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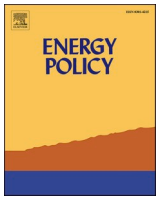

Let there be light, and lo and behold malaria returned: a cross country analysis of the electricity-malaria nexus in rural sub-Saharan countries

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ABSTRACT

Malaria remains a significant public health challenge in many sub-Saharan African countries, with more than 247 million people tested positive and about 600 thousand deaths every year. Its burden disproportionately affects vulnerable populations, with consequences for their health, labour productivity, and standards of living.

While various factors contribute to the occurrence of malaria, the role that the access and the use of electricity may play has received limited attention. The development related benefits of electrifying rural areas of sub-Saharan Africa -where 70 % of the total population is not connected to the grid-are undoubtful. Electricity, on the other hand, may represent a channel for a surge of malaria cases; malaria vectors are attracted by electric lights and the availability of light in the evening may encourage habits that increase people exposure to malaria vectors.

This paper investigates the nexus between access to electricity and malaria incidence in children aged between 0 and 5 living in the rural areas of 10 Sub-Saharan countries; the dataset -which aggregates 15 household-level surveys from the Demographic and Health Survey collected between 2015 and 2021- gathers data on about 50,000 households and relies on 87,500 malaria tests on children.

Controlling for a range of variables, the econometric results done at the household and at the individual level suggests that the relationship between electricity and malaria prevalence is positive and significant -and robust to model specification. Depending on the module specification, the use of electricity may increase the occurrence of malaria of between 15 and 42 %, with the nexus being stronger for the lower strata of the rural population.

1. Introduction

Malaria continues to be a major public health concern, particularly in Sub-Saharan Africa, where the burden of the disease is disproportionately high if compared to other areas (95 % of the cases and of the death happens in sub-Saharan countries (WHO, 2022)). Despite significant progress in reducing malaria cases over the past decades -the number of deaths has decreased by 30 % in the 2000–2021 period-several countries in the region still struggle to defeat this preventable and treatable disease.

Malaria affects countries in the sub-Saharan region in a different way; Nigeria in 2021 has recorded the highest number of death (193 thousand, with 47 million cases of malaria), followed by the Democratic Republic of Congo (78 thousand death), Tanzania (25 thousand) and Mozambique (22 thousand); those four countries account for just over half of all malaria deaths worldwide.

Malaria remains a significant barrier to development in sub-Saharan Africa, accounting for substantial morbidity and mortality, particularly among vulnerable populations -those in the lower income strata of the population-pregnant women and children, with 481,500 children under 5 years old losing their lives for causes related to malaria in 2021. This means that nearly every minute, a child under five dies of malaria (WHO, 2015).

The disease affects not only individuals and communities but also has far-reaching consequences for national economies (for a systematic review of the costs of malaria refer to Andrade et al., 2022). The economic impact of malaria includes direct costs such as healthcare and household expenses, as well as indirect costs associated with productivity losses, absenteeism from work, and reduced investments.

While numerous factors contribute to the occurrence and persistence of malaria, the role electricity access may play as a potential determinant of malaria occurrence has gained relatively increasing attention in recent years (see Pellegrini and Tasciotti, 2016, for a seminal paper on the electricity-malaria nexus). About 50 % of the population living in

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sub-Saharan countries have access to electrification, with differences across the region (8 % in South Sudan and 95 % in Cabo Verde)[1]; this percentage decreases to 30 % in rural areas -which are the ones this paper focuses on-with as low as 1 % of the rural households in Mauritania and the Democratic Republic of Congo being connected to the grid. In line with the Sustainable Development Goal 7 of providing affordable and clean energy to those 573 million people who lack electricity in their dwelling, a correct understanding of the spillovers effects electricity may have seems to be in place here.

Access to reliable electricity has a profound impact on various aspects of human development, including health outcomes. In the context of malaria, electricity access can contribute to both the transmission and the control of the disease.

Electricity enables the use of essential tools for vector control, such as electric fans, air conditioning, and insecticide-treated bed nets (see for example Hinze et al., 2021). These interventions reduce human-mosquito contact, limiting the transmission of malaria. The availability of electricity also supports the implementation of indoor residual spraying (IRS) campaigns, where insecticides are applied to the walls and ceilings of houses, further reducing the mosquito population (Okumu and Moore, 2011). Access to electricity is crucial for healthcare facilities, as it ensures reliable power supply for diagnostic tools, refrigeration systems for storing vaccines and medicines, and adequate lighting for nighttime healthcare provision (literature on this topic is rather extensive; see Adair-Rohani et al., 2013, for a review on this topic in sub-Saharan countries). A reliable source of electricity enables accurate and timely diagnosis of malaria cases, facilitates the availability of life-saving medicines, and improves the overall quality of healthcare services (Kasetsirikul et al., 2016).

Electrification also contributes to broader socioeconomic development, which can indirectly influence malaria control. Electrified communities often experience improvements in health infrastructure, including better-equipped health facilities and enhanced diagnostic and treatment services for malaria (Moner-Girona et al. (2021)). The presence of reliable electricity allows for the storage of temperature-sensitive medications and the use of diagnostic equipment, thereby improving the management of malaria cases. According to Moner-Girona et al. (2021), electrified health centres in Ethiopia reported better malaria diagnosis and treatment outcomes compared to non-electrified centres.

Furthermore, electrification can spur economic growth, increasing household incomes and enabling families to invest in malaria prevention measures such as insecticide-treated nets (ITNs) and indoor residual spraying (IRS). A study by Dinkelman (2011) found that electrification in South Africa was associated with higher household incomes, which in turn supported greater investment in health and education, indirectly contributing to lower malaria transmission. This relationship was measured by Tusting et al. (2016a) who measured that individuals are better equipped to afford and implement preventive measures and seek timely treatment if needed.

The quality of the housing is an important risk factor when measuring the occurrence of malaria; Tusting et al. (2015) conducted a systematic review to assess whether features of modern housing is associated with a lower/higher risk of malaria compared to more traditional housing. They look at the evidence in terms of material of the walls/roof/ceiling used in the dwellings, whether the eaves (the gap between the top of the wall and the over-hanging roof) are closed and malaria occurrence. The authors conclude that despite the (sometimes) low quality of the screened studies, 'the direction and consistency of effects indicate that housing is an important risk factor for malaria'.

Acknowledging the importance that electricity plays in terms of increase standards of living for the households and in terms of the economic benefit for the whole country, this paper investigates whether a positive relationship between the use of electricity and the incidence of malaria exists and whether this nexus is significant. This paper looks at the household level data collected by the DHS team in 10 Sub-Saharan countries between 2015 and 2021 (Table 1). The dataset boasts about 50 thousand rural household; the 21 household-level surveys gather information on the malaria tests on 87 thousand children aged between 0 and 5 years old.

Understanding the multifaceted relationship between electricity and malaria incidence can guide policymakers and public health practitioners in developing holistic interventions that address both energy poverty and malaria control, ultimately improving health outcomes and fostering sustainable development in the region.

The rest of the paper is organised as it follows; next section discusses the channels by which electricity may affect the occurrence of malaria (section 2). Section 3 offers the reader a glimpse on the data used and few summary statistics on the availability of electricity in the rural areas of the countries here considered and on the occurrence of malaria. Section 4 introduces the econometric models to be estimated and their results; section 5 concludes.

2. What does the literature on the electricity-malaria nexus say?

This paper theorises that malaria incidence (MI) depends on the amount of malaria vectors in one given area –what we here refer to as vector density- and on the exposure, which relates to the amount of time household members spend in places where malaria vectors are present (formula (1)) (see Fig. 1 for a summary of the two channels).

$$\mathrm{MI} = \mathrm{f}(\text{vector density}, \text{exposure}) \tag{1}$$

Regarding the 'vector density' channel, evidence points to the fact that mosquitoes are attracted to light, which is the reason why malaria vectors are captured using light traps (Degefa et al., 2020). This suggests that the indoor/outdoor use of lights after sunset can increase the overall density of malaria vectors; the increase in the number of indoor malaria vectors happens as dwellings in less developing countries may present multiple entry points for malaria vectors (Ng'ang'a et al., 2020).

The availability of electricity for lighting purpose comes together with several other improvements for the households, one of them being the possibility of using cleaner sources of energy for cooking. There is

Table 1
List of countries, year of the survey and number of observations.

Country	Year	Number of households	Number of children tested for malaria
Angola	2015	905	1589
Angola	2016	1258	2283
Cameroon	2018	1478	2603
Ghana	2014	1297	1901
Ghana	2016	1354	1917
Ghana	2019	1294	1807
Kenya	2015	2427	6359
Kenya	2020	2991	7660
Liberia	2016	1108	1584
Mali	2015	2584	5838
Mali	2018	2016	3186
Mali	2021	2953	6849
Mozambique	2015	2083	2891
Mozambique	2018	1976	2807
Nigeria	2015	2420	3983
Nigeria	2018	4395	6830
Nigeria	2021	4413	7607
Sierra Leone	2016	3258	5604
Tanzania	2015	3589	5795
Tanzania	2016	1546	2744
Tanzania	2017	3652	5715
Total	**48,997**		**87,552**

Notes: Authors' calculation from the Demographic and Health Surveys.

[1] https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=ZG&most_recent_value_desc=false.

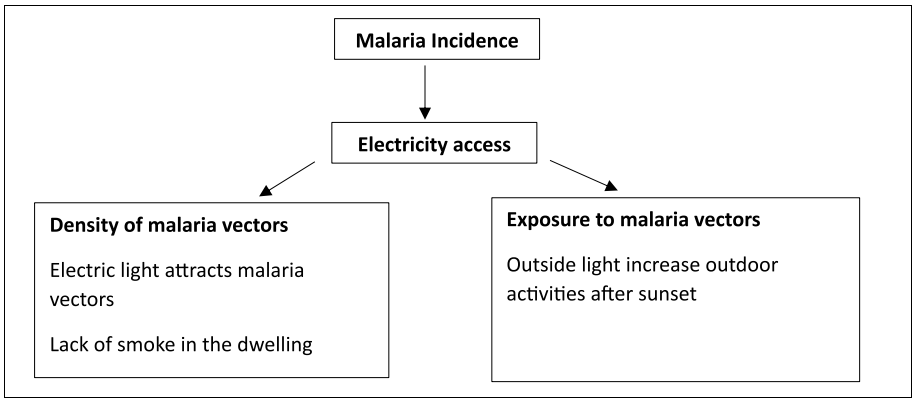

Fig. 1. Relationship between the use of electricity and malaria incidence.
Source: Author's elaboration

evidence suggesting that most of the households living in electrified dwellings decrease the use of firewood for cooking and start using cleaner source, e.g. gas or biogas (Aemro et al., 2021), for preparing their meals. The lack of smoke generated using biomass used for cooking purposes is one of factor responsible for the increase in the number of malaria vectors (vector density channel) as smoke acts as a natural repellent for mosquitoes (Wendimu and Tekalign, 2021). Evidence about this can be found in studies conducted in rural areas of Papua New Guinea (Paul et al., 1995) and Kenya (Seyoum et al., 2003). The evidence in those two studies point out the habits many communities living in rural areas have is to use aromatic smokes in addition to wood smoke -i.e. traditional fumigants-to deter mosquitoes. In rural Gambia, tree bark combined with synthetic perfumes -locally known *aschurai* - reduced the number of mosquitoes entering in the room.

Being connected to the electric grid facilitates the use of electric fans and/or air conditioning, tools which reduce mosquito bites. Fans create airflow that makes it difficult for mosquitoes to land and bite, while the use of air conditioning reduces indoor temperatures which can deter mosquito entry. Research by Lindsay et al. (2010) demonstrated that the use of fans/air conditioning in households significantly lowered the number of mosquito bites and thus the risk of malaria transmission.

For what concerns the 'exposure' channel, the changes electrification may bring in someone's life can be multiple, may go in different directions and are very likely to be extremely difficult to disentangle; for what concerns the impacts electricity use may have on malaria occurrence, the evidence suggests that electricity allows household members to spend more time outside the house after the sunset –artificial light may reduce people's perception of risk and may encourage them to spend more time outside the dwelling (Monroe et al., 2019)- when malaria vectors are more active (Cooke et al., 2015). This effect underscores the importance of promoting the use of protective measures, such as wearing long-sleeved clothing and using insect repellent when engaging in outdoor activities after dark (Moshi et al., 2018).

There is evidence pointing out the fact that spending time outside the dwelling during the evening hours has caused an increase in the rate of malaria occurrence; studies have been conducted in the Salomon Islands (Taylor, 1975) and rural Vietnam and Peru (Erhart et al., 2004). A study by Tusting et al. (2016) found that electrified households in rural Africa had a significantly lower prevalence of malaria compared to non-electrified households. The availability of electric lighting reduced outdoor activities and increased the use of protective measures such as bed nets.

It would be cumbersome to understand a priori how the use of electricity affect the incidence of malaria as there are too many factors to consider; the next two sections show how we aim to disentangle the spillovers effects caused using electricity in terms of malaria incidence with the use of household/individual level data.

3. Data

The Data used to test the electricity-malaria nexus comes from the Demographic and Health surveys (DHS).[2] The DHS surveys are nationally representative surveys, whose numerosity is based on the country's population. The DHS data used here covers 10 sub-Saharan countries -Angola, Cameroon, Ghana, Kenya, Liberia, Mali, Mozambique, Nigeria, Sierra Leone, and Tanzania; the dataset here uses one survey for Cameroon (2018), Liberia (2016) and Sierra Leone (2016), two surveys for Angola (2015 and 2016), Kenya (2015 and 2020), Mozambique (2015 and 2018), three for Ghana (2014, 2016 and 2019), Mali (2015, 2018 and 2021), Nigeria (2015, 2018 and 2021) and Tanzania (2015, 2016 and 2017).

All those surveys present a household level and an individual level dataset. The DHS data set collects household level data (use of electricity and source of energy used for cooking, construction material of the dwellings, assets owned by the households among other variable) as well as individual characteristics (including age, height, weight, use of malaria nets). Malaria tests are administered to children aged between 1 months and 5 years (those tests are sometimes administered to women in reproductive age; this variable has not been taken into account in this study as very fragmented); as the DHS website says, 'specially trained interviewers take a few drops of blood from the fingers of eligible respondents who consent to the tests', and malaria is tested 'with both a rapid diagnostic test in the field and microscopy in a laboratory'. In other words, blood samples (finger prick) are collected from children under age 5 and these samples are used for i. rapid diagnostic tests (RDTs) for malaria, ii. microscopy (in some cases, to confirm infection) and iii. haemoglobin testing (to assess anaemia, which can be related to malaria). The DHS surveys use 'standardized protocols' and 'rigorous, standardized survey instruments across countries, ensuring comparability and quality control'. Thousands of children are tested in many countries, providing statistically robust estimates for under-5 malaria prevalence.[3]

All the surveys were checked for data consistency and then combined in two unique datasets, one with the information at the household level and at the individual level. For what concerns the malaria incidence, the DHS teams test children between 0 and 5 (older children may be at school when the interview and the tests take place, hence they have been excluded from the malaria test).

Three malaria related variables were created (Table 2), two at the household level and one at the individual level. The first of the two-

[2] For more information about the DHS household level data, please refer to the following website, lastly accessed the 18/05/2025.

[3] For more information, refer to the following website https://dhsprogram.com/methodology/survey-types/mis.cfm lastly accessed the 11/06/2024.

Table 2
Description of the dependent variables.

Variable	Description
Household level malaria variable	It takes value '1' if one or more household members have tested positive for malaria; '0' otherwise
Household cumulative measure of malaria positive	It takes the value of the number of household members who have tested positive for malaria (e.g. 0, 1, 2, etc)
Individual level malaria variable	It takes value '1' if the given household member has tested positive for malaria; '0' otherwise

Notes: Authors' calculation from the Demographic and Health Surveys.

household level malaria related variable is a dummy one, which takes the value '1' if one or more household members have tested positive, '0' if no one within the household has tested positive for malaria. The second household level malaria variable is a categorical one, which takes the value of the highest number of household members which have tested positive (i.e. an integer number higher or equal to zero). The individual variable looks at all the individual which have been tested for malaria and returns the value '1' if the given individual has tested positive for malaria, '0' otherwise. All individuals -i.e. children-who were not tested for malaria have been dropped from the personal level data set; if a given household did not display any malaria test for any of its members, then the household had been dropped too. The final dataset consists of 48,997 households and 87,552 individuals aged between 0 and 5 years old.

Table 3 shows the share of households and individuals (column 3 and 4 respectively) having tested positive for malaria. In terms of household share, the lowest (highest) share relates to Tanzania 2017 with 10 % (Sierra Leone, 2016, 66 %), with the same evidence coming from the individual share too. Nigeria, which according to the WHO malaria report is the one with the highest number of deaths related to malaria, has a high share of cases, between 38 and 49 % depending on the year and the type of survey.

As the quantitative analysis uses wealth decile, Table 10 in the Appendix shows the incidence of malaria disaggregated by country, the year of the survey and wealth deciles. The incidence of malaria is highest in the lower deciles (first, second and third) and it then decreases from the fourth decile. The average malaria incidence for those children in the fifth decile or lower is lower than those in the first three deciles (exception being Ghana (2016) and Kenya (2015)). The malaria incidence rate is still relatively high for those children in wealth deciles after the fifth; the incidence rate is above 50 % -and similar to the malaria incidence for children in the lower deciles-in Ghana (2014), Liberia (2016), Mozambique (2018), Nigeria (in all the three surveys), and Sierra Leone (2016).

Table 3
Share of malaria positive by country and year, at the household and individual level.

Country	Year	Share of households	Share of household members
Angola	2015	17.34	13.85
Angola	2016	24.85	20.19
Cameroon	2018	30.22	25.46
Ghana	2014	43.88	42.18
Ghana	2016	35.07	32.42
Ghana	2019	28.72	25.04
Kenya	2015	16.85	12.86
Kenya	2020	14.83	10.27
Liberia	2016	55.61	50.54
Mali	2015	42.28	31.40
Mali	2018	19.50	15.66
Mali	2021	25.84	17.79
Mozambique	2015	35.69	31.59
Mozambique	2018	37.46	34.35
Nigeria	2015	49.42	43.59
Nigeria	2018	43.55	38.03
Nigeria	2021	45.49	38.33
Sierra Leone	2016	66.15	57.67
Tanzania	2015	11.66	10.09
Tanzania	2016	22.90	19.30
Tanzania	2017	10.26	8.43
Average		32.58	26.56

Notes: Authors' calculation from the Demographic and Health Surveys.

The other variable of interest relates to the use of electricity in the dwellings; the survey question asked to the head of the household was similar across countries and survey year ('What type of fuel or energy source is used in this dwelling?'); Table 11 in the Appendix shows the electricity access by country, year and wealth decile. The share of electrified households is low in all the countries here considered and for the households with a wealth status lower than the fifth decile. There are several countries (Liberia, Mozambique and Tanzania) in which households in the first five deciles do not live in an electrified dwelling. The share of households with electricity access increases for those households in the higher deciles, with the highest peak of electricity access for those in the tenth decile living in Ghana and Nigeria.

4. Econometric results

This section explains the econometric analysis performed to measure the sign, magnitude and the significance of the relationship between having electricity available in the dwelling and malaria occurrence at the household/individual level. The analysis is done taking into consideration the 87 thousand children surveyed across the 50 thousand rural households living in the 10 sub-Saharan countries being surveyed. A total of three models are estimated for the pooled household and individual level datasets; the three models take the form expressed in formula (2), (3) and (4)

$$Malaria_h = a_0 + b_1\,(electricity)_i + b_i\,X_i + e_{0i} \quad (2)$$

$$Malaria_i = a_0 + b_1\,(electricity)_i + b_i\,X_i + e_{0i} \text{ and} \quad (3)$$

$$Malaria_{cumulative} = a_0 + b_1\,(electricity)_i + b_i\,X_i + e_{0i} \quad (4)$$

where the dependent variable '$Malaria_h$' ('$Malaria_i$') in (2) ((3)) indicates whether the household '*h*' (individual '*i*') did test positive for malaria; the dependent variable $Malaria_{cumulative}$ indicates the variable measuring the number of malaria cases within the same household (0, 1, 2, etc if zero, one, two or more household members did test positive for malaria). Model (2) and (3) will be estimated via a logit model and via propensity score matching, whereas model (4) will be estimated via *poisson* regression.

The analysis is restricted to the households/household members living in rural areas, as existing evidence suggests that urban households are less likely to experience malaria even in countries in which malaria is endemic. The density of malaria vectors is on average higher in rural areas, where the environment is more suitable for malaria vectors' reproduction (Pellegrini and Tasciotti, 2016). Furthermore, households living in urban areas are on average wealthier than their rural counterparts -meaning better constructed houses, access to mass-media devices and larger availability of treated bed-nets- which are all factors which tend to reduce the occurrence of malaria cases.

The analysis here is done by taking into consideration the pooled rural households/individuals living in the 10 countries and in the different wealth decile. The wealth deciles variable –here considered as a proxy for the household's socio-economic status-affects the electricity-malaria nexus indirectly via influencing individual behaviours.[4] Better-

[4] The wealth decile variable is constructed so that each country taken into consideration here has 10 % of their rural households in the lowest decile, 10 % in the second lowest, and so on until the 10th decile.

off households are more likely to adopt malaria prevention strategies –purchase bed-nets, living in houses with no entry points for malaria vectors (i.e. built with better construction material), etc … - even though a number of studies point out that the nexus between income and malaria is positive but not significant (Worrall et al., 2005).

The econometric analysis that follows will use a range of control variables, those indicated by X_i in model (1), (2) and (3); in addition to the electricity use, the independent variables relate to the use of the radio, telephone and television, the condition of the dwelling (material used to build the wall and used for building the roof), the number of bedrooms used for sleeping, the amount of bed net used for sleeping by the household members, the typology of fuel used for cooking, the year of the survey and the country being surveyed (the summary statistics for those variables at both the household and individual level are in Tables 8 and 9). The choice of control variables relies on prior analysis done to explain the factor associated to malaria occurrence and it is summarised in Table 4.

The variable 'electricity' is a binary one, indicating whether a household is connected to electricity (value '1') or not (value '0'). Additionally, variables such as 'radio,' 'telephone,' and 'television' are included to gauge the level of connectivity of each household with the broader outside world. The premise is that greater connectivity facilitates access to information, including malaria prevention practices which are available via radio and television. Televisions and radios' ownership is anticipated to reduce malaria incidence by enhancing awareness among household members regarding malaria, its causes, and its consequences (Grimm et al., 2015).

Incorporating variables related to the number of household members sharing a room and the quantity of bed-nets used for adults and children addresses the heightened malaria risk associated with larger households (Huldén et al., 2014). Larger households may face challenges in affording bed-nets for all members, and their sanitation systems—positively correlated with disease occurrence—might be subpar (Ayele et al., 2012).

All variables concerning dwelling quality are included in the models because housing conditions can influence malaria occurrence (Guthmann et al., 2001). Poorly constructed houses, as well as those made of non-durable materials with traditional roofing like earth or thatch, are linked to increased malaria risk due to potential access points for malaria vectors (Yamamoto, 2010).

Table 4
Control variables used in the analysis.

Variable	Explanation	Reference
Household has electricity	Mosquitoes are attracted to light	Tasciotti (2017); Barghini and de Medeiros (2010)
Household has radio, television and telephone	Technology provides households with greater access to news which leads to more awareness	Grimm et al. (2015)
Number of rooms used for sleeping	Dwellings with several rooms for sleeping may not display bed nets for everyone	Ajadi et al. (2012)
Number of bed nets and number of bed nets for children	The use of bed net will reduce the occurrence of malaria	Holtz et al. (2002)
Household using polluting energy for cooking	Smoke from the use of firewood acts as a natural repellent for malaria vectors	Seyoum et al. (2003)
Wealth decile	Welathier households adopt malaria prevention strategies –purchase bed nets, more durables material used for the dwelling, etc	Worrall et al. (2005)
Poor material for the walls and roof	Dwelling built with non-durable materials may provide entry points for malaria vectors	Tusting et al. (2017)
Rural households	The density of malaria vectors is higher in rural areas,	Pellegrini and Tasciotti (2016)

Notes: Multiple sources.

Table 5 displays the results for the logit estimation of model (2), which looks at the electricity-malaria nexus at the household level. The dependent variable is a binary indicator of whether any household member had malaria (value '1') or not (value '0'). The analysis includes all rural households divided by wealth decile, as indicated in the table.

The relationship between electricity and malaria appears to be consistently positive and significant, although the nature and magnitude of this effect vary across different wealth deciles. The most pronounced positive effect is observed in the lowest wealth decile, where having electricity may increase the likelihood of malaria by 42 %, with this result being significant. Several factors may account for this relationship, detailed in Section 2; notably, electricity -along with light bulbs- can attract mosquitoes, particularly in dwellings with numerous entry points due to inferior construction materials (as often seen in poorer households).

Electricity has a positive impact on the likelihood of at least one household member contracting malaria for households below the 5th, 7th, and 9th deciles (with significant coefficients), albeit with diminishing effect sizes as wealth decile increases (15 %, 13 %, and 10 %, respectively). Conversely, the electricity-malaria nexus is negative and significant for households in the highest wealth decile, underscoring electricity's potential as a development tool and not as a malaria threat anymore. A 50 % reduction in malaria occurrence suggests the importance of having electricity as a development tool and as a way of reducing malaria occurrence too (e.g. use of electric fan).

Table 12 shows the results for model (2) by using the propensity score matching; this means that malaria outcomes between households with and without electricity are compared after matching households based on the control (observable) variables previously mentioned. Results shows a very similar story in terms of sign and significance, with the only difference being that the coefficient are smaller (in the range of -0.30 and $+0.26$).

The logit results in Table 6 refer to model (3) in which malaria occurrence and its relationship with electricity is measured at the individual level, for children aged between 1 month and 5 years which have been tested. The electricity-malaria nexus in this setting resembles the one we previously discussed; the nexus is positive and significant for lower-level wealth and become positive (and significant) for household members in the 10th wealth decile. The relationship is positive and significant in all the other deciles (apart from the second decile) with the magnitude of the effect decreasing; having electricity may increase malaria occurrence by 30 % if children are in households in the lowest wealth decile, with this effect being halved if the children belong to households in the seventh or lower wealth decile. The propensity score matching results for model (3) are in Table 13; the coefficients associated to the variable 'Electricity', once again, are in line with the ones showed here. While the signs and the significance of the coefficients do not change across the specifications, the magnitude does (coefficients range between -0.38 and 0.29 using the logit and between -0.20 and $+0.18$ using the propensity score matching).

Table 7 shows the results of model (4) in which the dependent variable is a categorical one as it assumes value zero if no children in the households has had malaria, 1 if only one household member has had malaria, 2 if two household members have had malaria and so not. Results are in line with the ones previously commented; having electricity seems to have an impact on the number of children having had malaria. The electricity-malaria relationship is positive but only significant when we restrict the analysis to those households in the lowest wealth decile. The relationship is positive and significant (although the marginal effect is lower) for children in households in the seventh wealth quintile or lower, and negative and significant for children in households in the tenth wealth quintile.

These findings shed light on the multi-faceted nature of the electricity-malaria nexus, which seems to be positive and significant in households having a lower wealth status. These findings do offer insights

Table 5
Results for the logit estimation of model (2).

	1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 7th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Electricity	0.42** (0.21)	−0.09 (0.17)	0.11 (0.13)	0.15*** (0.05)	0.13*** (0.04)	0.10*** (0.03)	−0.52*** (0.09)
Constant	124.13*** (32.74)	−6.25 (29.49)	44.85 (28.98)	64.72*** (13.06)	74.86*** (10.94)	53.28*** (5.51)	114.92*** (39.30)
# of obs.	4902	4899	4898	24,496	34,292	44,090	4893
Pseudo R2	0.01	0.001	0.03	0.03	0.03	0.03	0.06

Notes: Authors' calculation from the Demographic and Health Surveys. Malaria reported cases at the household level represents the dependent variable; the independent variables refer to the use of the radio, telephone and television, the condition of the dwelling (material used to build the wall and used for the roof), number of bedrooms used for sleeping, the amount of bed net used for sleeping by the household members and the typology of fuel used for cooking. The coefficients of all the control variables are not presented in the table but are available upon request. *, ** and *** indicate respectively significance at 10, 5 and 1 %.

Table 6
Results for the logit estimation of model (3).

	1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 7th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Electricity	0.29* (0.15)	−0.03 (0.13)	0.26*** (0.10)	0.16*** (0.04)	0.16*** (0.03)	0.15*** (0.02)	−0.38*** (0.07)
Constant	220.46*** (25.38)	46.70** (22.13)	81.77*** (22.17)	118.69*** (9.92)	123.58*** (8.32)	103.98*** (7.41)	175.90*** (30.95)
# of obs.	8762	8752	8757	43,774	61,279	78,783	8749
Pseudo R2	0.07	0.03	0.02	0.03	0.02	0.02	0.042

Notes: Authors' calculation from the Demographic and Health Surveys. Malaria reported cases at the individual level represents the dependent variable; the independent variables refer to the use of the radio, telephone and television, the condition of the dwelling (material used to build the wall and used for the roof), number of bedrooms used for sleeping, the amount of bed net used for sleeping by the household members and the typology of fuel used for cooking. The coefficients of all the control variables are not presented in the table but are available upon request. *, ** and *** indicate respectively significance at 10, 5 and 1 %.

Table 7
Results for the poisson estimation of model (4).

	1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 7th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Electricity	0.24*** (0.11)	−0.05 (0.12)	0.35 (0.07)	0.03 (0.03)	0.01* (0.01)	−0.00 (0.01)	−0.43*** (0.07)
Constant	105.73*** (19.28)	−6.24*** (20.48)	33.08** (16.88)	54.62*** (7.69)	57.41*** (6.58)	45.89*** (5.98)	113.14*** (31.23)
# of obs.	4902	4899	4898	24,496	39.189	44,090	4893
Pseudo R2	0.05	0.01	0.03	0.03	0.03	0.03	0.06

Notes: Authors' calculation from the Demographic and Health Surveys. Cumulative cases of malaria at the household level represents the dependent variable; the independent variables refer to the use of the radio, telephone and television, the condition of the dwelling (material used to build the wall and used for the roof), number of bedrooms used for sleeping, the amount of bed net used for sleeping by the household members and the typology of fuel used for cooking. The coefficients of all the control variables are not presented in the table but are available upon request. *, ** and *** indicate respectively significance at 10, 5 and 1 %.

for policymakers and public health practitioners; unpacking this relationship, we move closer to developing targeted interventions that address the root causes of disease vulnerability (e.g the condition of the dwelling), fostering healthier communities and brighter futures for children living in more vulnerable settings.

5. Conclusions and policy implications

This paper investigates the relationship between access to electricity and malaria occurrence among children aged 1 month to 5 years in 10 Sub-Saharan African countries, using data from 15 household-level surveys. The analysis reveals a positive and significant association between electrification and increased malaria risk, particularly among lower-income households. While electrification brings numerous benefits, such as improved living conditions and enhanced health infrastructure, it also heightens exposure to malaria vectors due to increased indoor activity after dark and the attraction of vectors to electric lights. This underscores the need for policymakers to address the dual challenge of advancing electrification while safeguarding public health.

Policymakers must recognize the unintended health risks associated with electrification and design integrated programs that combine electrification efforts with targeted malaria prevention strategies. Electrification projects should be accompanied by robust public health campaigns that promote the use of insecticide-treated nets (ITNs), indoor residual spraying (IRS), and structural modifications like window and door screens to reduce vector entry into homes.

The analysis highlights that lower-income households are disproportionately affected by the increased malaria risk associated with electrification. Policymakers should prioritize targeted interventions for this vulnerable share of the population, providing support -financial, in-kind or in the form of educational material-to lower-income households can enhance their capacity to adopt effective malaria control measures. Electrification related projects in rural sub-Saharan areas which are malaria endemic should be accompanied by:

i. Design and implementation: Electrification programmes should integrate ITN's with the provision of electricity; indoor lighting should be prioritized over outdoor lighting.
ii. Awareness and education: Complementary community awareness campaigns can inform rural residents about risks associated

with increased outdoor artificially lighted activity during peak mosquito hours.

iii. Monitoring and mitigation: National rural electrification plans should include malaria surveillance as part of their rollout to detect and manage unintended health effects.

iv. Cross-sectoral collaboration: Ministries of energy, health, and environment should coordinate infrastructure and public health policies to pre-empt potential trade-offs.

Public awareness campaigns should be a critical component of electrification projects and tailored to educate communities about the potential health risks associated with electricity use, such as increased exposure to malaria vectors, and promote protective behaviours. Educational efforts should be culturally sensitive and accessible to ensure broad community engagement and uptake.

Improving access to healthcare in electrified regions is essential for managing the increased malaria burden. Policymakers should ensure that health facilities in these areas are equipped with the necessary resources to diagnose and treat malaria effectively. This includes adequate staffing, training of health workers on malaria case management, and ensuring a steady supply of antimalarial medications.

To effectively address the evolving dynamics between electrification and malaria, continuous research and monitoring are necessary. Policymakers should support longitudinal studies that track the long-term impacts of electrification on malaria incidence, allowing for evidence-based adjustments to interventions. Monitoring and evaluation frameworks should be embedded within electrification programs to assess their health impacts regularly.

Effective malaria control in the context of electrification requires coordinated efforts across sectors. Governments, NGOs, international agencies, and private sector stakeholders should collaborate to leverage resources and expertise. International funding and technical assistance can support the scaling up of successful integrated interventions, ensuring their sustainability and effectiveness.

Electrification is a critical driver of development in rural Sub-Saharan Africa, but its implementation must be mindful of unintended health consequences, particularly the increased risk of malaria. A holistic approach that integrates electrification efforts with targeted malaria prevention and socioeconomic support is essential for maximizing the benefits of electrification while minimizing health risks. By adopting integrated, data-driven policies that address the complex interplay between energy access and health, policymakers can promote sustainable development and improve the quality of life for rural communities in Sub-Saharan Africa.

Declaration of competing interest

There are no interest to declare.

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Appendix

Table 8
Summary statistics at the household level

Variable	No. of obs.	Mean	Std. dev.	Min.	Max
Household level malaria	48,997	0.40	0.49	0	1
Cumulative measure of malaria	48,997	0.58	0.85	0	11
Household has electricity	48,997	0.21	0.41	0	1
Household has radio	48,997	0.50	0.50	0	1
Household has telephone	48,997	0.76	0.43	0	1
Household has television	48,996	0.22	0.41	0	1
Number of rooms used for sleeping	48,984	2.64	1.98	0	9
Number of bed nets	48,997	0.75	0.43	0	1
Household using polluting energy for cooking	48,997	0.91	0.29	0	1
Number of bed nets for children	48,997	0.58	0.49	0	1
Poor material for the walls	48,997	0.28	0.45	0	1
Poor material for the roof	48,997	0.30	0.46	0	1
Number of children sleeping under bed net	48,997	0.94	1.04	0	12

Notes: Notes: Authors' calculation from the Demographic and Health Surveys.

Table 9
Summary statistics at the individual level

Variable	No. of obs.	Mean	Std. dev.	Min.	Max
Individual level malaria variable	87,552	0.32	0.47	0	1
Cumulative measure of malaria	87,552	0.32	0.47	0	1
Household has electricity	87,552	0.19	0.40	0	1
Household has radio	87,552	0.52	0.50	0	1
Household has telephone	87,552	0.78	0.42	0	1
Household has television	87,549	0.23	0.42	0	1
Number of rooms used for sleeping	87,535	3.06	2.78	0	9
Number of bed nets	87,552	0.76	0.43	0	1
Household using polluting energy for cooking	87,552	0.89	0.31	0	1
Number of bed nets for children	87,552	0.60	0.49	0	1

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Table 9 (*continued*)

Variable	No. of obs.	Mean	Std. dev.	Min.	Max
Poor material for the walls	87,552	0.27	0.45	0	1
Poor material for the roof	87,552	0.31	0.46	0	1
Number of children sleeping under bed net	87,552	1.18	1.36	0	12

Notes: Notes: Authors' calculation from the Demographic and Health Surveys.

Table 10
Share of malaria positive by country, year and wealth quintile (at the individual level)

		1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 7th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Angola	2015	5.83	10.59	22.56	16.78	20.64	23.08	13.38
Angola	2016	0	27.19	26.95	24.35	25.38	26.69	17.55
Cameroon	2018	31.03	37.93	37.07	37.25	36.66	34.98	22.78
Ghana	2014	55.26	57.86	60.56	61.22	61.61	58.34	24.41
Ghana	2016	45.70	56.00	43.83	48.59	49.92	47.25	16.52
Ghana	2019	35.83	49.24	32.62	36.26	35.74	35.28	18.48
Kenya	2015	3.99	13.04	14.91	16.17	18.08	17.37	7.34
Kenya	2020	5.84	12.45	14.68	13.16	13.43	13.70	6.39
Liberia	2016	62.50	63.69	68.13	65.15	64.83	63.81	47.47
Mali	2015	49.46	43.16	45.23	44.77	42.55	39.81	14.72
Mali	2018	49.46	26.71	24.65	25.55	24.41	23.01	4.37
Mali	2021	28.64	26.75	20.38	23.40	24.24	22.77	5.31
Mozambique	2015	61.31	56.72	54.55	55.59	49.77	44.33	17.59
Mozambique	2018	61.97	55.26	59.76	55.61	52.74	49.01	16.49
Nigeria	2015	64.80	65.58	67.47	63.48	60.46	55.55	27.48
Nigeria	2018	53.32	59.55	56.84	55.43	52.41	49.07	23.38
Nigeria	2021	53.43	58.92	56.80	54.35	50.00	47.05	16.67
Sierra Leone	2016	62.92	65.00	67.91	66.74	66.81	66.56	57.07
Tanzania	2015	18.93	25.00	17.61	19.49	17.02	13.93	1.67
Tanzania	2016	21.68	25.71	20.82	23.09	22.02	21.17	1.64
Tanzania	2017	14.33	15.72	14.26	12.97	12.59	11.10	1.86

Notes: Notes: Authors' calculation from the Demographic and Health Surveys.

Table 11
Share of households with electricity access by country, year and wealth quintile (at the individual level)

		1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 7th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Angola	2015	0	3.53	0	1.37	3.30	4.91	44.37
Angola	2016	0.75	2.76	1.95	1.45	1.51	2.80	57.14
Cameroon	2018	0	0.38	2.70	1.73	11.01	22.44	85.33
Ghana	2014	3.32	10.00	25.35	16.54	29.29	42.16	100
Ghana	2016	7.53	8.00	20.85	16.99	32.45	45.42	95.54
Ghana	2019	12.30	14.72	42.25	30.64	45.04	55.83	98.58
Kenya	2015	0	0	1.15	0.49	1.01	2.80	48.43
Kenya	2020	1.2	1.38	3.07	3.58	8.44	15.15	77.08
Liberia	2016	0	0	0	0	0	0.28	11.39
Mali	2015	6.42	9.39	9.54	11.05	15.36	17.09	65.85
Mali	2018	8.08	14.33	17.61	15.29	22.86	29.04	79.08
Mali	2021	0	0.15	0.38	0.52	3.23	7.79	68.33
Mozambique	2015	0	0	0	0	0.25	2.08	47.93
Mozambique	2018	0	0	0	0	1.10	3.88	72.04
Nigeria	2015	2.63	5.19	8.90	5.84	13.10	25.88	92.75
Nigeria	2018	2.06	4.85	7.28	6.23	18.10	30.47	90.42
Nigeria	2021	0	1.14	3.35	3.31	10.19	21.51	89.43
Sierra Leone	2016	0	0.18	0.89	0.40	0.74	0.97	14.31
Tanzania	2015	0	0	0	0.11	0.19	0.47	68.57
Tanzania	2016	0	0	0	0	0.13	0.34	54.10
Tanzania	2017	0	0	0	0.09	0.33	1.50	55.04

Notes: Notes: Authors' calculation from the Demographic and Health Surveys.

Table 12
Results for the propensity score matching estimation of model (2)

	1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 8th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Electricity	0.26** (0.13)	−0.05 (0.10)	0.07 (0.08)	0.09*** (0.03)	0.08*** (0.02)	0.06*** (0.02)	−0.30*** (0.05)

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Table 12 (*continued*)

	1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 8th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Constant	74.86*** (20.04)	−4.12 (18.30)	27.17 (17.96)	40.19*** (8.09)	46.08*** (6.77)	32.43*** (5.96)	61.42*** (22.10)
# of obs.	4902	4899	4898	24,496	34,292	44,090	4893
Pseudo R2	0.07	0.03	0.03	0.03	0.03	0.03	0.06

Notes: Authors' calculation from the Demographic and Health Surveys. Malaria reported cases at the household level represents the dependent variable; the independent variables refer to the use of the radio, telephone and television, the condition of the dwelling (material used to build the wall and used for the roof), number of bedrooms used for sleeping, the amount of bed net used for sleeping by the household members and the typology of fuel used for cooking. The coefficients of all the control variables are not presented in the table but are available upon request. *, ** and *** indicate respectively significance at 10, 5 and 1 %.

Table 13
Results for the propensity score matching estimation of model (3)

	1st wealth decile	2nd wealth decile	3rd wealth decile	Less or equal than 5th wealth decile	Less or equal than 7th wealth decile	Less or equal than 9th wealth decile	10th wealth decile
Electricity	0.18* (0.09)	−0.02 (0.08)	0.15** (0.06)	0.10*** (0.02)	0.10*** (0.01)	0.09*** (0.01)	−0.20*** (0.04)
Constant	131.85*** (15.27)	28.50*** (13.60)	50.02*** (13.55)	72.70*** (6.06)	75.32*** (5.08)	62.84*** (4.49)	92.80 (16.92)
# of obs.	8762	8752	8757	43,774	61,279	78,783	8749
Pseudo R2	0.07	0.03	0.03	0.02	0.02	0.02	0.04

Notes: Authors' calculation from the Demographic and Health Surveys. Malaria reported cases at the household level represents the dependent variable; the independent variables refer to the use of the radio, telephone and television, the condition of the dwelling (material used to build the wall and used for the roof), number of bedrooms used for sleeping, the amount of bed net used for sleeping by the household members and the typology of fuel used for cooking. The coefficients of all the control variables are not presented in the table but are available upon request. *, ** and *** indicate respectively significance at 10, 5 and 1 %.

Data availability

Data will be made available on request.

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