Let there be (artificial) light, and lo and behold malaria returned

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Abstract

Electrification is currently a development priority for many countries in Sub-Saharan Africa that are facing multiple challenges that include the reduction of morbidity and mortality caused by malaria. We analyze in a large sample of Ugandan rural household (n=5,555) the relation between electrification and malaria incidence. Our findings suggest that households that use electricity are more likely to experience malaria once we control for variables related to households' welfare and geographical location. Our interpretation of the finding is that electric light attracts malaria vectors and lifestyle changes associated with outdoor lighting increase humans' exposure to the vectors. Our conclusions suggest that the electrification process in Uganda should be complemented by anti-malaria strategies at the household level (i.e. the delivery of insecticide treated bed nets). This is the first study highlighting the nexus between electricity and malaria using household level data representative at the country level; our findings suggest that similar studies should be carried out in other areas where electrification is implemented and where malaria is still endemic.

JEL Codes: electrification; malaria; Uganda; household survey data.

Section 1. Introduction

Rural electrification is considered a necessary precondition for improving many aspects of households' life and is a development priority (e.g. World Bank, 2008).[1] Artificial light brings a number of benefits ranging from extended hours for businesses, which in turn boosts income opportunities of the household, to increased study time for children, and from greater security in the village, to saving time for collecting fuel-wood. Electricity allows household's members to use television and radio, giving household's member the chance of following news, movies, cartoons and soap operas, which have a number of impacts on the empowerment of women (Chong and La Ferrara, 2009). Other modern fuels, most notably Liquid Propane Gas (LPG) are cleaner sources of energy for cooking purposes as opposed to the use of fire-wood and charcoal and the consequences of decreased indoor air pollution are remarkable for both children and adults' health and translate into a sensible decrease in the incidence of respiratory diseases and eye infections (e.g. Gurung et al., 2011; Torres-Duque et al., 2007). Notwithstanding these known benefits of electrification and fossil fuels at the household level, the full impact of these sources of energy are still being investigated

[1] See http://www.minbuza.nl/en/Key_Topics/Development_Cooperation for rural electrification projects in Africa and Asia. See http://www.fres.nl/ for projects undergoing in South Africa, Mali and Burkina Faso. See http://www.lightingafrica.org/ for the 'Lighting Africa' project. The project's longer-term goal is to eliminate market barriers for the private sector and to reach 250 million people in Africa without electricity, and using fuel based lighting, by 2030.

and it is difficult to draw solid conclusions across countries and scales (e.g. World Bank, 2008; Bruce et. al., 2002).

While we acknowledge beforehand the overall positive impacts of the use of electricity for lighting and LPG for indoor cooking, our research focuses on some little-studied (potential) negative impacts by exploring the link between the use of these energy sources and the incidence of malaria at the household level.

In this empirical study we look at the case of Uganda where the incidence of malaria is very high with 12 million suspected malaria cases and 6,296 malaria attributed deaths in 2009 –in a country with a total population of 33 million (WHO, 2011). Furthermore, recent statistics point to the fact that the number of malaria cases has been on the rise in the last decade (WHO, 2010). A the same time, Uganda is extensively investing in electrification as a way to foster growth and promote the startup of domestic businesses (Ministry of Energy and Mineral Development, 2002; Rural Electrification Agency, 2006; World Business Council for Sustainable Development, 2006). Still, the current electrification rate in Uganda is one of the lowest in the sub-Saharan countries with 9 percent of the household being connected to the grid or using solar panel (International Energy Agency, 2011) and also the penetration of LPG is rather limited especially in rural areas although there are ongoing projects to increase alternative energy sources (Doyle, 2002; Bizzarri, 2009).

Although the link between modern energy sources and malaria has not been thoroughly investigated, there have been researches focusing on some of the mechanisms potentially motivating this relationship. On one hand, artificial light is a powerful insect attractant (Barghini and de Medeiros, 2010) and both entomologists and epidemiologists have traditionally used light traps to capture insects (Mathenge et al., 2004; Shiff, 2008). On the other hand, artificial light is also a direct indicator of economic development, and lighted areas in night-time satellite picture coincide with areas of the world with higher levels of socio-economic development (Noor et. al., 2008). In turn, lifestyle changes associated with economic development can alter life styles, access to information, behavior in terms of prevention, etc. As an example, night lighting increases outdoor activities and hence exposure malaria vectors, but electricity can also increase access to mass media and to anti-malaria campaigns, which in turn can induce households to undertake preventive measures. Electricity and, on a similar note, LPG used for cooking purposes replaces biomass use and reduces indoor smoke –thus substantially improving indoor air quality. However, smoke can also function as an insect repellant and improved air quality can concur with increased density of malaria vectors. Here we just mentioned some of the channels that can link energy sources at the household level to the incidence of malaria; it appears that modern energy sources can have positive as well as negative effects and the issue of the overall effect is an empirical issue. This study provides the first empirical analysis of the linkage between modern fuels use and malaria incidence at the household level.

The idea of this study is not to discourage rural electrification projects or to diminish the importance that artificial light has for the households. The purpose is assessing if electricity, among many presumed and demonstrated benefits, has the undesired effect of increasing the incidence of malaria. If that is the case policy makers, energy specialists, medical doctors and epidemiologist should collaborate to couple the electrification with interventions to reduce / eliminate its negative impacts.

Section 2 presents the main studies on the link between electricity and malaria and explores the potential channels through which electrification can affect malaria. Section 3 provides an overview of the electrification process in Uganda and describes the severity of malaria in the country. Section 4 describes the main features of the dataset; furthermore it will highlight the main data problems and how we handled them. The empirical strategy and the regression results are presented in Section 5. Conclusion and policy implications are in Section 6.

Section 2. Is there a link between electricity and malaria? Evidence from the literature

Despite the seriousness of malaria incidence in many countries, its potential association with electrification and the increasing number of electrification projects taking places in many areas of Africa, Asia and Latin America, there is only circumstantial evidence on the relationship between electrification and malaria. In fact, the causal relationship between electricity and malaria occurrence is still very anecdotal.[2]

[2] The links between electricity and the occurrence of the Chagas disease and the leishmaniasis, on the other hand, have been properly addressed and studied. is a tropical parasitic disease caused by the flagellate protozoan Trypanosoma cruzi. The Chagas disease is commonly transmitted to humans and other mammals by an insect vector. Leishmaniasis is a disease caused by protozoan parasites that belong to the genus Leishmania and is transmitted by the bite of certain species of sand fly. The occurrence of these two types of disease has proved to increase in electrified areas.

We model the potential association between electrification malaria according to the following equation:

$$MI = f(vector\ density,\ exposure),$$

where *MI* indicates the Malaria Incidence, *vector density* the concentration of malaria vectors in the living space and *exposure* refers to household members staying in places where malaria vectors are present. Essentially, the previous formulation formally expresses that the incidence of malaria is a function of how many vectors are present in the exposure area and how much time we are exposed to malaria vectors. Now, we turn to the ways in which electrification can affect both *vector density* and *exposure*.

Vector Density

It has been argued that malaria mosquitoes are attracted to light as much as Chagas and leishmaniasis vectors (Barghini and de Medeiros, 2010), and malaria vectors are captured using suction light traps with heat or carbon dioxide bait (Govella et al., 2009; Jawara et al., 2008; Lee et al., 2009; Suarez-Mutis et al. 2009). This suggests that night lighting can increase the indoor density of malaria vectors.

Other examples pointing to vector density and electricity come from recent studies. Yamamoto et al. (2010), working with household data collected in Burkina Faso, found that, living in a place where electricity is available is associated with an increased risk of malaria, holding constant other variables. They explain their finding with the fact that the use of biomass for cooking and lighting purposes would produce a certain amount of smoke that might prevent insects from biting. Same evidence was found by Paul et al., 1995, in an experiment done in rural village in the Wosera area, Papua New Guinea. Repellency effects were associated with the burning of several species of plants in Kenya (Seyoum et al., 2002).

The discussion on whether smoke is a mosquitoe repellent is still open. Biran et al. (2007) reviewed the literature related to the effect of smoke on mosquitoes, concluding that there is no consistent evidence that smoke produced by charcoal and fire-wood provides protection from mosquitoes and malaria. Furthermore, using biomass for cooking and lighting inside the house could indirectly increase the risk of infection as house ventilation, which has the aim of reducing the level of indoor smoking, can provide entry point for mosquitoes. Nevertheless, the result of an experiment done in Sri Lanka pointed out that the risk of malaria is significantly lower in households using 'traditional fumigants' (van der Hoek et al., 1998).[3] A subsequent experiment contradicted the previous findings as a positive correlation between the use of fumigants and mosquito density was found (Konradsen et al., 2003). Other authors argue that smoke will inhibit the mosquitoes from biting but only during limited hours since cooking activities are normally concentrated between 6 and 8 pm and after that the smoke progressively disappears (Barnes et al., 2004; Ezzati et al., 2000).

Exposure

[3] Many communities living in rural areas where malaria is endemic use aromatic smokes in addition to wood fuel, i.e. traditional fumigants, to deter mosquitoes. In rural Gambia, tree bark combined with synthetic perfumes (locally known as*churai*) reduced the number of mosquitoes entering in a room even though the incidence of malaria is about the same. Traditional fumigants in Sri Lanka are supposed to decrease malaria. In Thailand, a mixture of DEET (N,N-diethyl-meta-toluamide) and a paste made from a local tree, wood apple, was an effective repellant when applied to the skin.

Electrification changes lifestyles in a number of ways. Barghini and de Medeiros (2010) provide evidence of the changes in lifestyle habits in some communities living in isolated areas of the Amazon. In particular, the authors show that electricity allows households' members to spend more time outside the house when vectors are more active, just after the sunset and the first few hours of the evening.

Similar patterns have been noticed by authors observing behavioral changes including social interactions taking place outdoors especially after the sunset (e.g. Winther, 2011). Also larger social events –such as sport activities– can now be practiced outdoors in the evening thanks to artificial lights and a major impact of electrification is to alter the 'light and day input' through controlling artificial light during solar darkness (Wright at al., 2005, Louzada et al., 2004). In fact, some authors have already argued that increased time spent outside the house during evening and night hours might have caused an increase in malaria infection in the Salomon Islands (Taylor, 1997). This increase in malaria infections followed a sensible decline in the numbers of infections due to the use of insecticide inside the dwellings. The fact that outdoor activities for people living in the Salomon Islands are not so common and are only present in areas where artificial lighting is available proves that electricity is changing the dynamics of the meeting points and of the activities practiced.

The relation between staying outdoor and exposure to malaria vectors is further underscored by studies that compare outdoor and indoor presence of malaria vectors. Gil et al., 2007, did an experiment in two villages located in the western part of the Brazilian Amazonas and they found that the number of mosquitoes captured outdoors are always 3 to 5 times higher than indoors. Considering the observed infectious mosquitoes which got trapped in a day, the risk for getting infective bites per year is approximately 5 times higher outside than inside the house in Vila Candelária and about 3 to 5 times more in Bate Estaca. Same kind of evidence was found in areas of Vietnam where malaria is endemic; outdoor night activities could be an important risk factor for malaria infection inside the village since the main vector, *An. dirus A,* is highly exophagic and exophilic, meaning that they mainly bite outdoors (Erhart et al., 2004). A study in the Peruvian amazon indicates that adults spending a significant amount of time outside their house had a 23 percent greater malaria incidence than those who did not. Children reporting to playing outdoors had an increased malaria incidence, although not statistically significant. Similarly, children who attended evening church services were recorded to have a 29 percent increase in malaria risk (Martha et al., 2000).

Nevertheless, electricity can also change behavior in ways that reduces exposure to malaria vectors and a stream of studies points out that households living in electrified areas suffer lower incidence of malaria. Mass media such as radio and television represent an important vehicle to promote awareness and non-risky behaviors (Tanner and Vlassoff, 1998**;** Thang et al., 2008; Tsuyuoka et al., 2010). The relationship between access to mass media and malaria is confirmed by a case study on the determinants of malaria morbidity in some provinces of Southern Iran. The study highlights that lack of accessibility to television and exclusion of educational programs raise the risk of malaria of 1.5 times if compared to other villages with similar effects identified for radio use (Asl et al., 2003).

In sum, from existing literature we know that electrification can have both beneficial and negative effects in relation to malaria incidence and the overall effect is an empirical question. This study provides the first attempt to find an answer to this question by analyzing a large sample of households in a country where malaria incidence is high and electrification is on the raise.

Section 3. Malaria incidence and electrification in Uganda: the state of affairs

On April 25, 2011, the malaria community marked the fourth 'World Malaria Day'; malaria is considered to be one of the world's most important public health concerns, responsible of over a million deaths and up to 500 million clinical cases each year. [4]

In the case of Uganda, malaria is considered one of the most serious diseases and even though some progress has been made in the last years in terms of prevention – the share of households with at least one net has doubled in the period from 2000 to 2004- the number of malaria certified cases in 2009 has been computed to be 12 million (World Health Organization, 2011). Malaria is still the leading cause of morbidity and mortality, accounting for 25 to 40 percent of outpatient visits to health facilities, 15 to 20 percent of all hospital admissions and 9 to 14 percent of all hospital deaths. Approximately half of the children deaths are attributed to malaria (UNDP, 2011). A very high percentage of people, 88 percent, are exposed to moderate to very high malaria transmission risk. Children under the age of 5 and pregnant women are considered the

[4] See the website http://www.rbm.who.int/worldmalariaday/ accessed on February the 23rd, 2012.

most biologically vulnerable. Children are the ones contributing the most to the malaria-related mortality (approximately between 70,000 and 100,000 annually world-wide). Poor households are perceived to be more exposed to malaria due to poor quality of the housing and malaria is a major threat for rural dwellers who live far from hospitals and clinics.

The Ugandan Ministry of Health reports that the number of malaria cases increased threefold between 2000 and 2004 and almost doubled in the following 4 years. Various factors are however responsible for such an increase: the rapid population growth, new health facilities which guaranteed easier access to the population to public health services and therefore better and more complete report (World Health Organization, 2010). These statistics also underscore increasing efforts which have been put in place in the last years. Uganda is one of 17 countries benefiting from the President's Malaria Initiative (PMI), a US led project. The PMI was launched in 2005 as a five-years, 1.265 USD billion, plan aiming to reduce the burden of malaria and help relieve poverty on the African continent. Notwithstanding the numbers of malaria cases previously cited, the PMI efforts are visible looking at a some malaria related indicators showing that the number of households, children and pregnant women using bed nets tremendously increased in a three years period (Table 1).

Table 1: key results from two following nationwide household surveys

Malaria Indicators in Uganda	PMI Baseline (DHS 2006)	MIS 2009
All-cause mortality rate in children under five	137/1,000	n/a
Proportion of households with at least one bed nets (in %)	16	47
Proportion of children under five years old who slept under an ITN the previous night (in %)	10	33
Proportion of pregnant women who slept under an ITN the	10	44

previous night (in %)		
Proportion of women who received two or more doses of IPTp during their last pregnancy in the last two years (in %)	16	32

Source: USAID, 2009. 'DHS' stands for demographic health survey and 'MIS' stands for malaria indicator survey.

There are a number of reasons why Uganda is still one of the country with the highest incidence of malaria; during the past 30 years the number and the area of cultivations of wetlands had created new breeding sites (Ugandan Ministry of Health, 2005); in addition massive deforestation, poor environment sanitation and other man-made sites, such as brick pits or fish ponds had increased malaria transmission. We note that, this increase in malaria is also coinciding with the raising number of electrification projects taking place in the country.

With the support of several donors and under the supervision of the 'Uganda Electricity Board', the organization responsible for supplying electrical power in Uganda, many electrification projects are under construction in various areas of the country. The 'Kisiizi Project' had installed mini grids in the Rukungiri district using electricity from a small hydro plant. Several grid extension projects have started in other distircts (Fort Portal, Bundibugyo, Nyahuka, Rugombre and Kyenjojo). With the support of Japan, a grid extension is under construction in the South of the country and in the same area, under the World Bank funding, a new electricity line has been put in place. Japan is also considering of constructing small hydropower projects in some other rural sites. These projects have been put in place in Uganda with the intention of supplying 480,000 rural residents with electricity by the end of 2012.

Uganda's finance minister, Syda Bbumba, during the signing ceremony for a 24.6 million USD project aimed at increasing rural electrification said that "rural electrification will now help in the industrialization of rural areas, reduce the urban-rural migration and create jobs" (World Business Council for Sustainable Development, 2006). She also stated that electrifying rural areas will have spillover effects as electricity will create the basis for the construction of health centers and rural schools. The country's rural electrification strategy aims at reducing the inequalities in electricity access and the associated opportunities for increased welfare, education, health and income generation activities.

Section 4. Data description and summary statistics

The following analysis is based on data from 'The Uganda National Household Survey, 2009-2010' for which 6,775 households have been surveyed. Almost 82 percent of the interviewed households resides in rural villages while the remaining 18 percent in urban areas. A number of questions had been asked to the head of the households –e.g. condition of the housing, source of electricity, food and non-food consumption, number of assets, etc– while others questions were asked to each household's member. In particular, the sections with questions regarding the educational attainments, income profiles and health status, the core of our analysis, have been asked to all household members (36,432 in total; 31,085 members living in rural areas and the remaining in urban areas).

Our data come from a multi purposes survey –not focusing specifically on malaria related issues– however there are several questions related to health problems. Each individual is asked whether s/he suffered from a number of illnesses (malaria, acute diarrhea, chronic diarrhea, acute fever, recurring fever, skin rash, weakness, severe headache, fainting, chills), if the individual had consulted a doctor for the problem s/he had, the reason why s/he did not see a doctor, where the doctor is located (in terms of distance from the household's residence) and if the individual had taken any medicine. Using a multi purposes survey has the advantage of collecting a number of other variables which could later be used as controls for the empirical analysis: house ownership, education of the head of the households, incomes of household' s members, condition of the dwelling, type of toilet used and geographical variables.

The fact that we use data on malaria incidence from a multi purposes survey might throw some doubt on the quality of the health data. In particular, the respondents' awareness regarding a number of illnesses might not be very good. We are confident that the malaria related data represent with a very good approximation the actual situation since t studies carried out in rural Uganda show that household's members, both male and female, know how to recognized malaria symptoms, how malaria is transmitted and which are the treatments when malaria is suspected (Kengeya-Kayondo et al., 1994).[5] A first look at the malaria incidence in the dataset we are using shows that

[5] Interviews in both high and low income areas of Mbarara municipality, South-Western of Uganda, on the cause of malaria transmission show that 95 percent of the interviewed people recognized that mosquitos are the main malaria vector, even though only one person named the microbe Plasmodium (Nuwaha, 2002). Women in particular, are able to recognize the symptoms associated with malaria which varies extensively and range from generally 'feeling unwell perception' to a specific fever diagnosis (usually in children) and to 'a rise in body temperature' (Kengeya-Kayondo et al., 1994).

both the share and the number of household's members having had malaria have a positive correlation with the income quintile classes (Table 2). The number of individuals having malaria does increase with the wealth of the households, with the exception of the members in the top quintile, but still the quintile differences are not particularly high nor statistically significant.

Table 2: Share and number of malaria cases, by income quintiles (rural households)

Share and number of cases	1st income quintile	2nd income quintile	3rd income quintile	4th income quintile	5th income quintile	Total
Share of hh. members having malaria (in %)	2.4	2.8	3.2	3.4	3.0	14.9
Number of hh. members having malaria	755	861	1,009	1,069	937	4,631

Notes: Author elaboration from 'The Uganda National Household Survey, 2009-10'.

The survey, includes data on the ways household's members prevent and cope with malaria. There are questions asking to each individual if s/he regularly use a bed net, the brand of bed net, if the bed net had been 'soaked or dipped in a liquid to repel mosquitos or bugs' and if the individual had consulted a doctor in the past 30 days. This set of information will be later used in the multivariate analysis (Section 5).

The other part of the survey which is important in finding a causal link between electricity and malaria incidence is the type of energy used by the households both for cooking and lighting. Table 3, first part, shows the share of households using various sources of energy; electricity is used for lighting in a fairly high share of households in the highest income quintile. Households in the income quintile from 1 to 4 mostly use paraffin lantern and tadooba, which is anyway largely used by households in the highest income quintile. Firewood is used by almost 10 percent of the households, with the percentage being particularly high for those having the lowest income (30 percent). Regarding the source of energy for cooking, Table 3 second part, biomass still represents the main energy source (97 percent on average). As expected, the share of households using electricity and gas, in general rather low, increases with higher income quintiles.

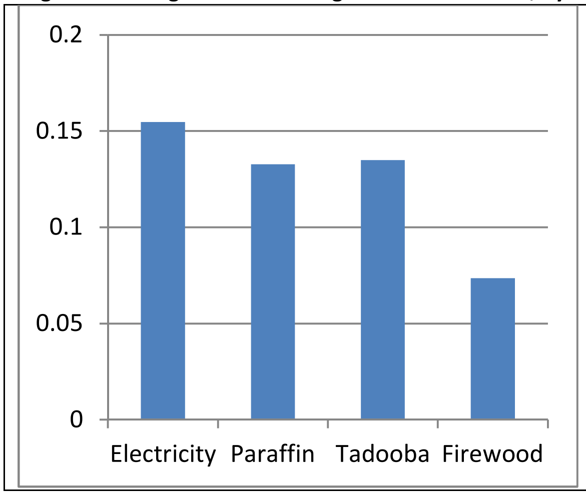
Table 3: Share of households using sources of energy for lighting and cooking, by income quintiles (rural households)

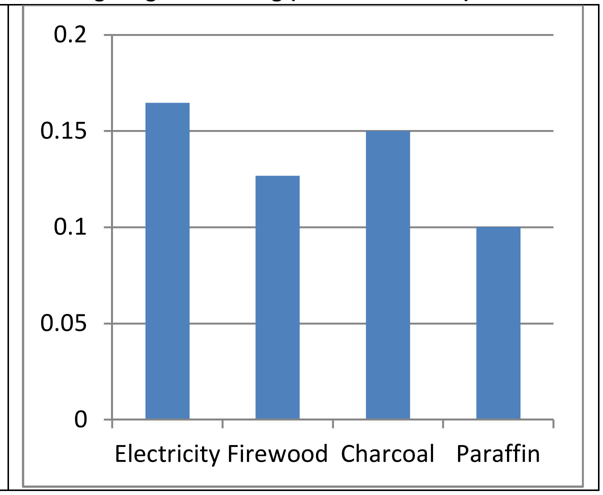
	1st income quintile	2nd income quintile	3rd income quintile	4th income quintile	5th income quintile	Total
			Sources of lighting			
Electricity	0.46	0.64	1.13	2.21	9.62	2.71
Paraffin lantern and tadooba	65.62	83.75	90.60	93.59	83.87	83.74
Firewood	30.33	11.45	4.97	1.52	0.97	9.74
Other	3.58	4.16	3.31	2.79	5.44	3.81
			Sources of cooking			
Electricity	0.27	0.18	0.17	0.33	0.40	0.27
Gas	0.00	0.00	0.00	0.00	0.20	0.04
Paraffin/ Kerosene	1.20	1.66	1.22	1.10	2.25	1.47
Firewood	96.78	94.46	93.65	90.63	70.90	89.56
Charcoal	1.75	3.51	4.44	7.09	22.66	7.67
Other	0.00	0.18	0.52	0.84	3.61	1.00

Notes: Author elaboration from 'The Uganda National Household Survey, 2009-10'.

Figure 1 and Figure 2 highlight the percentage of malaria cases according to the source of lighting and the type of fuel used for cooking. In both cases, using electricity is associated with increasing incidence of malaria. In the case of the source of lighting, 15% of household members using electricity did experience malaria in the last month compared to 13% of the household's members using paraffin and tadooba and 7% using firewood. Similar statistics are presented in Figure 2; households' members using electricity for cooking have a higher chance of getting malaria compared to members still using firewood, charcoal and paraffin. The differences in the percentages of malaria cases conditioned on the source of cooking and lighting are not major even though statistically significant. These descriptive statistics, while per se insufficient to derive causal claims, suggest that the relationship between energy sources and malaria incidence deserves further investigation. The multivariate analysis which will follow will shed further light on this causal relationship as it will control for additional variables which have not been considered here (e.g. housing condition, household's demographic and geographic location of the household).

Figure 1 and Figure 2: Percentages of malaria cases, by source of lighting and cooking (rural households)





Notes: Author elaboration from 'The Uganda National Household Survey, 2009-10'.

Section 5. Empirical strategy and main results

In order to study the link between the use of electricity and to assess the magnitude of this relationship, we estimate probit models where the dependent variable assumes value '1' if the household's member has had malaria in the last month and '0' otherwise. We estimate many models in order to identify the major channels through which malaria could manifest and to control for possible sources of endogeneity. As discussed above, electricity can affect malaria incidence because of changes to exposure and vector density. On one hand, an increased time spent outside the house, would increase exposure; reduced indoor air pollution and artificial lighting might increase the density of vectors indoor. On the other hand, access to mass media –made possible by electricity– might induce behavioral changes (such as the draining of ponds next to the dwelling) that reduce exposure and vector density.

For the channel i) we consider as ‘treated’ households those using electricity both for cooking and for lighting. In this circumstance there is no production of biomass pollution inside the house (this model aims at measuring the effect of what we previously called ‘vector density’). For the channel ii) we consider as ‘treated’ households the ones using electricity only for lighting, being not important what type of fuel they use for cooking (effect previously called ‘exposure’). The idea here is to disaggregate those households who can benefit from using electricity for lighting purpose from all the others. The first group is the one who has higher change of changing its lifestyle, spending less time inside the dwelling in evening hours.

The two models takes the following forms:

1) $Malaria_i=a_0+b_1\ (electricity\ for\ cooking\ \&\ lighting)_i + b_i X_i + e_{0i}$

2) $Malaria_i=a_0+b_1\ (electricity\ for\ lighting)_i + b_i X_i + e_{0i}$

where both the variables ‘*electricity for cooking & lighting*’ and ‘*electricity for lighting*’ are dummies. The ‘*X*’ is a vector of control variables referring to the demographic of the households, to the condition of the house they live in, the use of bed net, its income situation and its asset position. The control variables are the following: i) household size, ii) age of the household’s member, iii) per capita income (in logarithmic term), iv) type of the dwelling (dummy variable taking value ‘1’ if the household lives in a hut or barrack, ‘0’ otherwise), iv) if the household’s member use a bed net soaked in mosquito repellent, v) two variables related to the education of the head of the household and his/her spouse, vi) material used for the roof of the house (‘1’ if the roof is made with iron sheet, ‘0’ otherwise), vii) type of toilet used by the household (‘1’ if the household use an uncovered toilet or bush, ‘0’ otherwise), viii) asset variables (ownership of television and / or radio and of the house they live in, ix) a number of geographical dummies (Table 6 reports summary statistics of the variables used).

The choice of control variables depend on both the availability in the dataset and on the existing literature. It is well established that housing condition can have an impact on the risk of malaria (Guthmann, 2001). The way the house it is designed and the overall quality used for its construction are important factors in minimizing the access of insects, including those that are malaria vectors. Poorly constructed houses or houses built with cheap materials, for example, have been associated with an increased risk of malaria as they might have open spaces between the roof and walls (Ye et al., 2006). Likewise roofs constructed of traditional material such as earth or thatch can theoretically increase the risk of malaria by ‘providing access points, suitable resting places or breeding sites for malaria vectors’ (Yamamoto, 2010). For the same reason the type of toilet used could increase the risk of malaria, especially if the toilet is not covered as urine and feces attract all sort of mosquitoes. Floors material is not perceived as being a major threat for malaria (Palsson et al., 2004).

The use of repellent soaked bed nets is known to reduce malaria, while non-treated nets are not a powerful prevention tool. The reason is that bed nets tend to wear quickly and to have holes which provide entry point for malaria vectors (for example, in small-scale surveys done in Malawi and Kenya, between 80 and 90 percent of nets had holes; Holtz et al., 2002; Kachur et al., 1999).

Television / radio ownership is supposed to capture the fact that mass media advertisements can increase the household's awareness on malaria. At the same time being the owner of the dwelling might decrease the risk of malaria since house owners take take more care of their house, including repairing and sealing possible entry points for mosquitoes.

A set of geographical dummy is included to prevent that other factors related to the geography of the country will bias the results. The models indicated by 1) and 2) will be estimated for all the household's members, coefficients indicated by ' *_a*', '*_b*' and '*_c*', and just women in the family (coefficients indicated by ' *_d*', '*_e'* and '*_f*') (Table 4 and Table 5).

The idea here is to see if the effects of electricity on malaria incidence is different for different household's members. Women are the ones spending more time at home compared to man and if electricity is proved to have a positive impact on getting malaria, then the females in the households are more likely to suffer from this consequence.

The probit coefficients for model 1) show that household members using electricity for lighting and cooking purposes have higher chance of getting malaria. The marginal effects that electricity has on malaria are higher and statistically significant for women than for the household as a whole corroborating the hypothesis that women will suffer the most from the malaria related consequences of electricity use. The age of the household members has a negative effect on the dependent variables. Household size has the same sign, even though a positive correlation between the number of household's members and the incidence of malaria was expected. The negative signed is related to the Hulden's finding that malaria eradication tends to be more successful in countries with higher household size (2010). We did not observe any statistical significant associations between housing condition (general condition of the housing and roof or wall materials) and malaria in this study, in line with the findings of other articles (Ghebreyesus et al., 2000; Snow, 1998) while the use of an uncovered toilet or bush around the house will increase the malaria incidence. The material of the roof and ownership of the house are not influential. Using bed net has a negative sign, although it is significant only in one regression model. , the educational level of the head and his spouse and tv/radio ownership do not play an important role in assessing the risk of getting malaria.

The probit coefficient for model 2) show that households using electricity only for lighting purposes display an lower chance of getting malaria. The 'electricity' variable is not statistically significant when we estimate the model taking into account the whole household. When we restrict our analysis to the female members, the coefficient related to the 'electricity' variable is positive and statistically significant in the 3 model estimated, meaning that using electricity for lighting purposes is associated with an increase in the incidence of malaria among women. The coefficients of the other variables do not vary compared to model 1), indicating a degree of robustness in the results.

To further test the robustness of our results, we run models 1) and 2) just for i) those household's heads who had received education and b) those households in the fifth income quintile in order to check if the two channels would vary in highly educated or richer households. The coefficients associated to the variables 'electricity for cooking and lighting' and 'electricity for lighting' are still consistent with the previous findings. As a further check we run all the regression models omitting the tv and radio ownership variables (see Appendix 2 for details). We conduct this check since tv and to a certain extent radio ownership depend on access to the electricity network. Given the small coefficients of the tv/radio ownership coefficients in all the variables reported in tables 4 and 5, it is not surprising to see that our results slightly change.

Table 4: Determinants of malaria infection for all household members (Model 1_a, 1_b and 1_c) and for women only (Model 1_d, 1_e and 1_f)

Dependent variables	Model 1_a	Model 1_b	Model 1_c	Model 1_d	Model 1_e	Model 1_f
HH using electricity for cooking and lighting	0.377*	0.311	0.272	0.620**	0.611*	0.602*
	-0.222	-0.221	-0.221	-0.332	-0.335	-0.333
Household size	-0.008**	-0.010***	-0.013***	-0.004	-0.006	-0.009*
	-0.003	-0.003	-0.003	-0.005	-0.005	-0.005
Age of the household’s member	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Household's head can read and write	0.067***	0.029	0.032			
	-0.021	-0.021	-0.021			
Household's head spouse can read and write				0.026	0.004	0.002
				-0.03	-0.03	-0.03
Per capita income, in log	0.053***	0.045***	0.043***	0.044***	0.039***	0.035**
	-0.009	-0.009	-0.01	-0.014	-0.014	-0.015
Household living in a hut	-0.016	0	-0.058*	-0.017	-0.005	-0.062
	-0.027	-0.028	-0.031	-0.04	-0.042	-0.047
Bed net soaked in repellent	-0.053**	-0.007	-0.014	-0.017	0.03	0.01
	-0.022	-0.022	-0.023	-0.031	-0.032	-0.033
Roof made with iron sheet	0.017	0.015	0.02	0.01	0.007	0.009
	-0.026	-0.027	-0.028	-0.039	-0.04	-0.042
Uncovered toilet or bush	0.055**	0.038	0.025	0.081**	0.062*	0.051
	-0.024	-0.025	-0.025	-0.037	-0.037	-0.038
Household owns a radio/tv	-0.01	-0.03	-0.033	0.036	0.006	0.003
	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03
Household owns the house	-0.021	0.013	0.018	0.012	0.059	0.044
	-0.04	-0.04	-0.041	-0.062	-0.062	-0.063
Macro regional dummies	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED

Regional dummies	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED
District dummies	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED
Constant	-1.753***	-1.722***	-1.708***	-1.833***	-1.812***	-1.859***
	-0.141	-0.142	-0.183	-0.22	-0.22	-0.277
R-squared	0.10	0.10	0.13	0.10	0.10	0.13
N	20,124	20,124	20,124	9,055	9,055	9,055

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

Notes: Macro region dummies refer to Central, Western, Eastern and Northern rural areas; regional dummies refer to Central, Eastern-Central, Eastern, Mid-Northern, North-Eastern, Western, Mid-Western and South Western rural areas. District dummies refer to 80 rural districts.

Table 5: Determinants of malaria infection for all household members (Model 2_a, 2_b and 2_c) and for women only (Model 2_d, 2_e and 2_f)

Dependent variables	Model 2_a	Model 2_b	Model 2_c	Model 2_d	Model 2_e	Model 2_f
HH using electricity for lighting	-0.015	-0.002	0.018	0.046**	0.064***	0.109*
	-0.055	-0.056	-0.059	-0.019	0.08	0.064
Household size	-0.008**	-0.010***	-0.013***	-0.004	-0.007	-0.009*
	-0.003	-0.003	-0.003	-0.005	-0.005	-0.005
Age of the household's member	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Household's head can read and write	0.068***	0.03	0.032			
	-0.021	-0.021	-0.021			
Household's head spouse can read and write				0.026	0.004	0.002
				-0.03	-0.03	-0.03
Per capita income, in log	0.054***	0.045***	0.043***	0.044***	0.038***	0.034**
	-0.009	-0.009	-0.01	-0.014	-0.014	-0.015
Household living in a hut	-0.016	0	-0.058*	-0.018	-0.007	-0.066
	-0.027	-0.028	-0.031	-0.04	-0.042	-0.048
Bed net soaked in repellent	-0.051**	-0.005	-0.012	-0.014	0.032	0.012

	-0.022	-0.022	-0.023	-0.031	-0.032	-0.033
Roof is made with iron sheet	0.016	0.014	0.02	0.01	0.008	0.011
	-0.026	-0.027	-0.028	-0.039	-0.04	-0.042
Uncovered toilet or bush	0.054**	0.038	0.025	0.082**	0.064*	0.052
	-0.024	-0.025	-0.025	-0.037	-0.037	-0.038
Household owns a radio/tv	-0.01	-0.029	-0.033	0.036	0.006	0.002
	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03
Household owns the house	-0.021	0.014	0.019	0.015	0.062	0.047
	-0.04	-0.04	-0.04	-0.062	-0.062	-0.063
Macro regional dummies	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED
Regional dummies	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED
District dummies	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED
Constant	-1.912***	-1.742***	-1.720***	-1.822***	-1.803***	-1.953***
	-0.157	-0.144	-0.183	-0.223	-0.224	-0.296
R-squared	0.10	0.10	0.13	0.10	0.10	0.14
N	20,124	20,124	20,124	9,055	9,055	9,055

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

Notes: Macro region dummies refer to Central, Western, Eastern and Northern rural areas; regional dummies refer to Central, Eastern-Central, Eastern, Mid-Northern, North-Eastern, Western, Mid-Western and South Western rural areas. District dummies refer to 80 rural districts.

Section 6. Conclusions and policy implications

Rural electrification programs have been on the agenda of many developing countries in the last two decades. Electrifying urban and rural areas has the long run objective of eradicating poverty trough an increase in the overall socioeconomic development, creating small enterprises in rural areas, reducing the over-reliance on biomass sources, fostering activities in agriculture and promoting health and education programs. The increase in energy consumption as a result of electrification projects demonstrated that electricity is being used mainly for lighting and cooking purposes and for entertainment reasons (television, charging up mobiles, using radio); electricity use has proved to be beneficial for school attendance, for the quality of health services and lastly for reducing indoor air pollution from biomass use. Little is known about unintended negative health effects of rural electrification.

In this study we have presented evidences that electricity, used both for cooking and / or lighting purposes may increase the transmission of malaria. To our knowledge this study represents the first attempt using a large scale survey to estimate whether the use of electricity might influence the incidence of malaria. We chose to focus on rural Uganda because it is one of the country with a relative low share of electrified households and where the incidence of malaria is still very high. Furthermore, the country is currently experiencing a number of electrification projects involving both urban and rural areas.

Theoretically, the channels through which electrification might increase malaria incidence are twofold. The lack of indoor smoke generated by the use of biomass for cooking might have the consequence of attracting mosquitoes ('vector density' channel). Artificial lighting changes the behavior of people and thereby promotes more contacts between human beings and malaria vector species ('exposure' channel). This may lead to new and unpredictable ecological relationships that need to be fully understood so that electricity could be offered to rural populations in areas where malaria vector-borne diseases are endemic without increasing their risk of acquiring such disease.

The regression coefficients corroborate our hypothesis. The use of electricity for cooking and lighting purposes seems to influence in a more statistical significant way the occurrence of malaria. The link between electricity and malaria appears to be stronger when we estimate the model including women only, meaning that the female part of the household will be more affected by malaria if electricity is used for both cooking and lighting. The use of electricity only for lighting purposes does not always imply an increase in malaria incidence as the coefficients of the probit regressions are statistically significant in 1 out of 6 models.

Additional models have been estimated in order to avoid endogeneity problems. All the results go in the same direction indicating that electricity does have a positive influence in malaria incidence. It should be noted, though, that the previously discussed results refer to households living in rural Uganda meaning that our hypothesis has not been tested using data from other countries. In addition, in order to properly and more rigorously test this hypothesis, an *ad-hoc* questionnaire should be employed with a panel of households. The survey we used is not a malaria related questionnaire with the drawback that the number of questions related to malaria is not high. The use of a multi topic survey, though, has the advantage of having a very high number of additional data which, apparently not directly related to malaria, can be used as instruments to test the validity of the model.

It is worth stressing that the aim of this study is not to criticize electricity or the electrification projects; we are fully aware that electricity brings a number of benefits in the short, medium and long period for all the household members. The aim of this study is rather to highlight the possibility that electricity might be the cause of negative impacts as well. Policy makers should then address this problem and allow urban and rural households living in newly electrified areas to fully enjoy the benefits coming from the electrification. We trust that this contribution will shed light on this neglected implication and encourage epidemiologists and economists to carry out studies that take into account changes in human and vector behaviors which are related to artificial lighting.

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Appendix 1

Table 6: Summary statistics of dependent and independent variables

Variables	Mean value	Standard deviation	Minimum value	Maximum value
Malaria incidence – all household members (in %)	14.9	33.4	0	1
Malaria incidence – female household members (in %)	13.9	33.5	0	1
HH using electricity for cooking and lighting (in %)	2.71	3.61	0	1
HH using electricity for lighting (in %)	0.27	6.93	0	1
Household size	7.138	3.098	1	24
Age of the household members	19.374	17.789	0	98
Household's head can read and write(in %)	64.44	47.92	0	1
Household's head spouse can read and write (in %)	37.66	48.64	0	1
Per capita household income (in logarithm)	12.190	12053	59532	208644
Household living in a hut (in %)	36.15	48.04	0	1
Bed net soaked in repellent (in %)	28.73	45.83	0	1
Roof of the house made with iron sheet (in %)	47.45	49.92	0	1
Household has an uncovered toilet or use the bush (in %)	17.39	37.38	0	1
Household owns a radio / tv (in %)	49.74	50.20	0	1
Household owns the house (in %)	93.57	24.74	0	1

Table 7: Determinants of malaria infection for all household members (Model 1_a, 1_b and 1_c) and for women only (Model 1_d, 1_e and 1_f); these regressions omit the radio and tv ownership variable

Dependent variables	Model 1_a	Model 1_b	Model 1_c	Model 1_d	Model 1_e	Model 1_f
HH using electricity for cooking and lighting	0.326*	0.311	0.272	0.620**	0.611*	0.602*
	-0.187	-0.211	-0.221	-0.334	-0.335	-0.333
Household size	-0.008**	-0.010***	-0.013***	-0.004	-0.006	-0.009*
	-0.003	-0.003	-0.003	-0.005	-0.005	-0.005
Age of the household's member	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Household's head can read and write	0.067***	0.029	0.032			
	-0.021	-0.021	-0.021			
Household's head spouse can read and write				0.026	0.004	0.002
				-0.03	-0.03	-0.03
Per capita income, in log	0.053***	0.045***	0.043***	0.044***	0.039***	0.035**
	-0.009	-0.009	-0.01	-0.014	-0.014	-0.015
Household living in a hut	-0.016	0	-0.058*	-0.017	-0.005	-0.062
	-0.027	-0.028	-0.031	-0.04	-0.042	-0.047
Bed net soaked in repellent	-0.053**	-0.007	-0.014	-0.017	0.03	0.01
	-0.022	-0.022	-0.023	-0.031	-0.032	-0.033
Roof made with iron sheet	0.017	0.015	0.02	0.01	0.007	0.009
	-0.026	-0.027	-0.028	-0.039	-0.04	-0.042
Uncovered toilet or bush	0.055**	0.038	0.025	0.081**	0.062*	0.051
	-0.024	-0.025	-0.025	-0.037	-0.037	-0.038
Household owns the house	-0.021	0.013	0.018	0.012	0.059	0.044
	-0.04	-0.04	-0.041	-0.062	-0.062	-0.063
Macro regional dummies	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED
Regional dummies	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED

District dummies	EXCLUDED	EXCLUDED	INCLUDED	EXCLUDED	EXCLUDED	INCLUDED
Constant	-1.725***	-1.663***	-1.546***	-1.694***	-1.700***	-1.548***
	-0.126	-0.13	-0.169	-0.193	-0.197	-0.251
R-squared	0.10	0.10	0.13	0.10	0.10	0.13
N	20,124	20,124	20,124	9,055	9,055	9,055

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

Notes: Macro region dummies refer to Central, Western, Eastern and Northern rural areas; regional dummies refer to Central, Eastern-Central, Eastern, Mid-Northern, North-Eastern, Western, Mid-Western and South Western rural areas. District dummies refer to 80 rural districts.

Table 8: Determinants of malaria infection for all household members (Model 2_a, 2_b and 2_c) and for women only (Model 2_d, 2_e and 2_f); these regressions omit the radio and tv ownership variable

Dependent variables	Model 2_a	Model 2_b	Model 2_c	Model 2_d	Model 2_e	Model 2_f
HH using electricity for lighting	-0.017	-0.007	0.013	0.051**	0.065***	0.109*
	-0.055	-0.056	-0.059	0.009	0.08	0.084
Household size	-0.008**	-0.011***	-0.013***	-0.004	-0.006	-0.009*
	-0.003	-0.003	-0.003	-0.005	-0.005	-0.005
Age of the household's member	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***	-0.006***
	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Household's head can read and write	0.066***	0.026	0.028			
	-0.021	-0.021	-0.021			
Household's head spouse can read and write				0.029	0.004	0.002
				-0.03	-0.03	-0.03
Per capita income, in log	0.053***	0.043***	0.041***	0.048***	0.038***	0.034**
	-0.009	-0.009	-0.009	-0.014	-0.014	-0.014
Household living in a hut	-0.015	0.001	-0.057*	-0.02	-0.007	-0.066
	-0.027	-0.028	-0.031	-0.04	-0.042	-0.048
Bed net soaked in repellent	-0.051**	-0.005	-0.013	-0.014	0.033	0.012
	-0.022	-0.022	-0.023	-0.031	-0.032	-0.033
Roof is made with iron sheet	0.017	0.017	0.023	0.009	0.008	0.011
	-0.026	-0.027	-0.028	-0.039	-0.04	-0.042
Uncovered toilet or bush	0.054**	0.038	0.025	0.082**	0.064*	0.052
	-0.024	-0.025	-0.025	-0.037	-0.037	-0.038
Household owns the house	-0.021	0.012	0.017	0.015	0.062	0.047
	-0.04	-0.04	-0.04	-0.062	-0.062	-0.063
Macro regional dummies	NO	INCLUDED	NO	NO	INCLUDED	NO
Regional dummies	NO	INCLUDED	NO	NO	INCLUDED	NO

District dummies	NO	NO	INCLUDED	NO	NO	INCLUDED
Constant	-1.730***	-1.648***	-1.531***	-1.721***	-1.692***	-1.547***
	-0.127	-0.131	-0.168	-0.194	-0.199	-0.25
R-squared	0.10	0.10	0.13	0.10	0.10	0.14
N	20,124	20,124	20,124	9,055	9,055	9,055

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

Notes: Macro region dummies refer to Central, Western, Eastern and Northern rural areas; regional dummies refer to Central, Eastern-Central, Eastern, Mid-Northern, North-Eastern, Western, Mid-Western and South Western rural areas. District dummies refer to 80 rural districts.