When does electrification work? Evidence from sub-Saharan Africa

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- This policy brief explores findings from a study on the effects of rural electrification in sub-Saharan Africa, seeking to understand the determinants of its success and failures in terms of electricity access, adoption, usage, and the economic effects of electrification.
- This brief provides three insights for policy:
    1. Current grid infrastructure appears severely misallocated across space in large swaths of rural sub-Saharan Africa.
    2. "Last mile" problems in electrification can be overcome by identifying suitable productive uses of electricity across locations, either pre-existing or potential, as anchor customers.
    3. Improved targeting of grid electricity across rural locations implies substantial gains.

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Executive summary

This policy brief explores findings from a study on the effects of rural electrification in sub-Saharan Africa. The study seeks to understand the economic effects of electrification, and the determinants of success and failures in terms of electricity access, adoption, and usage.

In a majority of the Sub-Saharan African countries studied, villages connected to the electric grid fall into one of two categories: either very few households are connected, or nearly all households are. Over 410 million people in rural Sub-Saharan African countries find themselves in one of these two worlds.

Exploiting the country-wide roll-out of a recent rural electrification programme in one country, Zambia, we show that:

- The aggregate effects of rural electrification on adoption, usage and economic outcomes are modest at best, confirming existing evidence in the literature.
- Locations with pre-existing productive uses of electricity, such as grain mills, experience almost full household electrification in contrast to near-zero adoption elsewhere.
- Any major development effects of rural electrification are almost exclusively confined to the locations with pre-existing productive uses of electricity.

Additional evidence from other countries, such as Tanzania, confirms the Zambian results, pointing towards systemic ‘last mile’ problems that determine when and where electrification can work in causing economic development.

This brief provides three insights for policy:

1. Current grid infrastructure appears severely misallocated across space in large swaths of rural sub-Saharan Africa.
2. "Last mile" problems in electrification can be overcome by identifying suitable productive uses of electricity across locations, either pre-existing or potential, as anchor customers.
3. Improved targeting of grid electricity across rural locations implies substantial gains.

Policy motivation

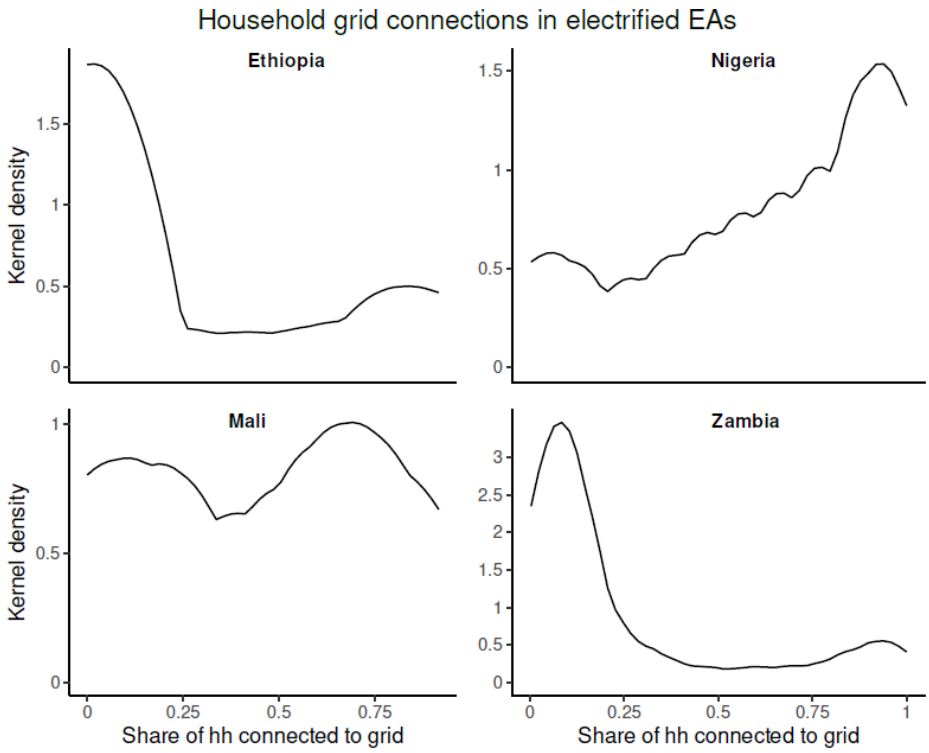
Electrification is highly positively correlated with economic development. This fact has motivated the massive expansion of electric grids in recent years. Over the last decade, low-income countries have extended their grids by 60%, building more than seven million kilometres of new lines (IEA, 2023). Focus on

universal access directed grid expansion into rural areas. However, existing causal evidence suggests that recent electrification programmes have had modest average effects at best.

This research is motivated by a new empirical fact that we uncover: in rural sub-Saharan Africa (SSA), the world's least electrified region and current electrification frontier, most rural locations with existing electric grid access display either close to zero or almost full electricity adoption. We document that in 18 out of 24 countries in SSA with suitable data, modest average household electrification rates mask a bimodal distribution across rural locations with grid access (see Figure 1 for a selection of four countries, and Appendix Figure 1 for all 24 countries with data). The bimodal adoption pattern indicates a spatial variation in the types of locations served by the electric grid and their newly connected populations. Villages that gain access to the grid tend to fall into one of two categories: either very few households are connected, or nearly all households have access to electricity.

What could drive high adoption of electricity in some locations but virtually none in others? In other words, when does electrification work?

FIGURE 1: Household Grid Connections in Electrified Areas



Overview of research and key findings

In this study, we empirically test for the potential determinants of successful rural electrification and proceed in four steps:

Step 1

We document a novel finding: electricity adoption across the world's current electrification frontier displays a bimodal distribution, as shown in Figure 1.

Step 2

We highlight that electrification is plagued by a "last mile" problem due to the high fixed cost of local low-voltage electricity lines, poles, service drops, meters and wires, which require a large, up-front investment for the community to enable the adoption of electricity for usage. Such "last mile" infrastructure is costly and translates into a fixed cost of connection for firms and households that is often multiples of monthly income—hardly affordable for the vast majority of potential end-users.

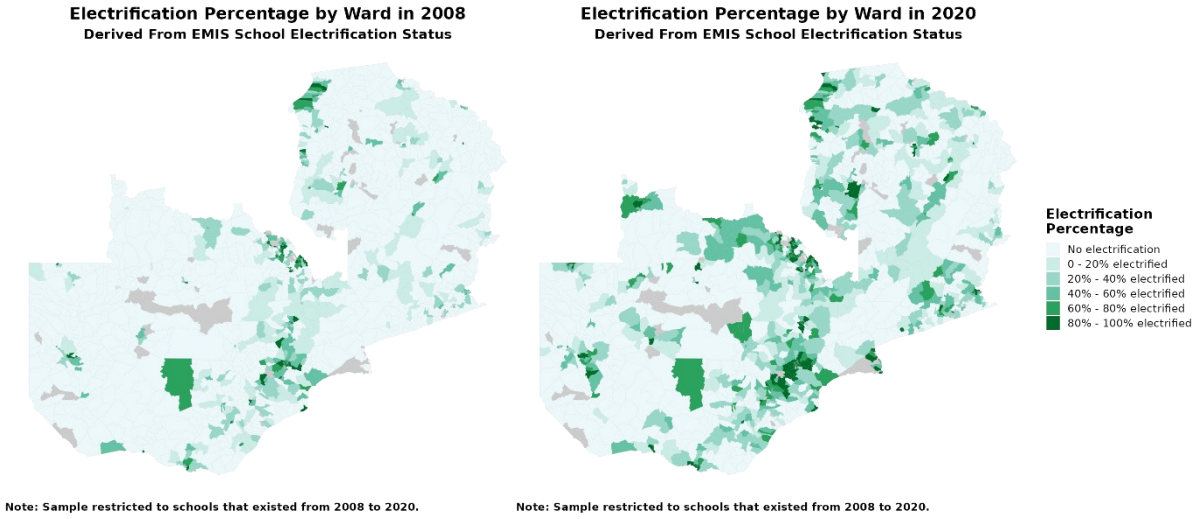
This barrier to electrification occurs after the electrical grid has arrived but before end-users can connect. This helps explain why certain locations experience either minimal electricity adoption—where the high fixed costs of establishing the "last mile" infrastructure are unaffordable—or near-complete electricity adoption in areas where these costs can be covered. In the latter case, connected firms (acting as anchor customers) and households share the burden of these high fixed costs among many parties.

Historically, the rationale for overcoming the "last mile" problem was to identify at least one relatively heavy end-user of electricity as an anchor customer, such that this customer could either contribute a disproportionate share of the fixed cost for the entire location or at least coordinate location-wide adoption by bringing in more interested customers such as residential households. A similar rationale is documented in rural electrification plans at today's frontier, such as in Zambia.

Step 3

We exploit a large-scale, country-wide rural electrification programme in Zambia which shares many of the features of other low-income countries' past and recent rural electrification programmes. The Zambian Rural Electrification Master Plan (REMP), initiated in 2009, has succeeded in dramatically expanding the electric grid into rural Zambia. Figure 2 highlights how hundreds of locations across Zambia experienced the arrival of the electric grid.

FIGURE 2: Electrification of Zambia from 2008 to 2020

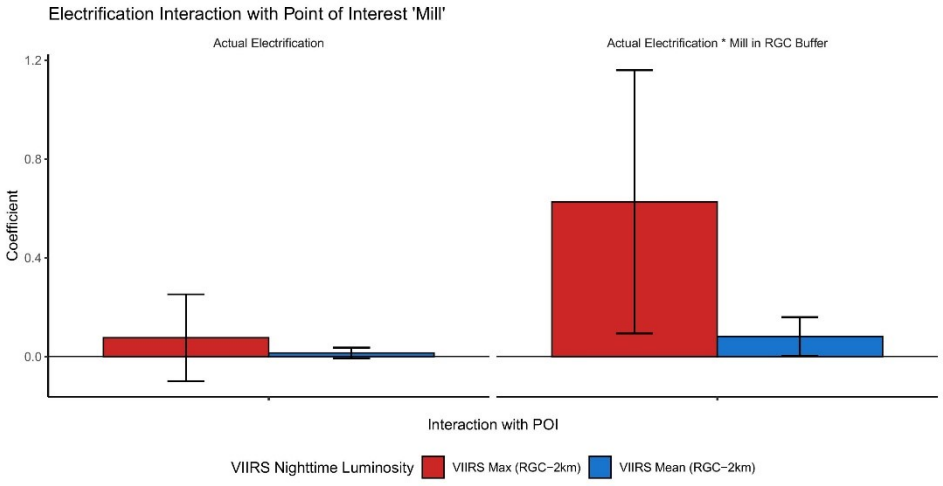


Despite this large-scale expansion of the grid, we find that the aggregate effects of rural electrification are indeed mixed, as shown in other rural contexts, for example in Kenya or India (Lee et al., 2020; Burlig and Preonas, 2024).

However, in line with historical precedent in the US and the original engineering plans in Zambia, we can show that the presence of pre-existing productive uses of electricity as anchor customers in newly electrified locations dramatically changes the effects of electrification: locations with pre-existing productive use experience almost full electrification, and any beneficial development effects of electrification are confined to the few rural locations with pre-existing productive uses.

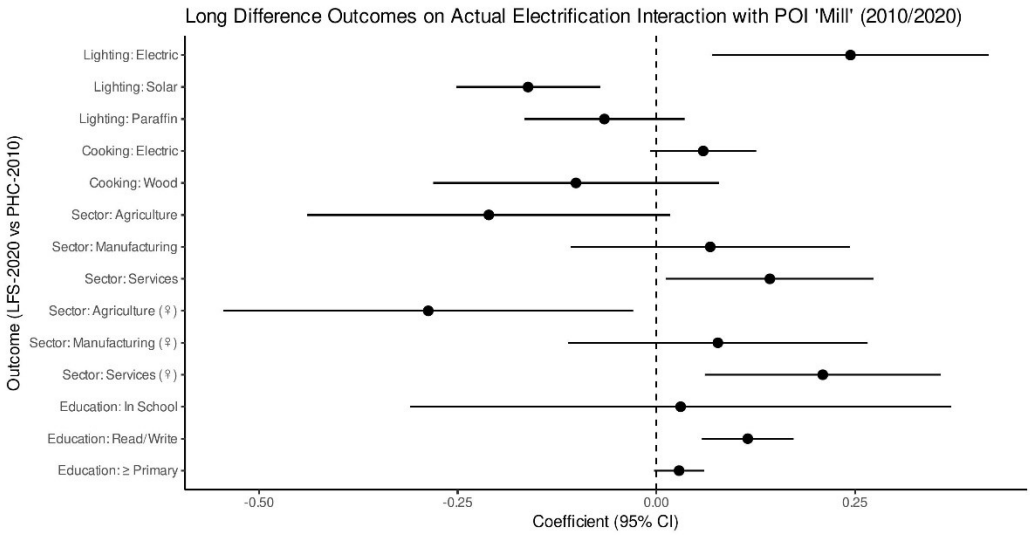
Figure 3 shows how nighttime luminosity, as one objective proxy measure of electricity adoption and usage, is vastly higher and statistically significantly positive in locations with preexisting productive uses of electricity (here: grain mills), compared to those locations without these uses.

FIGURE 3: Electricity Adoption and Usage in Rural Zambia



In addition, as Figure 4 shows, these locations with high adoption and high usage also experience positive development effects. Households switch from paraffin and solar to electric lighting and substitute cooking with firewood for cooking with electric stoves. A potentially large share of the workforce quits agriculture and joins the services sector, especially retail and wholesale. Interestingly, and in line with the results on in-home lighting and cooking changes, this structural transformation out of agriculture is particularly driven by women. Results we would expect to happen, happen. Finally, the large gains in village-wide educational attainment among the working-age population (measured either as literacy or as completed primary schooling) indicate significant in-migration of more educated adults to the newly electrified village.

FIGURE 4: Development Effects of Electrification in Rural Zambia



In contrast, locations without preexisting productive uses when the grid arrives do not experience any gains in nighttime luminosity, no significant increases in household electricity adoption, and no significant changes in workers moving out of agriculture.

What is an example of productive uses of electricity that could function as an anchor customer in rural low-income countries? In the context of Zambia, the most prominent example of productive uses of electricity are small-scale grain mills that switch from diesel power to electricity upon arrival of the grid. Millers anecdotally report cost savings of up to 80% upon switching from diesel to electricity, a disproportionate incentive to adopt electricity once the grid has arrived in the mill's village. Reassuringly, productive end-uses such as mills were originally mentioned as prime targets of rural electrification both in the Zambian Rural Electrification Master Plan and also by the United States' Rural Electrification Administration in the 1950s, which followed a similar targeting strategy.

This stark result is not driven by locations with preexisting productive uses being larger, more densely populated, richer or connected earlier. Instead, it appears that preexisting productive uses, as key beneficiaries of electrification in rural areas, contribute substantially to and/or help coordinate the payment of the high fixed cost of the "last mile" infrastructure inside the village.

Step 4

Finally, we confirm that a similar mechanism appears at play in other sub-Saharan African countries: we can show that in Tanzania, preexisting productive use of electricity also matters in translating grid arrival into electricity adoption, confirming our core hypothesis that electrification only works in places in which the "last mile problem" can be overcome.

Policy implications

Our key takeaway is that rural electrification can have positive development effects in rural sub-Saharan Africa — but probably not everywhere.

We show that the targeting of rural grid expansion to locations with preexisting productive uses provides one avenue for making electrification work. Importantly, these positive development effects are unlikely to be driven by the electrification of productive users alone. Instead, we provide suggestive evidence that productive users act as anchor customers and help overcome the "last mile problem" of rural electrification in their community, enabling wider adoption by other firms and households.

Therefore, our research provides three policy implications:

1. In rural grid expansion, targeting locations with productive uses of electricity provides the safest avenue to drive economic development. Accurate data on which productive users exist in which locations – obtained before electrification planning starts to inform the targeting process – is therefore essential for the success of rural electrification programmes.
2. In locations that do not already feature preexisting productive uses of electricity, a big push investment is required to overcome the "last mile" problem by providing the local low-voltage infrastructure to attract such productive users.
3. Rural electrification by means of grid expansion is extremely costly, and locations that cannot support productive uses of electricity are unlikely to display the economic returns that warrant such investments. Off-grid solutions appear better suited to provide electricity to these small, remote and less dynamic locations with limited economic growth potential.

References

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Appendix

Figure 1