily chores. In addition, no respondent mentioned the stoppage of free malaria testing and treatment as a concern related to closure of the project. This further reinforces the reasoning that disease prevention may not be a priority and that concerns about illness may only be prioritised once an illness strikes and points to the greater value placed on immediate rather than long-term benefits of public health interventions. This is consistent with other findings from resource-limited settings that have shown research activities are often equated with development projects whose aim is to improve the conditions in the community, rather than to collect information or test interventions (Molyneux, Wassenaar et al. 2005; Marsh, Kamuya et al. 2011; Vreeman, Kamaara et al. 2012; Mfutso-Bengo, Manda-Taylor et al. 2015). This often results in placing a greater emphasis on the tangible and often immediate research benefits including medical care, monetary and material incentives and medical diagnosis. These expectations for direct benefits should inform how researchers design and present research interventions to the community, while ensuring that interventions are feasible and sustainable in such resource-limited settings. While this recognition may have informed the inclusion of house lighting and telephone charging, the impact on research participants’ interest on malaria control may have been underestimated. In the end, the inclusion of the electrification component in the technical intervention played a key role in the high levels of acceptability and maintenance of the system. In addition, repair of damaged SMoTS was paid for and carried out by the project. However, after the research phase has ended, residents may focus on sustaining the electrification component at the expense of the mosquito trap. This is especially likely to be the case when faced with limited funds for maintenance and sustainability and having to prioritise one component over the other. However, even aside from financial limitations, observations during the research period revealed some research participants failed to fence, clean, or report malfunctions of the mosquito trap even though none of these activities cost them any money of huge investments in time (Chapter 3). Although including an electrification component was useful to test the proof of principle for effectiveness of malaria control, the benefits of house lighting and telephone charging do not seem to have a clear benefit towards malaria control in the absence of a dedicated social mobilisation effort. Electrification will, however, continue to provide socio-economic benefits associated with house lighting and telephone charging.

c. The continuous process of customising the innovation to the local context

A key component of the SolarMal intervention was social science action research. It provided a very effective approach to support mechanisms for an iterative, reflective, and evaluative approach that enabled on-going learning and adaptation as well as identifying and learning from emergent ideas and strategies. Insights from social science research revealed some tensions regarding the approach to community engagement during the earlier stages of the intervention. The project acted on the feedback and restructured the strategy to reflect the critical role of legitimacy and shared interests among project partners (Chapter 2).

During the implementation of the SolarMal intervention, in addition to studying outcomes of the intervention, social science research was employed to gather information on the implementation process especially to inform learning and adaptation. Although many projects usually begin documenting the intervention process from the project implementation phase, as this study showed, there were opportunities to customise the innovation to the intervention context as early as during the design phase (Chapter 2). Incorporating research into the implementation phase also contributes important information for testing the transferability of a successful demonstration programme (Sim and Mackie 2008), and for developing a clearer understanding of the determinants of a successful roll-out (Simmons and Shiffman 2007). As the SolarMal intervention incorporated a participatory action research component, it enabled incorporating contextual research findings into the implementation process thus providing on-going opportunities to customise the intervention to the context. The aims of the participatory action research were achieved through a cyclical process of exploration, knowledge construction, and action at different moments throughout the research phase. Social science research also helped to define the community engagement strategy best suited to the trial setting. In addition to exploratory research, monitoring of the design and implementation process was accompanied by timely feedback to the process to enable timely action on the feedback (Chapters 2, 3 & 6).

This research has shown that participatory action research provides a good opportunity to customise an intervention to the local context. The role of action research has also been noted by other researchers (Williams, Jones et al. 2002; Madon, Hofman et al. 2007; McIntyre 2007). Information gathered during formative and piloting activities, which tested the feasibility of delivering the intervention and acceptability to end users, was used to customise the SMoTS and study design. The research also helped project implementers to better understand the complex array of contextual factors that played a role in the success of the intervention. During this intervention, researchers worked with the community to select the strongest possible research methods while balancing scientific rigour with responsiveness to the community e.g. the opinion and wishes expressed by the community were continuously evaluated and incorporated, whenever possible (Chapter 2). In addition to informing the intervention process, the process questions asked during the intervention also contributed to revealing reasons for the intervention working and why e.g. the special arrangements that involved both tenants and house owners in rental houses, the effect of migration on use of traps, the critical role of women in caring for and sustaining SMoTS, the interaction between SMoTS and existing malaria strategies and the unique role of house lighting in the intervention (Chapters 3, 4, 5 & 6). This understanding was important not only to improve the intervention but also to extrapolate the impact the intervention may have in other settings as currently designed or with some alterations.

Based on the recognition of the multi-stakeholder nature of malaria control, the SolarMal intervention employed participatory approaches to facilitate the engendering of shared understanding and commitment, and the need to gain access to the wide range of contextual knowledge and experience needed for decision making. This initially targeted community partners but later on expanded to include representatives of the county government. This inclusive approach enabled mapping constraints, having the flexibility to redesign, learn-do cycling, and being able to call in a more complete set of stakeholders. Using available data and experimenting underlies many successful intervention approaches and have been identified as more likely to lead to success (Peters 2009), but they are not always applied during an actual intervention.

Although the contributions to action were significant as presented above, there were also some challenges to carrying out action research within the multidisciplinary project. Especially during the early days; priorities, assumptions and approaches to communication varied among research team members. There was also tension between looking at communication from a linear model (with an emphasis on sending/teaching aimed at changing the community) and as an interactive model (also using communication for listening aimed at adapting the project). Addressing these challenges and creating an environment in which team members could express their points of view and conduct open and inclusive discussions took time. For a multidisciplinary team to achieve an enabling environment to conduct such a complex intervention, members need to be open to an iterative process of on-going learning, adaptation and the creativity to deal with unexpected situations and findings. Divergent thinking should be encouraged as it creates room for reconciling different approaches and opinions that are at the centre of knowledge production (Viseu 2015). But while achieving this harmony is an essential basis for conducting productive multi-disciplinary research, experience sometimes shows that the slow process that such an approach entails and its benefits are not always valued (Brown, Deletic et al. 2015; Bagnol, Clarke et al. 2016).

d. Lessons for scaling-up from prospects for sustaining SMoTS

As is often the case with a proof of principle trial, the initial focus of the SolarMal project was on how to establish accurate measures to establish whether or not SMoTS worked. Project planning and action was therefore geared towards ensuring accurate entomological and epidemiological measures (the efficacy component). Key approaches in this were; skills to ensure adherence, technical expertise to maintain SMoTS in working condition, and, the creation of a CAB. Community workshops and listening surveys during installations were used to ensure households had skills to deploy SMoTS appropriately. Another early focus was on equipping a few community members distributed across metaclusters with technical skills to install and repair SMoTS. Training community members as solar technicians was meant to ensure technical skills to repair and install systems during and after the research phase, thereby also contributing to the sustainability plan. The third priority during the life of the project was to create a CAB to provide a link between the community and project in brainstorming ideas and decision-making.

While all three approaches also contributed to sustainability planning, an additional process of stakeholder mapping and exploration of options for sustainability started much later into the life of project. This delay had some immediate negative implications for later efforts to explore sustainability plans (Chapter 6). The main factor in the sustainability related to the implication of the big shift at the end of the research phase when financial responsibility for maintenance and replacement of SMoTS parts would shift to the individual households.

Social research revealed that while some aspects of the sustainability plan for SolarMal could be optimised at the individual household level, others (especially those relevant for the mosquito control component) required collective action among residents to realise the objectives. Community members, however, generally preferred largely individual approaches to organising sustainability. Their preferences were mainly informed by concerns relating to trust about the accountability and cooperation of group leaders and members in potential collective undertakings. Residents mainly attribute the pessimism towards collective undertakings to previous experiences within the community, which included an experience with the current intervention (Chapter 6). There is a growing consensus that conditions for sustainability should be considered early on in the process of introducing an innovation (Pluye, Potvin et al. 2004; Pluye, Potvin et al. 2005). But for a proof of principle trial such as SolarMal, the priority was to prove effectiveness before sustainability strategies could be adequately explored.

The finding that structural factors relevant to the broader community informed individual decision making towards organising collectively for sustainability hints at the limitations of focussing exclusively at the individual level in researching interventions that require behaviour change. Interventions are likely to produce sustainable health gain when they integrate change to the organisational, community and institutional conditions that make up the social context because individual action occurs within and is maintained by a social context. The social research of SolarMal was informed by theoretical frameworks ranging from the individual (Health Belief Model in Chapter 3 & Experience as Value in Chapter 4), to a hybrid of individual and collective (Social Dilemma in Chapter 6), and a collective-level theory (System Innovation in Chapter 2). Using theories encompassing the individual and collective levels enables this thesis to have a comprehensive view of the socio-behavioural factors relevant to the intervention at both levels.

The research found that trial participants often deployed SMoTS properly and maintained them well during the research phase. Project reminders to the community, including through the CAB and field staff, and disincentives of withdrawing misused and neglected systems may have played a role in the motivation towards proper deployment and maintenance of SMoTS. As the social mobilisation and project-initiated reminders ended with the research phase of the project, an alternative way to ensure continued motivation and support towards maintenance and continued use of SMoTS may be needed, especially for the mosquito trap. One potential way to encourage adherence to use and maintenance of SMoTS could be through the already forged links with the county health, energy and malaria control interests at both the ministries of health and energy. Other partnerships that could play a role in providing motivation towards continued use of mosquito traps could be links with healthcare workers at facilities on the island and its vicinity, CBOs, and NGOs that serve the trial community. Community health workers could provide support services in homes to encourage maintenance of SMoTS. Healthcare providers could remind clients about the role of SMoTS in malaria control, as they currently do for LLINs. Such collaborations would act to broaden the base of support for the intervention.

The SolarMal intervention proved effective in controlling malaria-transmitting mosquitoes (Homan et. al., In Press), under the conditions in which it was carried out on Rusinga Island. The approach may therefore be considered for a scale-up and possible inclusion in the malaria strategy. The aim of scaling-up public health innovations is to improve the coverage and equitable access to the innovation and its intended benefits (Mangham and Hanson 2010). Scaling-up involves processes to introduce innovations with demonstrated effectiveness through a programme delivery structure. The programme to scale up the intervention to other trial settings could be improved by recognising the different components that were part of the intervention and that contributed to making it effective in the current trial setting. The scale-up will therefore need to be of SMoTS, the process and the social organisation that contributed to the effectiveness of the trial. Ensuring broad uptake and adherence to SMoTS will require community mobilisation, service integration, and economic intervention such as savings schemes to ensure households have means to adequately repair and replace worn out parts of the systems. Community participation and intersectoral collaboration have been shown to be key moderators for facilitating change in the social environment (Wagemakers, Vaandrager et al. 2010).

One factor that national malaria programmes could consider when including SMoTS in the package of malaria strategies is that SMoTS heavily rely on adherence to proper deployment by households; the mosquito trap must be in good working condition, the catch bag must regularly be emptied of trapped mosquitoes, electricity supply must be available, and the odour strips must be replaced as recommended so as to trap mosquitoes effectively. Even if these roles could be assigned to someone else, the best way to ensure all these activities are undertaken is if the household members are primarily responsible for them as they are routine activities carried out on the installed SMoTS. The main programme cost for scale-up will probably be on building human capacity at both the individual household and community levels, which requires action at both the household and community levels. This process will involve prioritising investment in continuous training of technical skills for installation and repairs and facilitation skills to transfer maintenance skills to households. This research showed the costs of scale-up and maintenance can partially be covered by the community but the implication for this cost-sharing must take into account community ownership and sustainability (Chapter 6). The other critical factor in the operation of SMoTS is availability of electricity to power traps. The role of electricity is especially critical as the burden of malaria is higher in rural areas which have the lowest levels of electrification. This requirement for electrification necessitates some integration of energy and health sectors.

Another factor for a scale-up programme to consider would be that SMoTS, perhaps similar to IRS, requires a more complex and costly delivery mechanism compared to LLINs as it requires the installation of a number of components. Electricity is also a central component of SMoTS. This will require extra financial, human and infrastructural resources to ensure high coverage adequate for malaria control. Another consideration that relates to responsibilities at the household level is about who benefits most from malaria control and who would make energy (electricity-related) decisions in the family when the house is electrified. In Rusinga Island, women were responsible for house lighting (even though the resources sometimes came from the men) when kerosene-fuelled lamps were used prior to house electrification. However, with the installation of SMoTS women continued to ensure cleaning and day-to-day maintenance while the man "owned" the SMoTS. As has been the case with other malaria control strategies deployed at the household level, it will be necessary to explore household dynamics around electricity use to inform a scale-up strategy. For the SolarMal project, the central role of women has been clear in not only daily caring for installed systems but also enthusiasm and initiative towards a community-driven sustainability mechanism for SMoTS.

e. Recommendations for projects, research and policy

The results presented in this thesis provide a basis for a follow-up study in the trial site at least 1-2 years after project closeout. This further implementation science would contribute to generating programme lessons and would mainly assess how households and the community keep up with repairs and maintenance of SMoTS. This could involve evaluating the arrangements for organising the various components of SMoTS and the roles of the community, the business partner and project in these arrangements. Given the uniqueness of combining malaria control with house electrification, it may also be informative to evaluate how the malaria control and electrification components of SolarMal interact after the research phase has ended and households maintain SMoTS on their own or how community members work collectively to organise sustainability.

Future studies could also explore ways to ensure a scale-up is successful in terms of coverage, adherence, and maintenance of SMoTS in real life conditions when there is no donor support for maintenance of installed systems, purchase of spare parts, and supply of odour baits. The observation that the interactions with the SolarMal intervention did not interfere with residents' perceptions and practices related to LLINs and malaria care-seeking reported at the end of the SolarMal intervention, just like the generally good adherence and maintenance of SMoTS, was likely contributed to by the social mobilisation campaign and perhaps the awareness campaign accompanying mass net distribution in August 2014. However, behaviour changes slowly over time and starts with small steps that accumulate to make large differences and immediate gains aren't always sustained. Furthermore, change can only be sustained if incorporated into daily lives and social relationships that support the new routines (Rotheram-Borus, Swendeman et al. 2009), highlighting the role of sustained efforts. The effect of the awareness campaigns may need to be tracked in the medium to longer term to generate more conclusive evidence of their contribution to behaviour change.

Based on the evidence from the social science research component of SolarMal, another recommendation for scale-up is that SMoTS may need to be promoted together with the existing malaria strategies so as to ensure continued use of LLINs and prompt malaria care seeking. This would mean that SMoTS become one approach embedded within the larger malaria control strategy. The main advantage of SMoTS and hence the value it adds to the malaria strategy is that host-seeking mosquitoes are trapped and killed without the use of insecticides, exempting SMoTS from the threat of insecticide resistance (Hiscox, Maire et al. 2012) and Homan et. al., 2015 submitted. Additionally, as SMoTS is designed to target both indoor and outdoor biting malaria vectors prior to house entry (Hiscox, Maire et al. 2012), it would be a complementary method to LLINs and IRS that primarily target indoor resting mosquitoes. Entomological surveys carried out at 6-8 week intervals from September 2012 until study end revealed that SMoTS are most effective at trapping *An. funestus* (Homan et. al 2015, submitted) and this information could be used to target SMoTS to areas where this species significantly contributes to malaria transmission. This integration would also provide opportunities for continuous reminders to end users and perhaps motivation towards using all the components of the strategy. Future research on best approaches for integrating SMoTS into the malaria strategy could provide useful insights into how to structure and implement the process.

A final policy recommendation for policy is for the integration of health and electrification policy. This will provide a firm foundation for the intersectoral collaboration required to provide support for projects that seek to address the wider range of the social determinants of health and general well-being. Such integration will also contribute to addressing the impact of respiratory diseases.

Conclusion

This thesis shows that SolarMal was not only a technical innovation, but required new social organisational arrangements to go with it. The intervention was a composite of which the technical component was one and focussing on it without the others may have negative implications for effectiveness. When viewed through a systems lens, it is evident that the power of an intervention comes not from where it is targeted, but rather how it works to create change within the system. Innovation thus involves numerous simultaneous changes, and its effects cannot be usefully reduced and/or attributed to a single component. By implication, the scaling up of SMoTS will also require scaling-up the intervention process and social organisation that played a role in its effectiveness in the trial setting.

This thesis also demonstrates the importance of flexibility and continuous learning in multiple spheres in a complex multidisciplinary innovative intervention to control malaria. The key addition to the knowledge base for similar public health programs is that intervention design is not a one-off occurrence and neither is implementation a linear process. Rather, customising the SolarMal intervention to the trial context involved continuous learning and action especially during design, implementation and further adaptation of the intervention idea. Social science research was a core component in this process and the process required not only integrating social inquiry into the design, but also into planning, implementation, and monitoring. This contributed to ensuring that flexibility and adaptability to the local realities were built into the SolarMal intervention and contributed to the success of the intervention.

Rather than project management, persons involved in rolling-out innovations should perhaps focus on adaptive and proactive management and on facilitating change. While managing emphasises control and certainty, an innovation process requires flexibility to allow continuous adaptations which characterise the process. This greater requirement for facilitation skills results from a shift in orientation to the orchestration of other actors – in an attempt to let them find their ‘space and place’ in the process, and perhaps to make them coalesce around a common agenda or understanding of the priorities. In practice, this means keeping attuned to perceiving signals, analysing feedback loops and using those signals to mitigate what is not going well or amplify what is going well.

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Thesis summary

Chapter 1 presents the background information relevant to the subject matter and methods of this thesis. These include the application of social and behavioural sciences in malaria control, the SolarMal project and malaria in Kenya. It also presents the research objective, question and design that informed this thesis.

Chapter 2 systematically documented and analysed how the mosquito trapping technology and related social contexts mutually shaped each other and how this mutual shaping impacted the design and re-design of the intervention. Our analysis focused on the design, re-design and piloting of the innovative approach to controlling malaria largely before its field implementation had started. During the pre-intervention year, various aspects of the intervention were re-designed ahead of the project roll-out. Changes to the technology design included removal of carbon dioxide from the blend, trap improvements and re-design of the electricity provision system. In order to gain and maintain the support of the community and organisations on the island, the project adapted its implementation strategies regarding who should represent the community in the project organisation team, who should receive solar-powered mosquito trapping systems (SMoTS), and in which order the systems should be rolled out. This process involved not only the project team and the producers of the different components of SMoTS, but also included feedback from the residents of Rusinga Island. This process of incorporating feedback from a broad range of stakeholders utilized data from the entomological, technical and socio-behavioural researches as well as data from more broad engagements with the social environment of the study population and setting. The analysis demonstrates how system innovation theory helps to provide insights into how a promising malaria control intervention evolves and matures through an interaction between technical and social phenomena. This part of the study demonstrated that SolarMal was not only a technical innovation, but similar to other malaria strategies, required new social organisational arrangements to go with it.

In chapter 3, this thesis investigated immediate community response to the innovation and the implications for ongoing implementation and supportive community communication outreach. The explorations found that the main benefit of SMoTS to study participants was house lighting and suggested that the main reason that people adhered to recommended behaviours for SMoTS deployment was to ensure uninterrupted lighting at night, rather than reducing mosquito biting or malaria risk. Electrification led to a number of immediate benefits including reduced expenditure on kerosene and telephone charging and conveniences (such as lit early mornings and late nights, increased study hours, etc.). The changes brought about by electric lighting provided conveniences which improved the welfare of residents. Some respondents also reported hearing fewer mosquito sounds when interviewed a few weeks after a SMoTS was installed in their house. On the question of maintenance, we found that residents of Rusinga Island adequately maintained SMoTS. Households also reported maintenance needs to the project and project technicians carried out repair and maintenance needs.

Chapter 4 documented the perceived impact of SMoTs on family dynamics, social and economic status, and the community as a whole. The findings suggest that even when the use of energy is restricted, electricity can enhance the value of life. Although data on malaria prevention was yet to be fully collected and analysed, there was evidence of enhanced socio-economic and emotional well-being of study participants which may enhance the desire to sustain the intervention. In the end, this may be a double-edged intervention that delivers health benefits and contributes to improved welfare. The utility, social significance and emotional benefits experienced with the lighting component of SMoTS may create the desire to sustain the intervention. However, the motivation to sustain the whole SMoTS will also depend on the results of the entomological and parasitological components of this intervention.

Chapter 5 evaluated the knowledge, perceptions and practices related to malaria control before and after the roll-out of solar-powered mosquito trapping systems. As a malaria control strategy, SMoTS were installed in Rusinga to complement the existing use of long-lasting insecticidal nets (LLINS) and prompt malaria care seeking. The message about the complementariness of SMoTS as a malaria strategy was further stressed during social mobilisation to encourage continued use of LLINs and prompt malaria care seeking. The findings suggest that overall, the SolarMal project did not induce a negative effect of the innovation on the uptake of existing malaria strategies. The continuation of LLIN use and recommended malaria treatment seeking was likely contributed to by the social mobilisation component of the SolarMal intervention as well as a mass distribution of LLINs campaign, suggesting the need for a strong continuous demand generation exercise. The number of respondents who reported that mosquito densities had reduced was much higher at the end of the research phase confirming that the recorded entomological changes (that showed SMoTS had proved effective in controlling mosquitoes) had also been experienced by residents.

Chapter 6 investigated whether the community preferred individual or cooperative solutions for organising the sustainability components of SMoTS, and whether and how known social dilemma factors could be recognised in the reasoning of actors. The findings of the explorations of sustainability of installed SMoTS beyond the research period did not portray a promising picture. While residents were unanimous that they would like to continue enjoying the benefits of SMoTS (especially house electrification), it appeared that residents preferred largely individual approaches. Yet the individual approaches suggested by residents for sustaining SMoTS may be realistic for sustaining only the lighting component. Sustaining the mosquito control component, which is what would impact malaria, requires more resources (than the lighting component) and may be better facilitated by more collective undertakings by residents. Residents expressed concerns about working collectively with others that seemed to suggest that the situation had features of a social dilemma.

Chapter 7 synthesises the main findings. Subsequently, this results in the overall conclusions of the thesis that are discussed within the broader debates on research and policy. This thesis shows that SolarMal was not only a technical innovation, but required new social organisational arrangements to go with it. The intervention was a composite of which the technical component was one and focussing on it without the others may have negative implications for effectiveness. By implication, the scaling up of SMoTS will also require scaling-up the intervention process and social organisation that played a role in its effectiveness in the trial setting. This thesis also demonstrates the importance of flexibility and continuous learning in multiple spheres in a complex multidisciplinary innovative intervention to control malaria. The key addition to the knowledge base for similar public health programs is that intervention design is not a one-off occurrence and neither is implementation a linear process. Social science research was a core component in this process and the process required not only integrating social inquiry into the design, but also into planning, implementation, and monitoring. This contributed to ensuring that flexibility and adaptability to the local realities were built into the SolarMal intervention and contributed to the success of the intervention. Rather than project management, persons involved in rolling-out innovations should perhaps focus on adaptive and proactive management and on facilitating change. While managing emphasises control and certainty, an innovation process requires flexibility to allow continuous adaptations which characterise the process. In practice, this means keeping attuned to perceiving signals, analysing feedback loops and using those signals to mitigate what is not going well or amplify what is going well.

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Thank you!

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31 August 2016

About the author

Prisca Adhiambo Oria was born on 11 September 1979, in Mombasa, Kenya to Mr. Lazarus Maurice Oria and Ms. Gaudencia Florence Anyango Lumbe. After graduating from Ng'iya Girls' High School in 1998, she joined University of Nairobi where she obtained a Bachelor of Arts degree in Anthropology in March 2005. In December 2009 she graduated from the same university with a Master of Arts degree in Communication Studies.

In May 2007, Prisca joined the Kenya Medical Research Institute/Centres for Disease Control (KEMRI/CDC) Research and Public Health collaboration in Nairobi, Kenya as an Assistant Research Officer. In this role, she provided technical support towards researches on management of diarrheal illnesses in children and perceptions of avian influenza. In September 2010, she was promoted to the position of Research Officer. In this role, she contributed to researches and response to seasonal and the 2009 H1N1 pandemic influenza. She also presented and published research papers on caretakers' management of childhood diarrheal illness, healthcare workers' perceptions of pandemic influenza vaccine, and mothers perceptions of childhood seasonal influenza vaccine.

In February 2012, Prisca was awarded a scholarship by University Fund Wageningen to pursue PhD studies at Wageningen University, the Netherlands. She enrolled for the PhD studies in April 2012, based at the Knowledge, Technology and Innovation Group. She conducted fieldwork for her PhD in Rusinga Island while based at the International Centre of Insect Physiology and Ecology (icipe), Kenya.

List of publications

1. **Prisca A Oria**, Jane Alaii, Margaret Ayugi, Willem Takken, and Cees Leeuwis. *Combining malaria control with house electrification: adherence to recommended behaviours for proper deployment of solar-powered mosquito trapping systems, Rusinga Island, western Kenya.* Tropical Medicine and International Health. Volume 20, Issue 8, August 2015, Pages 1048-1056.

2. **Prisca A Oria,** Jane Alaii, Margaret Ayugi, Wolfgang R Mukabana, Willem Takken, Cees Leeuwis. *Tracking the mutual shaping of the technical and social dimensions of solar-powered mosquito trapping systems (SMoTS) for malaria control on Rusinga Island, western Kenya.* Parasites and Vectors. 2014, 7(1):523.

3. Henry Njuguna, Jamal Ahmed, **Prisca A Oria**, Gideon Emukule, Geoffrey Arunga, John Williamson, Abigael Kosgey, Philip Muthoka, Joshua A Mott, Robert F Breiman, Mark A Katz. *Uptake and effectiveness of monovalent influenza A (H1N1) pandemic 2009 vaccine among healthcare workers in Kenya, 2010.* Vaccine. Volume 31, Issue 41, 23 September 2013, Pages 4662–4667.

4. **Prisca A Oria**, Geoffrey Arunga, Emmaculate Lebo, Joshua W Wong, Gideon Emukule, Nancy Otieno, Philip Muthoka, David Mutonga, Robert F Breiman, Mark A Katz. *Assessing Parents' Knowledge and Attitudes towards Seasonal Influenza Vaccination of Children Prior to and following a Seasonal Influenza Vaccination Effectiveness Study in Urban and Rural Kenya, 2010-2011.* BMC Public Health. 2013, 13: 391.

5. Alexandra Hiscox**,** Nicolas Maire**,** Ibrahim Kiche**,** Mariabeth Silkey**,** Tobias Homan**, Prisca Oria,** Collins Mweresa**,** Bruno Otieno**,** Margaret Ayugi**,** Teun Bousema**,** Patrick Sawa**,** Jane Alaii**,** Thomas Smith**,** Cees Leeuwis**,** Wolfgang R Mukabana and Willem Takken**.** *The SolarMal Project: innovative mosquito trapping technology for malaria control. Malaria Journal* 2012, 11(Suppl 1):O45

6. Lauren S Blum, **Prisca A Oria**, Christine K Olson, Robert F Breiman, and Pavani K Ram. *Examining the Use of Oral Rehydration Salts and Other Oral Rehydration Therapy for Childhood Diarrhea in Kenya.* American Journal of Tropical Medicine & Hygiene. Volume 85, Issue 6, 1 Dec 2011

7. Christine K Olson, Lauren S Blum, Kinnery N Patel, **Prisca A Oria**, Daniel R Feikin, Kayla F Laserson, Annah W Wamae, Alfred V Bartlett, Robert F Breiman, and Pavani K Ram. *Community Case Management of Childhood Diarrhea in a Setting with declining use of Oral Rehydration Therapy: Findings from Cross-sectional Studies among Primary Household Caregivers, Kenya, 2007.* American Journal of Tropical Medicine & Hygiene. Volume 85, Issue 6, 1 Dec 2011

8. **Prisca A Oria**, Wycliffe Matini, Ian Nelligan, Gideon Emukule, Martha Scherzer, Beryl Oyier, Hezron N Ochieng', Laura Hooper, Anne Kanyuga, Phillip Muthoka, Kathleen F Morales, Charles Nzioka, Robert F Breiman, and Mark A Katz. *Are Kenyan Healthcare Workers Willing to Receive the Pandemic Influenza Vaccine? Results from a Cross-sectional Survey of Healthcare Workers in Kenya about Knowledge, Attitudes and Practices about Infection with and Vaccination against 2009 Pandemic Influenza A (H1N1), 2010.* Vaccine. Volume 29, Issue 19, 27 April 2011, Pages 3617-3622.

9. Alexandra Hiscox, Tobias Homan, Collins K Mweresa, Nicolas Maire, Aurelio Di Pasquale, Daniel Masiga, **Prisca A Oria,** Jane Alaii, Cees Leeuwis, Wolfgang R. Mukabana, Willem Takkem, and Thomas A. Smith. *Mass mosquito trapping for malaria control in western Kenya: study protocol for a stepped wedge cluster-randomised trial.* In press: Trials.

10. Tobias Homan, Alexandra Hiscox, Collins K. Mweresa, Daniel Masiga, Wolfgang R. Mukabana, **Prisca A. Oria,** Nicolas Maire, Aurelio Di Pasquale, Mariabeth Silkey, Jane Alaii, Teun Bousema, Cees Leeuwis, Thomas A. Smith, and Willem Takken. *Stepped wedge cluster-randomised trial of the impact of mass mosquito trapping on malaria (SolarMal).* In press: Lancet.

11. **Prisca A. Oria,** Michiel Wijnands, Jane Alaii, and Cees Leeuwis. *Options for Sustaining Solar-Powered Mosquito Trapping Systems (SMoTS) on Rusinga Island, western Kenya: a Social Dilemma Analysis.* Submitted for Publication. **(Chapter 6 in this thesis)**

Prisca Adhiambo Oria

Wageningen School of Social Sciences (WASS)

Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Writing PhD Research Proposal	WASS	2012	6
Introduction to Communication and Innovation Studies, CPT 23804	WUR	2012	4
Advanced Communication Science, CPT 33806	WUR	2012	6
Research Methodology: From Topic to Proposal	WASS	2012	4
'SolarMal Social Sciences: Progress, Results and Plans' *'SolarMal Social Sciences update 2013-2014'* *'SolarMal Social Sciences Results and Implications'*	SolarMal Annual Scientific Workshops.Icipe/KTI	2013 2014 2015	1.5
Science for Impact: enabling optimal conditions for social and technical innovation	PE & RC	2014	0.3
B) General research related competences			
WASS Introduction course	WASS	2012	1
Techniques for Writing and Presenting Scientific Papers	WGS	2014	1.2
'*Weaving together the technical, social and ecological perspectives in an innovative malaria control project'*	3rd Global Symposium in Health Systems Research	2014	1

'Malaria control with solar-powered mosquito trapping systems: socio-economic and perceived health benefits of electric lighting in Rusinga Island, western Kenya'	64th American Society of Tropical Medicine and Hygiene Conference	2015	1
Presenting at and attending bi-weekly KTI seminars	KTI	2013, 2014 & 2016	1.5
C) Career related competences/personal development			
Writing Grant Proposals	Wageningen in'to Languages	2015-2016	2
Co-supervising 2 masters students	WUR & University of Nairobi	2013-2015	2
Interpersonal Communication for PhD students	WGS	2012	0.6
Total			**32.1**

*One credit according to ECTS is on average equivalent to 28 hours of study load