Household effects of electrification through mini-grids: Evidence from a nation-wide policy reform in Tanzania[*]

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Abstract

Mini-grids are becoming the mainstream solution to provide electricity to communities in access-deficit countries, but little is known about their effectiveness in increasing electricity access and improving household welfare. We provide novel empirical evidence on this matter in the context of Tanzania, where two policy reforms doubled the number of mini-grids since 2008. Exploiting spatial and temporal variation created by the distance to the households in proximity to mini-grids and the timing of their deployment, and using data from two different surveys, we find local electrification rates increased by about 16-23%. This result is consistent with a surge in nighttime light radiance nearby newly developed projects. We document mini-grids reduced the use of pollutant fuel-based lighting devices and increased the uptake of electric-powered devices. Further evidence suggests the prevalence of diarrhea among children decreased, plausibly driven by improved food security.

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1 Introduction

As of 2022, around 800 million people do not have access to modern energy services; about three-quarters of them are in Sub-Saharan Africa (SSA). Lack of access to electricity is often associated with lower household income, indoor pollution, and poor health outcomes (Dinkelman, 2011; Van de Walle et al., 2013; Barron and Torero, 2017). Even though enabling universal access to electricity by 2030 is UN's Sustainable Development Goal #7, and despite the efforts of many institutions to reduce energy poverty, achieving this goal remains a costly challenge: the International Energy Agency (IEA) estimates it will require about $49 billion per year. Identifying least-cost solutions and evaluating the effectiveness of the different infrastructure options is, thus, essential to optimally allocate investment and aid.

As also occurs with other projects targeted by development assistance, the debate surrounding the provision of power-related infrastructure has often been limited to two opposing approaches: large-scale, centralized projects (national grid), and small-scale, decentralized options (home-based solar panels) —see Deichmann et al. (2011) and Lee et al. (2016).[1] In fact, various research articles document the impact of both centrally-planned grid expansions projects —e.g., in India (Burlig and Preonas, forthcoming), Brazil (Lipscomb et al., 2013), and South Africa (Dinkelman, 2011)—, and home-based, off-grid solutions —e.g., in Kenya (Lee et al., 2020b) and Rwanda (Grimm et al., 2020)—, often presenting mixed evidence. Neither of these types of projects, though, is likely to bring *per se* any additional investment in generation capacity or power-related facilities to local communities.

However, many developing countries have recently witnessed massive investment in mini-grids — a "middle ground" infrastructure option between large-scale and small-scale approaches— aimed at spurring a faster and greener path towards universal electrification (Suri, 2020), that also contribute to creating jobs at the local level (Joshi, 2021; Pueyo et al., 2022). This trend has been particularly marked in SSA, where according to ESMAP (2019) there are around 1,500 mini-grids (representing a total investment of about $4 billion) with an additional 4,000 in the planning stages (almost two in every three of the total ones planned globally).[2] Despite the significant financial investment and aid initiatives directed towards mini-grids —e.g., the World Bank allocated $1.6 billion to these projects between 2015 and 2019,

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[1] Similar debates regarding centralized versus decentralized provision of essential infrastructure for development exists in some other sectors, such as telecommunications (Aker and Mbiti, 2010), and water and sanitation (Kresch, 2020).

[2] The COVID-19 pandemic slowed down the growth of this sector in 2020 and 2021. Still, as explained by AMDA (2022), mini-grid developers in Africa almost doubled the number of connections between 2019 and 2021.

with additional commitments of more than $1.3 billion in the coming years— there is a lack of empirical evidence on their effectiveness in promoting electrification and, more generally, household well-being.

In this paper, we close this gap in the literature by estimating the causal economic and health impact of mini-grids in the context of a series of groundbreaking regulatory policies and financial support schemes that encouraged massive investment in this sector in Tanzania. Following these mandates, the number of mini-grids in this country doubled between 2008 and 2018, making it the regional leader in mini-grid development (Odarno et al., 2017). This setting is, therefore, particularly appropriate for studying ongoing electrification efforts, as it provides a unique opportunity to extract insights for other countries with similar low electrification rates on the benefits of the promotion of mini-grid investment.

Empirically, we combine geo-localized data on the universe of mini-grids deployed in Tanzania until 2017 with two different household-level survey datasets; namely, four waves of the National Panel Survey (NPS) of Tanzania 2008-2014, and seven waves of the (cross-sectional) Demographic and Health Survey (DHS) 1999-2017. Using this data, we exploit household spatial distance to a mini-grid within relatively narrowly defined geographical zones (of 10 km around each mini-grids) and the timing of deployment of the projects (frequently affected by administrative delays and engineering constraints) to estimate the causal effect on electricity access and some other welfare-related outcomes by defining treatment and control households based on their proximity to a mini-grid. Our empirical strategy is, thus, closely related to that used in a standard difference-in-differences design, as we compare outcomes in the treatment group (households relatively close to mini-grids) with households located relatively far from mini-grids before and after their deployment.[3] In the main specification of our regression model we also control for unobservable differences between mini-grids powered by different technologies, household characteristics, and region-wide (temporally dependent) shocks.

Our identification strategy rests, in particular, on three key and related assumptions, for which we provide evidence and hard facts that support them. First, households located in closer proximity to a mini-grid are (*ceteris paribus*) more likely to benefit from it —i.e., to get connected and, if so, to get a more reliable service— than those that are relatively far from it. Second, the exact location of a mini-grid within our relatively narrowly defined geographical zones is explained by (exogenous) topography-related features, such as surface roughness, the slope of the nearest water body, or any other features

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[3] In a related context, a very similar strategy is used, for example, by Benshaul-Tolonen (2019) and Bazillier and Girard (2020), who exploit the distance to mines to study the impact of the mining sector on household welfare in SSA.

of the terrain. Third, the outcomes of interest for households relatively close to a mini-grid and those relatively far from it would have trended similarly in the absence of the mini-grids —as we show that, indeed, pre-mini-grid trends are similar across the treatment and the control groups. We further support this assumption by showing that the estimated effects do not stem from a previously existing trend.

Our main estimates suggest that households concentrated within 5 km from a deployed mini-grid are on average about 16-23% more likely to have a connection to electricity in the post-deployment period, while this effect vanishes as households are located further away from it. These results are remarkably stable across various model specifications that include a rich set of socio-demographic controls and region-specific time trends using both the NPS and the repeated cross-sectional DHS datasets. Moreover, in both cases, they probe robust to the use of an alternative estimation strategy that takes into account potential spillovers between treated and control units, and also to the use of a propensity score matching procedure that corrects minor imbalances in some of the household characteristics across these two groups. Finally, the effect we document on the increase in electricity connections is further supported with satellite data, as we detect an increase in nighttime light radiance in areas close to the mini-grids in the "post-treatment" period that are not observed as we move further away from them.

An electricity connection, however, is not inherently valuable but is rather a means to achieving a variety of benefits for households, such as increased wealth, access to appliances, and improved health outcomes. Therefore, we then ask if the deployment of mini-grids is also causally associated with improvements in economic and health-related outcomes among the households in our sample. First, we provide evidence using the NPS dataset that, among the households that gained energy access through mini-grids, there is also a significant increase in the use of electricity as the main lighting source, to the detriment of fuel-based lighting devices such as oil lamps or paraffin. These lighting technologies, which are particularly popular across SSA (Choumert-Nkolo et al., 2019), are the main factors that contribute to indoor pollution and, therefore, are casually associated with severe respiratory diseases and premature death (Hanna et al., 2016; Imelda, 2018). Our estimates suggest that mini-grids have the potential to reduce the prevalence of health issues associated with indoor pollution.

Second, we also find a significant increase in the DHS wealth index among households located relatively close to a deployed mini-grid.[4] This finding is further supported by additional evidence from

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[4] As explained in the DHS website, this wealth index is a "composite measure of a household's cumulative living standard", and "is calculated using data on a household's ownership of selected assets".

both the DHS and NPS datasets, which shows that treated households also increase the ownership of selected electrical appliances, such as refrigerators and televisions. The use of refrigerators, in particular, can lead to improved food preservation and, consequently, to a lower prevalence of infectious and viral diseases (Hoffmann et al., 2019). Therefore, as a final empirical exercise, we examine whether the deployment of mini-grids in Tanzania had a positive impact on the prevalence of such diseases. Consistently, using some rounds of the DHS dataset, we find suggestive evidence that the installation of mini-grids reduced by up to 23% the incidence of diarrhea among children in nearby households.

As mentioned above, previous empirical studies focus on large-scale (Dinkelman, 2011; Moneke, 2020; Thomas et al., 2020; Moradi and Schmidt, 2022) and small-scale electrification projects (Lee et al., 2020b; Grimm et al., 2020). However, despite the increase they have experienced, relatively little is known about the impact of mini-grids. Moreover, the evidence in these previous studies is mixed and often contradictory. According to Fetter and Usmani (2020) and Lee et al. (2020a), this could be due to the fact that large-scale (grid extension) and small-scale (home-based) initiatives may not have a meaningful impact unless combined with "complementary investments" at the local level, or unless they target "households that are positioned to take actions" and that may "exploit new business opportunities". This concern is of less importance in our context because part of the rationale of mini-grids is precisely to bring investment that leads to new economic opportunities at the local level, as they involve routine operation and maintenance tasks (e.g., managing a generator, billing collection, etc.) that are carried out by the communities (Eras-Almeida and Egido-Aguilera, 2019; Joshi, 2021; Pueyo et al., 2022).

A closely related paper that focuses in particular on solar micro-grids in India is by Burgess et al. (2020). These authors document that household surplus from electrification tripled following the deployment of these projects. However, they show that the demand for connections to these microgrids is influenced by the availability of the central grid (perhaps due to the intermittency problem). In the same vein, Fowlie et al. (2019) also show that the demand for connections to solar mini-grids is relatively low due to a perception that the government would subsidize connections to the central grid.[5]

The overall lack of causal evidence on the economics of mini-grids stands in stark contrast to an abundant literature that provides descriptive analysis (e.g., based on case studies and/or survey data) documenting their effect on communities in different countries. For example, Kirubi et al. (2009) presents

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[5] A very similar conclusion in the context of the Indian electricity sector is by Comello et al. (2017).

descriptive survey data from Kenya that suggests a positive effect of mini-grids on nearby residents; Herbert and Phimister (2019) develop a wind-powered mini-grid case-study also in Kenya to discuss the expected benefits of it for both nearby rural households and small commercial consumers; and Tenenbaum et al. (2018) discuss the impact on local communities of three mini-grids in rural Cambodia.

Finally, this paper also contributes to the area of development economics that studies and quantifies the economic impacts of infrastructure projects.[6] As argued above, most of the previous papers have focused either on large-scale centralized projects or on small-scale, decentralized solutions in different sectors. However, the literature exploring the impact of "intermediate" infrastructure options —very well-represented by mini-grids for the particular case of the power industry— is scarce.

The rest of the paper is as follows. In Section 2 we present some background on mini-grids and the policies implemented in Tanzania. Section 3 provides the regression models, discusses the identification assumptions, and explains the data. Section 4 contains the empirical result, while Section 5 concludes.

2 Background

2.1 Mini-grids and their expansion in developing countries

A mini-grid is a stand-alone network that can operate autonomously without being connected to a centralized grid by using a locally operated and managed small-scale generator that supplies electricity to a relatively reduced group of users (Peskett, 2011; Franz et al., 2014). It thus provides an intermediate solution between the national grid, intended to serve a large group of users from several generators, and an off-grid, home-based system, which serves just one or a few users using, typically, a solar panel. A mini-grid can supply up to 15 megawatts (MW) of power and, thus, is able to meet the basic needs of households, small businesses, schools, dispensaries, and other users in a few villages (UNFCC, 2014).

The sources harnessed to turn mini-grids small-scale generators vary widely. Traditional ones use diesel, biomass (agricultural residues or wood), or hydro-power, although in recent years solar-powered and hybrid mini-grids that combine solar panels with batteries or diesel backup generators are becoming increasingly popular (IRENA, 2020). Other features, such as the ownership (which can be in the hands of a utility, a pro-business third party, or an NGO), the type of tariff (consumption- or capacity-based; pre-

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[6] Contributions are abundant in many industries and sectors (besides the electricity one), such as water (Kremer et al., 2011), sanitation (Armand et al., 2021), and transportation (Gonzalez-Navarro and Quintana-Domeque, 2016; Banerjee et al., 2020).

or post-paid), and the payment method (cash or mobile payments) may also differ across mini-grids.

Over the last years, there has been a massive investment in mini-grids in the developing world —according to ESMAP (2019), there are about 19,000 mini-grids globally, representing a cumulative global investment of about $28 billion—, and different international institutions (including the World Bank) have already committed more than $1.3 billion for mini-grid investment for the next years, as one of the key strategies to reach universal access to electricity. This trend has recently been particularly marked in SSA, where $300 million per year of financing was allocated to these projects both in 2018 and 2019 (SEforALL, 2020), and about 4,000 new mini-grids are being planned for development.

The expansion of mini-grids in SSA as a mainstream solution to provide electricity to local communities responds to three main reasons. First, the rapid decline in their capital costs, which are expected to further decrease through 2030 (ESMAP, 2019; Zigah et al., 2023). Second, the lack of proper national grid networks that leaves numerous communities (especially in rural areas) without access to electricity. Mini-grids have thus become for many countries in SSA a least-cost solution to provide "last-mile" infrastructure to electrify villages far from the national grid. Third, contrary to alternative electrification solutions, mini-grids bring investment to the communities in which they are installed, contributing thus to generate job opportunities —according to Power for All (2022), a mini-grid site creates, on average, 150 positions for every MW of installed capacity— and economic opportunities at the local level.[7]

2.2 The Tanzanian mini-grids policy reforms

Mini-grids have existed in Tanzania since colonial times. They were built mostly in big cities and near mineral and agricultural facilities (e.g., diamond and gold mines; tea and cotton plantations). In the 1970s, several network expansion projects connected the existing mini-grids, creating thus the embryo of the current national grid (Odarno et al., 2017). However, the coverage of this network was limited and many regions, as shown in Figure 1, remained (and still remain) unserved. In fact, the electricity access rate has historically been low in Tanzania, reaching just 15% as of 2010. According to ESMAP (2019), Tanzania ranks among the top 20 countries worldwide with the greatest electricity access deficit, with a rate almost 10% lower than the average in SSA, and a significant urban-rural gap.

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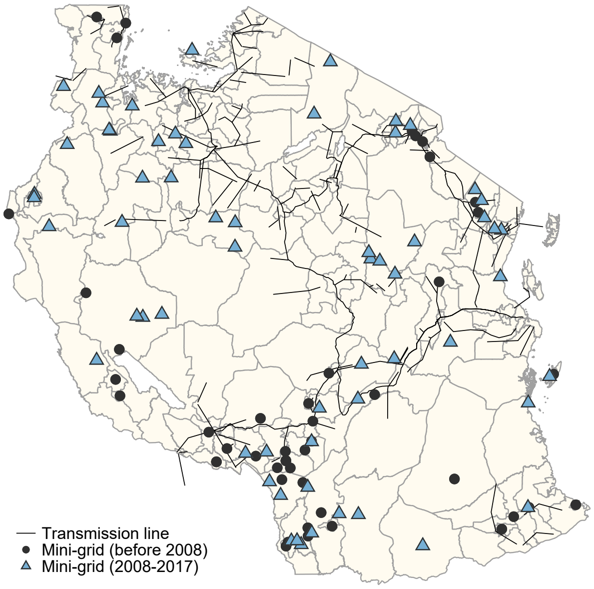
[7] As explained by González Grandón and Peterschmidt (2019) and Sayar (2019), some mini-grids are installed alongside new raw materials processing businesses that are expected to use the electricity generated. These businesses become a secondary revenue source for the mini-grid developer. Additional figures on the jobs created by mini-grids and anecdotal evidence on the business opportunities they generate locally are in IRENA (2017); ESMAP (2019); AMDA (2020); Pueyo et al. (2022).

Figure 1. Map of mini-grids deployed in Tanzania up to 2017



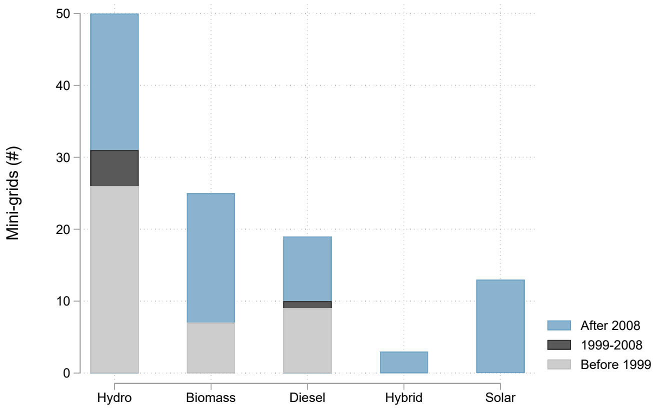
Note: This figure includes a map of all the mini-grids deployed in Tanzania up to 2017. The 46 mini-grids that were commissioned before 2008 (the year of the implementation of the Electricity Act) are indicated with black circles, while the 51 mini-grids commissioned between 2008 and 2017 are indicated with light blue triangles. The black lines represent the existing high and medium-voltage transmission lines of the Tanzanian national grid as of 2016, obtained from World Bank Data Catalog, and collected for the Africa Infrastructure Country Diagnostics (AICD). The light gray lines capture the boundaries of the regions of Tanzania.

To tackle this historically low access rate, the Tanzanian government implemented a series of thoroughly designed financial support schemes to attract investment from development financial institutions and donor agencies in mini-grids. The key milestone was the *Electricity Act 2008*. Among other things, it introduced the so-called first-generation feed-in tariff (FiT), which recognized and favored Small Power Producers (SPPs) —private power plants with up to 10 MW of capacity— that supply to mini-grids. This pioneer regulation led the Tanzanian mini-grid sector to take off earlier than those in other countries in SSA. However, policymakers recognized some room for improvement, as the deployment of mini-grids, was fairly concentrated on those that were hydro- and biomass-powered.

Thus, to foster investment in other technologies (particularly, in solar-powered mini-grids), some changes were implemented by the Tanzanian Energy and Water Utilities Regulatory Authority (EWURA) in 2015. This reform created different remuneration mechanisms based on the cost differences between technologies, equalized the payments to SPP that supply to the main grid and to isolated mini-grids (the previous regulation slightly favored the former ones), reduced the size of eligible projects from 1 to 0.1 MW, and pegged the FiT to the US dollar to reduce the risk of investment (Odarno et al., 2017).

Following these policy interventions, the number of mini-grids in Tanzania doubled since 2008. By

Figure 2. Total cumulative number of mini-grids in Tanzania by technology up to 2017



Note: This figure displays the cumulative number of mini-grids in Tanzania until 2017 by technology. In light gray we capture the number of mini-grids deployed before 1999 (the first year for which we have survey data). In black we capture those built between 1999 and 2008 (the year of the implementation of the Tanzania Electricity Act). Finally, in light blue we capture those built after 2008.

2017, there were 109 mini-grids across this country, representing a total capacity of 157.7 MW, and providing connections to about 183,705 customers (Odarno et al., 2017). Figure 1, which contains the map of Tanzania, indicates the mini-grids that were built before the Electricity Act 2008 (indicated with black circles) and after that (light blue triangles). Then, in Figure 2, we show the evolution of mini-grids in Tanzania by technology. It is worth noting that, after 1999 —the first year included in our survey data—, there was an increase in the number of mini-grids across all the technologies (particularly, in hydro).[8]

3 Empirical framework and data

3.1 Identification

A linear regression of an outcome of interest (e.g., access to electricity) on a dummy that equals 1 for households located in a community where a mini-grid was built and 0 otherwise leads to likely biased and inconsistent estimates inasmuch as the (unobservable) characteristics that explain the construction of a mini-grid in that community correlate with the characteristics of the households that live there. Instead, and following Lee et al. (2016), Benshaul-Tolonen (2019), and Bazillier and Girard (2020) (among many others), we can identify the causal effect of mini-grids on households by exploiting two key features in our data. First, the time effect of the deployment of different mini-grids across Tanzania.

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[8] According to IRENA (2017), as of 2015, around 1,000 people in Tanzania were employed in the construction, operation, and management of hydro-powered mini-grids only.

Second, the location that defines households in proximity to a mini-grid as being either relatively close to it or far from it. This identification strategy rests, in particular, on the following assumptions.

To begin with, it relies on the assumption that, within relatively narrowly defined geographical zones (defined below), the location of a mini-grid is uncorrelated with factors affecting electricity access and other outcomes of households on their premises. That is, at the "very local" (i.e., community) level, mini-grids are not built relatively close to the households that (for pre-existing characteristics) are more likely to get an electricity connection, and/or far from those less likely to do so. Instead, the exact location of a mini-grid within a narrowly defined geographical area is determined by other (exogenous) factors, such as surface roughness, the slope of the nearest water body, or any other features of the territory.

Appendix A provides supporting evidence for this assumption, as it includes several high-resolution maps showing that, even though the mini-grids target some particular communities, their exact location on the premises of these communities responds to different (presumably exogenous) factors. For example, the location of hydro-powered mini-grids is determined by the presence of a water body and, moreover, they are built where there is a sufficiently steep slope and the current is ample.[9] Likewise, the location of solar mini-grids is dictated not only by solar radiance but also by the presence of a sufficiently ample flat terrain that is closely connected to a road. Something similar is observed for biomass: as they use (relatively heavy) agricultural waste, they must be located in areas where there is agricultural activity and also nearby roads. Finally, diesel mini-grids must also be built near primary roads, as diesel must be transported by tank trucks (there are no pipelines in Tanzania).[10] Appendix A provides a detailed discussion of these features, along with the high-resolution maps that support these ideas.

Next, we also rely on the assumption that households relatively close to a mini-grid are (*ceteris paribus*) more likely to benefit from it than those relatively far from it. This assumption seems reasonable because, as explained by Odarno et al. (2017), *(i)* the cost of delivering electricity increases with the distance between the mini-grid and consumers and, *(ii)* in many cases, the fees charged to households for a connection include a variable fee that depends on this distance. Hence, we could expect that, being other things equal, households relatively close to a mini-grid will be more likely to get a connection,

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[9] World Bank (2017) provides a list of the exact places in Tanzania that are suitable for small hydro generators, given the characteristics of the terrain and the water bodies.

[10] One may be concerned that, since diesel-fueled mini-grids do not depend on the availability of natural resources and the characteristics of the terrain, their exact location is "less exogenously" dictated than that of, say, the solar and hydro ones. Thus, as a robustness check, we provide in Appendix B.3 our main empirical results after excluding them from our sample.

and will also benefit from a more reliable service than those far from it. This assumption is consistent with the evidence by Blimpo et al. (2018), who document a decline in the household probability of being connected as the distance to the infrastructure increases.[11]

Further evidence in support of this assumption is included in Figure 3, which captures the average nighttime light captured by Visible Infrared Imaging Radiometer Suite (VIIRS) (in nanoWatts/cm2/sr) for different concentric rings around the Segese biomass mini-grid, located in Kahama (Shinyanga Region), the year before and the year after its deployment. While no radiance is observed the year before the construction of this mini-grid —Figure 3(A)—, we observe a significant increase the year after it was built —Figure 3(B). Moreover, such an increase in nighttime radiance is stronger in the concentric circles that are close to the mini-grid, while it decreases in the concentric circles that are far from it.

Figure 3. Average nighttime lights (VIIRS radiance) around the Segese mini-grid in Kahama (Shinyanga Region) before and after its construction (2014)

(A) Radiance in 2013

(B) Radiance in 2015

Note: The figure shows the change in Visible Infrared Imaging Radiometer Suite (VIIRS) Nighttime Lights (in nanoWatts/cm2/sr) for different concentric rings (with constant radii increment of 200m) around the Segese biomass mini-grid, located in Kahama (Shinyanga Region). Figure 3(A) displays the radiance for the year before this mini-grid was built (2013), while Figure 3(B) displays the radiance for the year after it was built (2015). The data was obtained from the National Centers for Environmental Information (WorldPop, 2018).

Figure 3 is just a case in point. However, the same pattern is observed in the rest of the mini-grids in our sample, as we illustrate in Figure 4. This figure captures the average VIIRS Nighttime Lights for different concentric rings (drawn at 1 km intervals) within a radius of 10 km around all the 97 mini-grids included in our sample. It is fairly evident that there is substantial nighttime radiance in the concentric rings that are close to the mini-grids, which disappears as we move far away from them. In fact, the incremental effect of the mini-grids on radiance vanishes for concentric rings that are over 5

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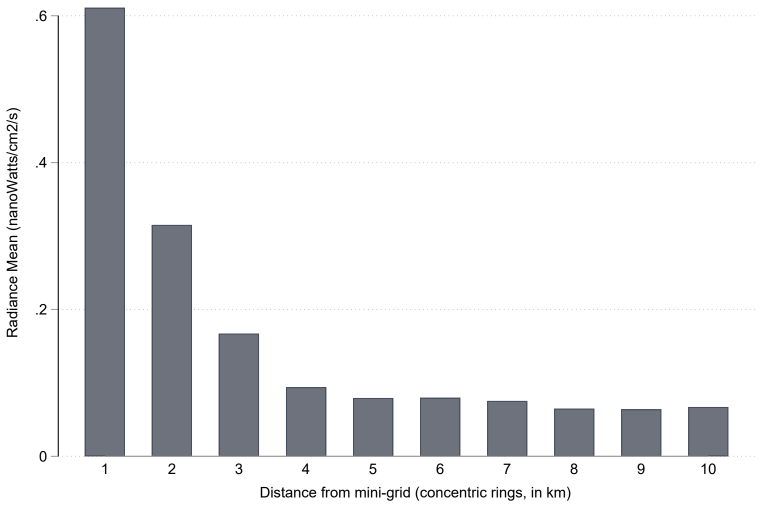
[11] The decline in the probability of electrification and in the reliability of the service for customers further away from the power infrastructure is also the basis of the empirical strategy of some other papers (Van de Walle et al., 2013; Squires, 2015).

km away from the mini-grids. This 0-5 km threshold is, thus, the one that we use in the first empirical approach that we explain below to identify the "treated" households.[12] Moreover, as we thoroughly explain below, this observed decline in nighttime radiance as the distance from the mini-grid increases also motivates our alternative empirical strategy, in which we exploit instead a "continuous treatment" approach, along the lines of Huet-Vaughn (2019) and Gavrilova et al. (2019) (among others).

Figure 4. Average nighttime lights (VIIRS radiance) in different concentric rings around all the mini-grids in Tanzania



Note: The figure captures the average Visible Infrared Imaging Radiometer Suite (VIIRS) Nighttime Lights (in nanoWatts/cm2/sr) for different concentric rings around all the 97 mini-grids included in our sample. We consider all the concentric rings (drawn at 1 km intervals) within a radius of 10 km from each of these mini-grids. Each concentric ring has a surface of $\pi[r^2 - (r-1)^2]$, for $r \in \{1, \cdots, 10\}$, where r denotes the corresponding ring (from closest to farthest from the mini-grids).

Next, and bearing in mind that we restrict the empirical analysis to households in communities where a mini-grid is installed, we assume that the timing of their roll-out is uncorrelated with the economic development of the targeted communities. This assumption is standard in our context, given the documented constraints that dictate electrification project deployment, as outlined by Moradi and Schmidt (2022). In fact, Odarno (2017) and Odarno et al. (2017) point out that mini-grid developers in Tanzania often experience administrative delays and other constraints that lag their investment projects.

Finally, and related to the previous one, the last identifying assumption is that all households on the premises of the mini-grids (including those that are relatively close to and those that are relatively far from each of them) would have trended similarly in terms of electricity access and other relevant

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[12] This threshold is not only a reasonable one in accordance with Figure 4, but also a technically convenient one: the DHS suggests using buffers of at least 5 km, given that the geo-localization of the households is slightly (randomly) displaced from their true location to preserve their anonymity (Perez-Heydrich et al., 2013). The same randomization procedure was applied also to the localization of the households in the NPS (TNBS, 2011).

outcomes had the mini-grids not been built. Additional details and evidence in support of this final assumption, including tests on the parallel-trend assumption and on the lack of pre-trends, are provided in a stand-alone "validity" sub-section in the light of our main empirical results (Section 4).

3.2 Regression model

Bearing the previous ideas in mind, we now present the regression model we use to examine the impact of the rollout of mini-grids across Tanzania on energy-, wealth-, and health-related outcomes at the household level. To do so, we exploit variation both in the timing of the deployment of different mini-grids and in the distance from them, comparing outcomes before and after their deployment in treated units (those geographically closer to a mini-grid) relative to control units, as defined below. The empirical strategy is thus based on a generalized difference-in-difference (*DiD* hereafter) approach, in which our main regression model is as follows

$$y_{i,c,r,t} = \beta_0 + \beta_1 \mathrm{MG}_{c,r} + \beta_2 \mathrm{MG}_{c,r} * post_t + \boldsymbol{X}_{i,c,r,t} + \alpha_r + \sigma_r * t + \delta_t + \varepsilon_{i,c,r,t}, \tag{3.1}$$

where an outcome $y_{i,c,r,t}$ of household i in cluster c,[13] region r, at year t is regressed on the following variables. First, on $\mathrm{MG}_{c,r}$, which captures the treatment variable. In our first approach, we consider as treated households within a radius of less than 5 km to a mini-grid, while households within a radius of 5-10 km to a mini-grid provide our control group. Hence, in this binary-treatment version, $MG_{c,r}$ is defined by the following indicator function: $MG_{c,r} = \mathbb{1}_{\{d_{c,r}<5\}}$ for all $d_{c,r} \in [0, 10]$, where $d_{c,r}$ is the distance (in km) between households in cluster c and the closest mini-grid. This threshold is based on the information in Figure 4 (and also later in Figure 5), as we see that the incremental average nighttime radiance around mini-grids vanishes for concentric rings that are more than 5 km away from them.

Even though this 5-km threshold allows us to implement a standard *DiD* regression based on a binary treatment, still one might be concerned that the threshold is somehow arbitrarily chosen, or that it is not the appropriate one for all the mini-grids in our sample (as the presence of nighttime radiance up to 5 km away might be driven just by a few of them). If this were the case, then households dwelling near the 5 km threshold would contaminate our empirical results.[14] To overcome these concerns, we

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[13] A cluster is the smallest (anonymized) geographical unit defined by groupings of households in the surveys. Both surveys use a fixed number of households per cluster, with an average of 23 households for the DHS and 9 households for the NPS.

[14] Given these concerns, following Benshaul-Tolonen (2019), as an additional robustness check we include in Appendix B.4

follow previous literature (Acemoglu et al., 2004; Cicala et al., 2019; Gavrilova et al., 2019; Huet-Vaughn, 2019) and use alternatively a continuous-treatment version by defining the degree of exposure to the treatment (i.e., begin close to a mini-grid) based on the (inverse) distance between households and mini-grids. That is, $MG_{c,r} = 1 - \frac{d_{c,r}}{10}$, for all $d_{c,r} \in [0, 10]$, and where $d_{c,r}$ is as defined above.

Outcome $y_{i,c,r,t}$ is also regressed on the interaction between $MG_{c,r}$ and a dummy variable $post_t$, which takes a value of 1 if the mini-grid is active at year t and 0 otherwise. The coefficient associated with this interaction, denoted by β_2, captures the impact of mini-grid installation on the selected household outcomes, and is therefore the one of interest in this study. More precisely, in the binary-treatment version, β_2 captures the impact on outcome $y_{i,c,r,t}$ for households within 5 km from the closest mini-grid (relative to households within 5-10 km) following its deployment, while in the continuous-treatment version it measures the marginal increase in the outcome when decreasing the distance to the closest mini-grid by 1 kilometer after its deployment. The identification of the causal effect on $y_{i,c,r,t}$ captured by this coefficient is based on the main identifying assumptions extensively discussed above.

Finally, the right-hand side (RHS) of equation (3.1) also includes a vector of household and mini-grid characteristics ($\boldsymbol{X}_{i,c,r,t}$), and a battery of fixed effects. Namely, we include year fixed effects (δ_t), which control for changes over time that affect all households similarly (e.g., national policies and growth), and region fixed effects (α_r), which control for all time-invariant differences between regions (e.g., ethnic and cultural background, and geographic characteristics). In an alternative specification of our model, we replace the latter by cluster fixed effects (α_c),[15] which control for a wide range of cluster-specific characteristics that may affect the outcomes of interest —helping thus to support the robustness of our empirical results. In both cases, we also include in some specifications region linear time trends ($\sigma_r * t$) to control for potential time-varying shocks that may affect some regions specifically (e.g., droughts).[16]

3.3 Data and summary statistics

We assemble a unique dataset that combines geo-localized information both on mini-grids and on households obtained from disparate sources. First, we obtain data on all the mini-grids deployed in

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our main results using the aforementioned binary treatment approach but excluding households that are in the 4-6 km area.

[15] The inclusion of α_c implies that time-invariant cluster-specific variables, such as $MG_{c,r}$, are dropped.

[16] To account for potential correlation of outcomes at the region level, and bearing in mind that households are randomly sampled from the population of every cluster c (Abadie et al., 2022), we cluster the standard errors at the region-year level. Nevertheless, our results prove robust to alternative levels of clustering (e.g., region, cluster, and cluster-by-year).

Tanzania from the World Resources Institute (WRI). This dataset contains detailed information (geo-localization, year of commission, capacity, and technology) for the 109 mini-grids deployed in this country from the thirties up to 2017. However, we drop 12 of them for which either the commissioned year or the geo-location is missing. Figure 1 provides the spatial location of all the mini-grids included in our final sample across Tanzania before and after 2008 (the year of the implementation of the Tanzania Electricity Act), while Figure 2 displays their evolution by technology (their average capacity is 1.6 MW).

This information is combined with household-level (secondary) data from two nationwide surveys, namely, four biennial waves of the National Panel Survey (NPS) between 2008 and 2014, and seven cross-sectional rounds of the Demographic and Health Survey (DHS) between 1999 and 2017. Both surveys contain a rich set of socio-economic, health, and demographic characteristics (including also their geo-localization) for up to 2,231 and 39,483 representative households across the country, respectively.[17] Bearing in mind that each of these surveys presents specific advantages and drawbacks —the sample size of the NPS is relatively small and covers a shorter period of time, while the DHS contains information for a larger set of households for a longer time window— we separately use data from both surveys to estimate the regression model above in order to confer robustness to our empirical results.

We use the geo-localization of the households in these survey datasets to calculate their distance (as the crow flies) to the nearest mini-grid. Using this distance, we define the sample we use to estimate equation (3.1), which is restricted to households within 10 km from a mini-grid.[18] Following the 2008 policy reform, the construction of new mini-grids led to a reduction in the average distance between households in our sample and the mini-grids. For example, we observe a 56% increase in the number of households that are less than 5 km from the nearest one after 2008 in the NPS. We exploit this variation in "pre-post" distances to estimate the impact of newly deployed mini-grids on the selected outcomes.

Importantly for our purposes, both surveys include information on the electrification status and other wealth- and health-related characteristics of the households, which we use to define our main outcomes of interest. First, we focus on the impact of a dummy variable that identifies whether a household has an electricity connection. We use the responses to the following question in the DHS to create this

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[17] The number of households that are repeatedly included on multiple rounds of the NPS is fairly low. This precludes us from estimating equation (3.1) by also including household fixed effects.

[18] To preserve the anonymity of the respondents, the geo-localization of the households was slightly distorted and averaged at the cluster level in both surveys; see TNBS (2011) and the DHS website for further details. However, as mentioned above, the use of buffers of (at least) 5 km around households is adequate to obtain unbiased estimates (Perez-Heydrich et al., 2013).

dummy variable: "Does the household have electricity?". For the NPS, we use instead the responses to the following question "What is the household main source of electricity?", for which we define our dummy equal to 1 if an answer to this question is recorded (excluding a few households whose main source of electricity is either a car battery, an own generator, or a motorcycle battery) and 0 otherwise.[19]

Second, the NPS also provides information on the households' primary fuel source for lighting. Using this information, we create a dummy that equals 1 if a household uses electricity and 0 otherwise (paraffin, oil, firewood, etc.). This variable allows us to study whether the construction of a mini-grid increased the use of electricity as the primary lighting source *in lieu* of other fuel-based devices that are popular in Tanzania, such as oil lamps or paraffin.[20] This empirical exercise is particularly relevant in light of the indoor pollution problems associated with these devices, which are causally linked to respiratory problems and premature death in developing countries (Hanna et al., 2016; Imelda, 2020).

Third, we examine different outcomes related to household asset wealth. In particular, we first study whether the construction of mini-grids had an effect on the DHS wealth index, which is a composite measure of households' living standards calculated based on the ownership of selected assets and other amenities (water and electricity access, sanitation facilities, quality of the materials, etc.) —see Rutstein (2015). In addition, we examine using both the DHS and the NPS the impact of mini-grids on the ownership of specific electric-powered appliances, such as refrigerators and televisions. To do so, we construct two different dummy variables that equal 1 if they own these appliances, and 0 otherwise.

Finally, we turn to estimate the impact on health outcomes. In particular, and bearing in mind we find a positive and significant impact on the uptake of refrigerators, we examine whether the incidence of diarrhea —an infectious disease usually linked to improper food storage and preservation— among children lowers following the deployment of a mini-grid. To do so, we use the responses to the question of whether any children less than 5 years of age in the household had diarrhea within the last two weeks to build a dummy variable that equals 1 if the answer to this question is yes (and 0 otherwise).[21]

We use as controls other variables in these surveys that are likely to confound the selected outcomes, such as the gender, age, and education of the heads of household (where the latter is captured by a dummy equal to 1 if the head of household completed primary education). In addition, we use as con-

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[19] In both surveys, we remove from our sample the very few households that own solar panels.

[20] About 71% of households in the NPS use kerosene or oil lamps for lighting, while other sources like gas or solar are rare.

[21] Data for this question is only available for certain DHS rounds (1999, 2010, and 2015-2016).

Table 1. Summary statistics by distance to the closest mini-grid before and after its deployment

	(1) *Control (5-10 km)*	(2) *Treated (0-5 km)*	(3) *Control (5-10 km)*	(4) *Treated (0-5 km)*	(5) *All*
	Panel A. DHS dataset				
	Panel A1. Before		*Panel A2. After*		
Electricity (d)	0.014	0.074	0.081	0.327	0.178
(log-) Age of Hoh	3.813	3.732	3.774	3.685	3.736
Education of head (d)	0.702	0.761	0.814	0.890	0.827
Sex of head (d)	0.753	0.765	0.753	0.712	0.737
Wealth index	-7.061	-2.289	-4.331	3.756	-0.867
Television (d)	0.022	0.067	0.071	0.251	0.142
Refrigerator (d)	0.004	0.007	0.014	0.079	0.040
Diarrhea incidence (d)	0.176	0.172	0.133	0.183	0.167
N. Observations	490	459	1,330	1,713	3,992
	Panel B. NPS dataset				
	Panel B1. Before		*Panel B2. After*		
Electricity (d)	0.091	0.081	0.053	0.352	0.172
Elect. lighting (d)	0.091	0.081	0.056	0.355	0.174
(log-) Age of Hoh	3.787	3.716	3.835	3.749	3.779
Education of head (d)	0.640	0.644	0.527	0.708	0.629
Sex of head (d)	0.731	0.698	0.740	0.700	0.718
Television (d)	0.113	0.081	0.044	0.324	0.163
Refrigerator (d)	0.027	0.020	0.006	0.104	0.047
N. Observations	186	149	338	383	1,056

Note: Summary statistics for all households included in the sample. Panel A: DHS dataset —Panel A1: before the deployment of the closest mini-grid; Panel A2: after the deployment of the closest mini-grid. Panel B: NPS dataset —Panel B1: before the deployment of the closest mini-grid; Panel B2: after the deployment of the closest mini-grid. Column (1) and (4): means for the subgroups of households within a radius of 5-10 km to the closest mini-grid (control households in the binary treatment approach). Column (2) and (5): means for the subgroups of households within a radius of 5 km to the closest mini-grid (treated households in the binary treatment approach). Column (3): means for all households in our sample. All dummy variables are indicated with a (d).

trols dummies that indicate the technology of the corresponding mini-grid (solar, hydro, hybrid, etc.). Table 1 provides summary statistics for both the treated (0-5 km) and the control (5-10 km) households before and after the deployment of the closest mini-grid, for both the DHS and the NPS datasets. The reader should be aware that some of the households in our sample already had an electricity connection before the deployment of the closest mini-grid. This is because a few mini-grids in our sample were built in areas already served by the national grid, as shown in Figure 1. Due to the potential concern that our results might be affected by this pre-existing infrastructure, as a robustness check, we provide in Appendix B.2 the main set of empirical results after dropping the mini-grids (and the corresponding households) that are relatively close to the national grid transmission lines.[22]

4 Empirical results

This section presents our main empirical results. We estimate the impact of mini-grids on household energy-related outcomes first, and then examine their effects on wealth and health outcomes.

4.1 Effect of mini-grids on energy outcomes

Main results. We start by providing the results of equation (3.1) (estimated by OLS) on the probability of households being connected to electricity after the deployment of a mini-grid. Table 2 presents the coefficients of the linear probability model (LPM) using the dummy that defines treated and control households based on the 5-km distance cut-off (binary treatment approach) in columns (1)-(4), and using the variable that defines the degree of exposure to the treatment based on the distance between households and mini-grids (continuous treatment approach) in columns (5)-(8). Panel A displays the estimates obtained using the DHS dataset, while Panel B contains those obtained using the NPS dataset.

First, column (1) presents the results of the model specification that includes the full set of controls —age, education, and sex of the head of household, as well as dummies indicating the technology of the closest mini-grid—, and region and year fixed effects. The coefficient of the interaction term "Mini-grid × post" using the DHS dataset is significant at the 1% level and suggests a 17.6% increase in the probability of having an electricity connection among households located within 5 km of a mini-grid after its deployment. Similarly, the effect is positive, significant at the 1% level, and slightly higher in magnitude when using the NPS dataset. In column (2) we add region-specific time-trends, and the results suggest an increase of about 16-23% in the outcome. Then, in columns (3) and (4) we use the same model specifications as those in columns (1) and (2), respectively, but replace region fixed effects with cluster fixed effects. In this case, the point estimates using the DHS are similar in magnitude to the previous ones, indicating an increase in the probability of having a connection for treated households of 16-18% (significant at the 1% level). However, when using the NPS dataset, the coefficient decreases to

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[22] Table 1 reveals slight imbalances in a few characteristics across treated and control households in our sample; e.g., in the DHS wealth index and in television ownership (NPS). As a robustness check, we provide in Appendix B.1 the main set of results obtained by using a propensity score matching estimator that helps resolve these slight imbalances in our sample.

Table 2. Impact of mini-grids on household probability of having an electricity connection

	Binary treatment approach $\left(MG_{c,r} = \mathbb{1}_{\{d_{c,r}<5\}}\right)$				*Continuous treatment approach* $\left(MG_{c,r} = 1 - \frac{d_{c,r}}{10}\right)$			
				Panel A. DHS dataset				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	0.0244	0.0346			0.133	0.144		
	(0.0428)	(0.0435)			(0.0807)	(0.0884)		
Mini-grid × post	0.176***	0.163***	0.160***	0.181***	0.255***	0.238***	0.279***	0.281***
	(0.0507)	(0.0556)	(0.0498)	(0.0688)	(0.0788)	(0.0940)	(0.0788)	(0.0940)
R^2	0.209	0.224	0.341	0.363	0.225	0.238	0.342	0.363
N. Observations	3,992	3,992	3,992	3,992	3,992	3,992	3,992	3,992
				Panel B. NPS dataset				
Mini-grid	0.0166	0.00198			0.178***	0.150**		
	(0.0463)	(0.0450)			(0.0646)	(0.0625)		
Mini-grid × post	0.206***	0.231***	0.0613*	0.0844*	0.261***	0.307***	0.0954*	0.148**
	(0.0570)	(0.0540)	(0.0358)	(0.0431)	(0.0859)	(0.0908)	(0.0556)	(0.0603)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.245	0.259	0.381	0.398	0.264	0.279	0.381	0.398
N. Observations	1,053	1,053	976	973	1,053	1,053	976	973

Note: The outcome is a dummy equal to 1 if the household has an electricity connection (and 0 otherwise). Linear probability models estimated by OLS using data from the DHS (Panel A) and from the NPS (Panel B) with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, in which the variable "Mini-grid" is a dummy one defined as follows $MG_{c,r} = \mathbb{1}_{\{d_{c,r}<5\}}$ for all $d_{c,r} \in [0, 10]$, where $d_{c,r}$ is the distance (in km) between households in cluster c and the closest mini-grid; while in columns (5)-(8) we use the continuous treatment approach, in which the variable "Mini-grid" is a continuous one defined as follows $MG_{c,r} = 1 - \frac{d_{c,r}}{10}$, for all $d_{c,r} \in [0, 10]$. Columns (1) and (5): full set of control variables —including head of household (log-) age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid (solar, hydro, biomass, hybrid or diesel)—, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

approximately 8% (significant at the 10% level).[23]

Next, column (5) contains the results of the continuous treatment approach for the model specification that includes the full set of controls, and region and year fixed effects. The coefficient of interest using both the DHS and the NPS is around 0.26 (significant at the 1% level). This finding indicates that the probability of having a connection after a mini-grid installation for a household located 2.5 km away from it (i.e., the household "in the middle" among those in the treated group, as defined by the binary variable above) increases by roughly 19%.[24] This effect coincides in magnitude with the estimated (average) effect in column (1). Extremely similar results are also obtained when we add the region-specific trends using both the DHS and the NPS —column (6)—, and also for the specifications that contain cluster fixed effects using the DHS only —columns (7) and (8), Panel A. In all these cases, we estimate the probability of having a connection for a household at 2.5 km far from a mini-grid rises by 18-22%. However, for the latter specification of the regression model estimated using the NPS, the increase in the probability is slightly lower (about 8-10%). Overall, the results are extremely similar in magnitude to those obtained using the binary treatment approach.

Validity. In order to evaluate the policy intervention of interest —i.e., the effect of being close to a newly developed mini-grid for any household *i*— we need to compare outcomes for that household after the deployment of a mini-grid to what it would have been had the household not been close to it (Blundell and Dias, 2009). This treatment effect is captured by the coefficient β_2 in equation (3.1). However, it is important to note that one of the necessary assumptions to identify this effect is that outcomes in treatment and control cohorts would follow the same time trend in the absence of the installation of a mini-grid (see Section 3.1). Unfortunately, testing this parallel trend assumption is not straightforward due to two main reasons. First, the distance to a deployed mini-grid is obviously not the same for treated and control households. Second, given the staggered rollout of the mini-grids in our sample, there is not a clear point in time that can be used as a cut-off date to distinguish the *before* and *after* periods. Nevertheless, we can perform alternative tests to support the common trend assumption in our setup and strengthen the validity of our identifying strategy.

First, we provide evidence that there are no differential pre-trends in electricity usage across house-

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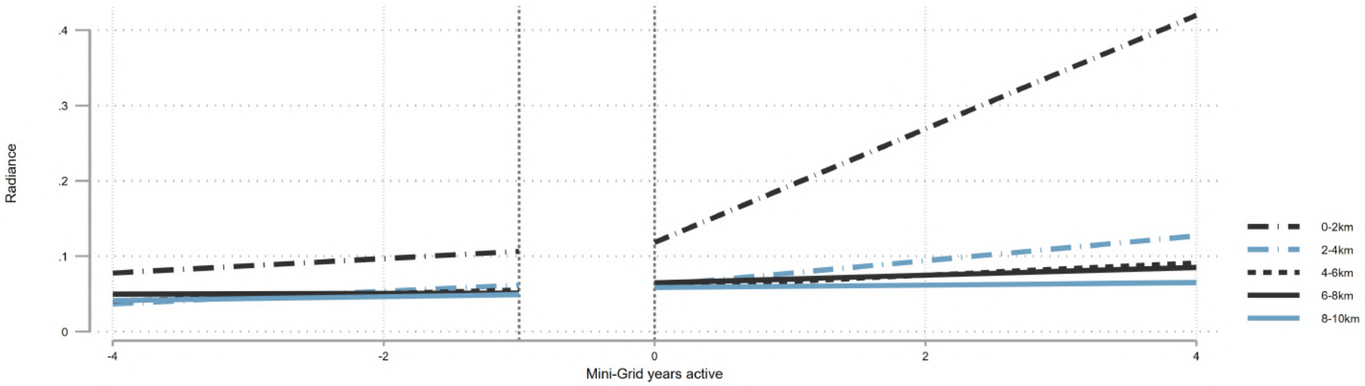
[23] The reader should be aware of the relatively low number of observations in the NPS dataset, which may significantly contribute to generating these deviations in the estimated coefficients when using different model specifications.

[24] This number is obtained as follows: $(0.26) * \left(1 - \frac{2.5}{10}\right) = 0.195$.

Figure 5. Average satellite-based nighttime light (VIIRS radiance) in different concentric rings around mini-grids relative to the year of deployment



Note: The figure captures the average satellite-based nightlight radiance for five concentric rings (with constant radii increment of 2 km) around all the mini-grids in our sample that were deployed between 2012 and 2016. These averages are calculated using Visible Infrared Imaging Radiometer Suite (VIIRS) Nighttime Lights (in nanoWatts/cm2/sr) for 1-hectare pixels —obtained from WorldPop (2018)—, and are plotted for each year relative to the year of the deployment of each mini-grid (ranging from -4 to 4 years). As done by Benshaul-Tolonen (2019) (Fig. 3), we allow for a trend break at year -1, to avoid capturing a potential increase in light radiance occurring in the investment phase.

holds in the treatment and control groups. For that purpose, we use average satellite-based nightlight luminosity data obtained from WorldPop (2018) for all the 1-hectare pixels within 10 km of the mini-grids in our sample built between 2012 and 2016.[25] Given the large number of pixels, we create five concentric rings around each mini-grid (with constant radii increment of 2 km) and obtain the mean radiance at each year relative to the year of installation of the mini-grids for each of these rings.[26]

The result of this exercise is presented in Figure 5. To begin with, the five rings around each of the considered mini-grids were on similar trends in terms of average satellite-based nightlight radiance in the years before their installation. These trends were, in fact, mostly flat. This figure thus provides some evidence of the parallel trend assumption, as it suggests that mini-grids were unlikely built in rings in which nightlight radiance was already increasing relative to other ones. Moreover, following the deployment of the mini-grids, we observe that the average radiance at different rings evolves differently: there is a stark deviation from the flat trend both in the 0-2 km and in the 2-4 km rings right after the investment phase. This result provides additional evidence of the positive effect of mini-grids on electricity use —captured by an increase in nightlight radiance in areas where our treatment cohort is located (i.e., within a radius of less than 5 km to the closest mini-grid).

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[25] We limit our analysis to mini-grids built between 2012-2016 due to a lack of accurate data on satellite nighttime light prior to 2012. To avoid contamination of luminosity from pre-existing power-related infrastructure, we exclude mini-grids within 10 km of another pre-existing one and those within 10 km of the Tanzania national grid.

[26] Following Benshaul-Tolonen (2019) (Fig. 3), we allow for a trend break at year -1, to avoid potentially capturing an increase in light radiance occurring that may occur during the investment phase.

Second, we also test for the existence of differential trends in the number of electricity connections prior to the installation of a mini-grid among treated households to confirm the validity of our identifying strategy. To do so, we extend our main regression model —equation (3.1), binary treatment version— by including several leads of the treatment variable, in the spirit of Autor (2003). This alternative specification allows us to check whether the uptake of electricity connections documented above comes from the installation of a mini-grid or, alternatively, whether it is stemming from a pre-existing trend among the households in the treated cohort. Figure 6 provides the results obtained by estimating this alternative version of our main regression model augmented with leads of the treatment variable. For the sake of completeness, we do so using the binary treatment approach for both the model specification that includes region fixed effects and also for the one that includes cluster fixed effects.

Panel A includes the point estimates that capture whether there are pre-trends in the uptake of electricity connections among treated households up to four years prior to the deployment of the mini-grids using the DHS. The treatment effect on the outcome is significant and similar in magnitude (around 17-21%) to that obtained in Table 2 in the *Post* period both in Figure 6(A) (specification with region fixed effects) and 6(B) (specification with cluster fixed effects). However, all the lead indicators are statistically indistinguishable from zero —except for the $t-1$ lead in Figure 6(B), which suggests that the uptake of connections could have already started in the investment phase—, ruling thus out the existence of such pre-trends. Then, Panel B contains the results using the NPS dataset. In this case, due to data limitations, we only include one lead that corresponds to the impact of mini-grids up to two years before their deployment.[27] The treatment effect is positive, significant, and similar in magnitude in the *Post* period using both the region fixed-effects (Figure 6(C)) and the cluster fixed-effects model specification (Figure 6(D)), but the lead variable is again not significant. These results further confirm that the increase in the probability of having an electricity connection among treated households only occurs after the installation of the mini-grids and, therefore, is not stemming from a pre-existing trend.

Additional results. The empirical results above suggest that the deployment of mini-grids in Tanzania causally led to a surge in the uptake of electricity connections among treated households. The question that follows is, thus, whether they also increased the *actual* use of electricity for basic needs,

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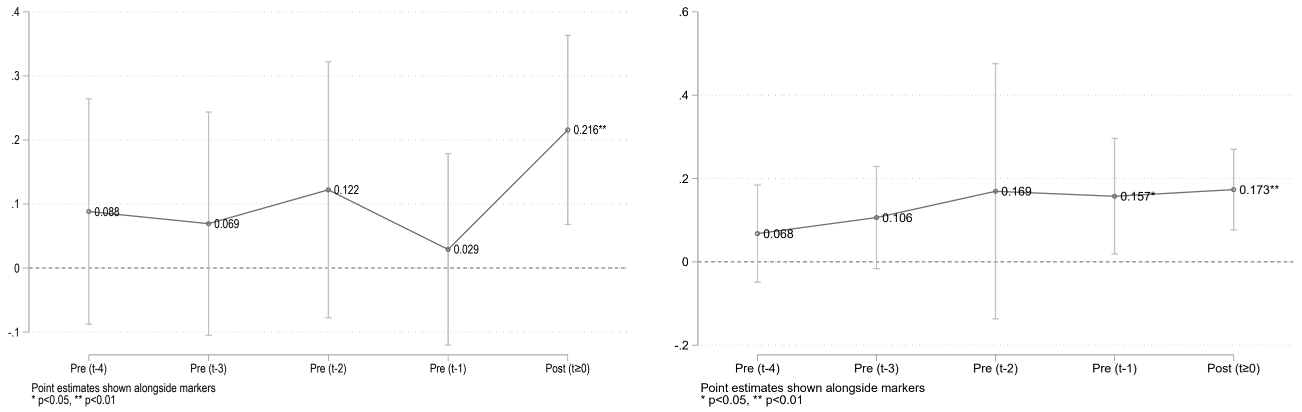
[27] Due to the limited number of observations in the NPS, and bearing in mind that we only have four survey rounds, we include only one lead of the treatment variable, which is a dummy that indicates the two years prior to the deployment of the corresponding mini-grid. Adding more than one lead is not possible, as we lose most of the observations in our sample.

Figure 6. Estimated impact on the probability of having an electricity connection for treated households (as defined using the binary treatment approach) relative to the time of installation of the mini-grids

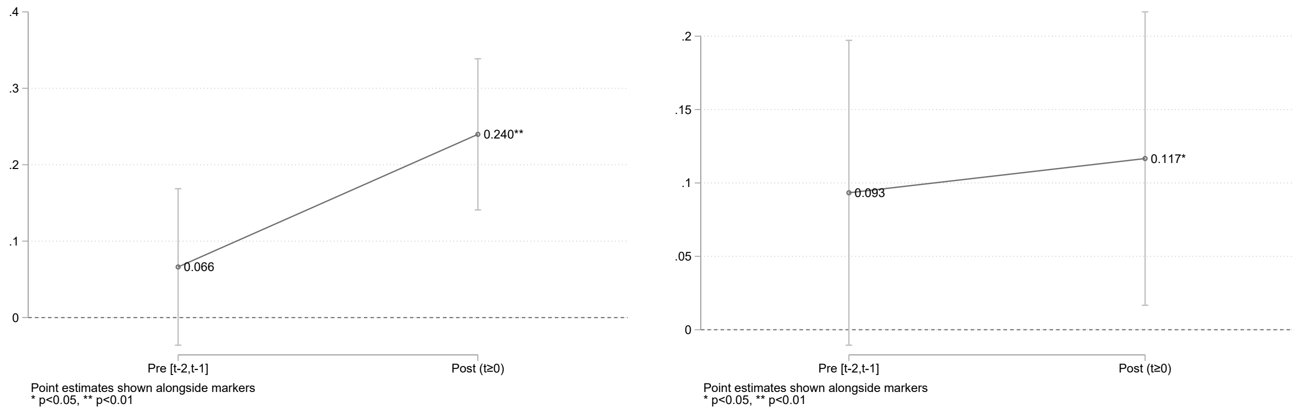
Panel A: DHS dataset



(A) Model specification with Region FE

(B) Model specification with Cluster FE

Panel B: NPS dataset



(C) Model specification with Region FE

(D) Model specification with Cluster FE

Note: The figures capture the impact that the deployment of the mini-grids in our sample had on the uptake of electricity connections among treated households —as defined in the binary treatment approach, i.e., those within 5 km from a mini-grid— using both the DHS dataset (Panel A) and the NPS dataset (Panel B). For the DHS, we consider the impact four years before the year in which the mini-grids in our sample were deployed. For the NPS, we consider the impact two years before the year in which these mini-grids were deployed. Estimates in Figures 6(A) and 6(C) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables (head of household age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid), region fixed effects, and year fixed effects. Estimates in Figures 6(B) and 6(D) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables, cluster fixed effects, and year fixed effects. Standard errors are clustered at the region-year level. Vertical bands represent 95% confidence intervals for the point estimates.

such as lighting. This question is of particular relevance bearing in mind that about 71% of the households in our sample use either oil- or paraffin-based devices to light their homes. These devices, which are popular not only in Tanzania but also in many other developing countries (Choumert-Nkolo et al., 2019), are well-acknowledged sources of indoor air pollution and are causally associated with respira-

Table 3. Impact of mini-grids on household probability of using electricity as the main source of lighting

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	0.0148	0.000311			0.173***	0.146**		
	(0.0464)	(0.0451)			(0.0646)	(0.0626)		
Mini-grid × post	0.205***	0.230***	0.0628*	0.0854*	0.261***	0.306***	0.100*	0.152**
	(0.0568)	(0.0537)	(0.0357)	(0.0434)	(0.0855)	(0.0902)	(0.0556)	(0.0611)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.248	0.262	0.381	0.397	0.267	0.281	0.381	0.397
N. Observations	1,053	1,053	976	973	1,053	1,053	976	973

Note: The outcome is a dummy equal to 1 if the household uses electricity as the main source of lighting (and 0 otherwise). Linear probability models estimated by OLS using data from the NPS with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, in which the variable "Mini-grid" is a dummy one defined as follows $MG_{c,r} = \mathbb{1}_{\{d_{c,r}<5\}}$ for all $d_{c,r} \in [0,10]$, where $d_{c,r}$ is the distance (in km) between households in cluster c and the closest mini-grid; while in columns (5)-(8) we use the continuous treatment approach, in which the variable "Mini-grid" is a continuous one defined as follows $MG_{c,r} = 1 - \frac{d_{c,r}}{10}$, for all $d_{c,r} \in [0,10]$. Columns (1) and (5): full set of control variables —including head of household (log-) age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid (solar, hydro, biomass, hybrid or diesel)—, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

tory problems and premature death (Hanna et al., 2016; Imelda, 2020). Thus, our goal is to check whether the deployment of mini-grids also induced households to replace the use of oil or paraffin devices with electricity to light their homes, contributing thus to mitigating indoor air quality-related problems.

Hence, we estimate equation (3.1) again using a binary outcome variable that captures whether a household uses electricity as the main source of lighting instead of fossil fuel-based devices —this variable is available only in the NPS dataset (see Section 3.3). The results are presented in Table 3, where columns (1) and (2) show the coefficients obtained using the model specifications with region fixed effects based on the binary treatment approach. The estimates suggest that the installation of a mini-grid raises the probability of using electricity for lighting by 20-23%, with this effect being significant at the 1% level. However, when we replace region fixed effects with cluster fixed effects, the magnitude of the coefficient slightly decreases to about 9% (significant at the 10% level). Next, columns (5)-(8) present estimates using the continuous treatment approach. The most complete specification of our model —columns (6) and (8), which include the full set of controls, year and spatial fixed effects, and region-specific trends— estimates an increase of about 11-22% in the probability of using electricity for lighting for a household located 2.5 km away from a mini-grid (significant at least at the 5% level). Our empirical findings suggest mini-grids increased the use of electricity as the main source of lighting, reducing the reliance on fossil fuel-based devices like oil or paraffin lamps that are popular in Tanzania but have negative effects on indoor air quality.

Robustness checks. So far, we provide substantial evidence mini-grids in Tanzania increased the uptake of electricity connections for nearby households and promoted the use of electricity for lighting (while decreasing that of pollutant devices). These results are robust to various robustness checks, which are included in Appendix B. Here, we provide a summary of the analysis performed in that Appendix.

First, as shown in Table 1, we acknowledge an imbalance in some observable characteristics across the subsets of households in our sample (e.g., in the education of the head of household). As a consequence, one may be concerned that these imbalances might also explain the results we obtain. To address this concern, we use a propensity score matching procedure that corrects such imbalances. In particular, we proceed as follows. First, we estimate the propensity score of being in the treatment group (as defined by the binary treatment approach) using household-level observable characteristics. Then, we match treated and control households based on such an estimated propensity score. Finally, we re-estimate our main regression model using the subset of matched households. The main empirical results obtained using the matched sample are shown in Appendix B.1. These results, included in Tables B.2 and B.3, are quantitatively and qualitatively similar to those included in Tables 2 and 3, respectively.

Then we show in Appendix B that our empirical results are consistent and robust to alternative sample selection and definitions of the treated and the control groups. In particular, results in Tables 2 and 3 prove robust *(i)* after dropping from our sample households that are relatively close to the national grid transmission lines (Appendix B.2, Tables B.6-B.7), *(ii)* after excluding from the set of mini-grids those that are diesel-fueled (Appendix B.3, Table B.11), and *(iii)* after considering potential spillovers across treated and control households, as defined in the binary treatment approach (Appendix B.4, Tables B.14-B.15).

4.2 Effect of mini-grids on wealth- and health-related outcomes

Main results. Next, we turn to present the results from equation (3.1) using the wealth index provided by the DHS as our outcome of interest.[28] As extensively explained in Section 3.3, this wealth index is a composite measure of households living standard and is calculated based on the ownership of selected assets, household access to water and electricity, and other amenities (Rutstein, 2015). Our goal is to check whether the deployment of mini-grids is also reflected in a positive effect on this index for households that are relatively close to them (i.e., among the treated households).

Table 4. Impact of mini-grids on the DHS wealth index

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	3.893^{**}	3.831^{*}			8.307^{***}	7.749^{**}		
	(1.691)	(1.945)			(2.830)	(3.203)		
Mini-grid × post	2.279	2.722	6.040^{***}	6.454^{***}	3.331	4.176^{*}	8.442^{***}	8.821^{***}
	(1.816)	(2.031)	(1.436)	(1.897)	(2.242)	(2.395)	(1.929)	(2.210)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.314	0.337	0.454	0.466	0.325	0.344	0.451	0.463
N. Observations	3,691	3,691	3,691	3,691	3,691	3,691	3,691	3,691

Note: The outcome is the (log-) DHS wealth index. Linear regression models estimated by OLS using data from the DHS with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, in which the variable "Mini-grid" is a dummy one defined as follows $MG_{c,r} = \mathbb{1}_{\{d_{c,r} < 5\}}$ for all $d_{c,r} \in [0, 10]$, where $d_{c,r}$ is the distance (in km) between households in cluster c and the closest mini-grid; while in columns (5)-(8) we use the continuous treatment approach, in which the variable "Mini-grid" is a continuous one defined as follows $MG_{c,r} = 1 - \frac{d_{c,r}}{10}$, for all $d_{c,r} \in [0, 10]$. Columns (1) and (5): full set of control variables —including head of household (log-) age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid (solar, hydro, biomass, hybrid or diesel)—, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 presents estimated coefficients of the linear regression model using both the binary treatment approach —columns (1)-(4)— and the continuous treatment approach —columns (5)-(8). First, columns (1) and (2) contain the estimates for the model specifications that include region fixed effects. These columns indicate that the DHS wealth index increased among households within a radius of less than 5

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[28] A similar wealth index is not available in the NPS dataset.

km to a mini-grid by about 2.3-2.7 points in the post-deployment period, although these coefficients are not statistically significant.[29] However, using the continuous treatment approach, we estimate a very similar increase in the DHS wealth index of about 2.5-3.1 points for treated households (these numbers are obtained using the calculation explained in footnote 24), which is significant at the 10% level in the most complete specification included in column (6). Moreover, this coefficient is also positive, higher in magnitude, and significant at the 1% level in columns (3)-(4) and (7)-(8), where we replace the region fixed effects with cluster fixed effects. In all these cases, the estimated average impact on the DHS wealth index among treated households is about 6-6.6 points. Therefore, these results suggest that mini-grids increased the wealth of households that are close to them.

Validity. In order to confirm the validity of the empirical results above, we estimate again the augmented version of equation (3.1) that includes leads of the binary treatment variable. The goal is to test if the increase in the DHS wealth index observed in Table 4 is the result of the deployment of the mini-grids or, alternatively, if it is stemming from a pre-existing trend in this index among the households treated prior to the installation of a mini-grid. The results of this exercise are included in Figure 7.

First, the point estimates obtained for the *Post* coefficient using both the model specification including the full set of controls, year fixed effects, and region fixed effects —Figure 7(A)— and that in which the latter are replaced by cluster fixed effects —Figure 7(B)— are positive and equal to 3 and 6.6, respectively (being the latter one significant at the 1% level). These results are consistent with those in Table 4. Furthermore, the lead indicators that capture the impact on the DHS wealth index in the years prior to the deployment of mini-grids, namely, four $(t-4)$, three $(t-3)$, and two $(t-2)$ years before, are statistically insignificant and very close to zero in some cases. This rules out that the documented increase in the wealth index among treated households is stemming from a previously existing trend.

However, the reader should be aware that the lead variable at $t-1$ is positive (in between 9.2 and 8.6 points) and significant at the 1% level, indicating a slight anticipation effect in the wealth index one year before the construction of the corresponding mini-grid. As discussed by Benshaul-Tolonen (2019) in a similar context, one could expect a deviation from the pre-trend during the investment period of capital-intensive projects, as they can generate local employment and create wealth. Therefore, following her

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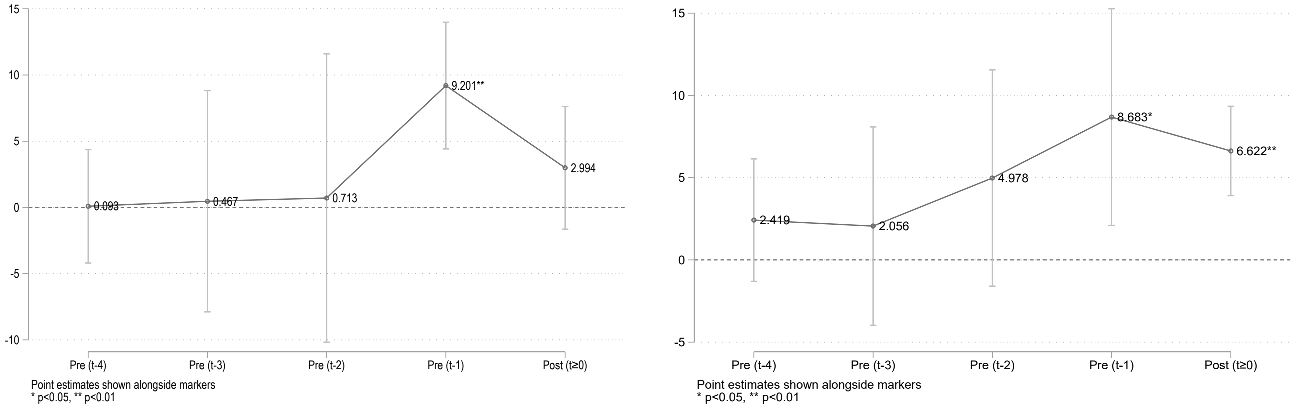
[29] As extensively discussed later in the "Validity" subsection, the lack of statistical significance might be due to a slight anticipation effect. Hence, as a robustness check, in Appendix B.5 we provide the same set of results using an alternative version of our main regression model that accounts for this potential effect.

Figure 7. Estimated impact on the DHS wealth index for treated households (as defined using the binary treatment approach) relative to the time of installation of the mini-grids



(A) Model specification with Region FE

(B) Model specification with Cluster FE

Note: The figures capture the impact that the deployment of the mini-grids in our sample had on the (log-) DHS wealth index among treated households —as defined in the binary treatment approach, i.e., those within 5 km from a mini-grid— using the DHS dataset. We consider the impact four years before the year in which the mini-grids in our sample were deployed. Estimates in Figure 7(A) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables (head of household age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid), region fixed effects, and year fixed effects. Estimates in Figure 7(B) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables, cluster fixed effects, and year fixed effects. Standard errors are clustered at the region-year level. Vertical bands represent 95% confidence intervals for the point estimates.

approach, in Appendix B.5 we provide as a robustness check an alternative set of results in which the *Post* variable is re-defined to also capture the investment phase; see Table B.19 and Figure B.1.

Additional results. The DHS wealth index is a composite measure of household living standards. However, it could also be informative to study the effect that mini-grids have, in particular, on the ownership of electric-powered appliances. Therefore, as an additional empirical exercise, we examine whether the deployment of mini-grids in Tanzania had a positive impact on the uptake of two basic appliances, namely, refrigerators and televisions (Lee et al., 2016; Wen et al., 2023). To do so, we estimate again equation (3.1) using as our outcome of interest a dummy variable that is equal to 1 if a household owns these appliances (and 0 otherwise) using data from both the DHS and the NPS. Table 5 contains the estimation results. For the sake of expositional clarity, we include in this subsection the results using only the binary treatment approach, while the same set of results using the continuous treatment approach are in Appendix C.1 (with additional robustness checks using this approach in Appendix C.2).

First, Panel A shows the estimates using the "refrigerator" dummy as the outcome variable. The coefficient of the "Mini-grid × Post" interaction term is positive, significant at the 1% level, and extraor-

Table 5. Impact of mini-grids on household probability of owning selected appliances (refrigerator and television)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	-0.00150	-0.0120		
	(0.00935)	(0.00970)		
Mini-grid × post	0.0480***	0.0636***	0.0958***	0.109***
	(0.0152)	(0.0164)	(0.0355)	(0.0333)
R^2	0.0834	0.113	0.161	0.188
N. Observations	3,987	3,987	3,987	3,987
	Panel A2. NPS dataset			
Mini-grid	-0.00235	-0.00462		
	(0.0161)	(0.0173)		
Mini-grid × post	0.0807***	0.0831***	0.0504***	0.0365***
	(0.0207)	(0.0225)	(0.0141)	(0.0105)
R^2	0.107	0.113	0.137	0.180
N. Observations	1,053	1,053	976	973

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.0361	0.0515*		
	(0.0273)	(0.0280)		
Mini-grid × post	0.0898***	0.0795**	0.112***	0.134***
	(0.0310)	(0.0325)	(0.0382)	(0.0488)
R^2	0.175	0.190	0.257	0.269
N. Observations	3,991	3,991	3,991	3,991
	Panel B2. NPS dataset			
Mini-grid	0.0125	-0.00394		
	(0.0441)	(0.0421)		
Mini-grid × post	0.189***	0.215***	0.0211	0.0260
	(0.0595)	(0.0542)	(0.0350)	(0.0369)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.248	0.263	0.351	0.389
N. Observations	1,053	1,053	976	973

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS (Panels A1 and B1) and from the NPS (Panels A2 and B2) with standard errors clustered at region-year level. In all these columns we use the binary treatment approach, in which the variable "Mini-grid" is a dummy one defined as follows $MG_{c,r} = \mathbb{1}_{\{d_{c,r}<5\}}$ for all $d_{c,r} \in [0,10]$, where $d_{c,r}$ is the distance (in km) between households in cluster c and the closest mini-grid. Column (1): full set of control variables —including head of household (log-) age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid (solar, hydro, biomass, hybrid or diesel)—, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

dinarily similar in magnitude across all the specifications of our regression model using both the DHS (Panel A1) and the NPS (Panel A2). In the former case, our results suggest an increase between 5% (for the least robust model specification) and 11% (for the most robust model specification) in the uptake of refrigerators among treated units relative to the control ones. When we use the NPS instead, the least and the most robust model specifications suggest an increase of about 8% and 5%, respectively. Then, we include in Panel B the results using as our outcome of interest the probability with which households own a television. This probability increases by about 8-13% for treated households in the post-treatment period —being this effect is significant at least at the 5% level— if we use the DHS (Panel B1). A slightly higher effect (of about 15-23%) is obtained if we use instead the NPS dataset. However, while this effect is significant at the 1% level for the model specifications that include region fixed effects —Columns (1)-(2)—, it is not for the ones that contain cluster fixed effects —Columns (3)-(4).

Table 6. Impact of mini-grids on the incidence of diarrhea among children (less than 5 years old)

	(1)	(2)	(3)	(4)
Mini-grid	0.0264	0.0798^{***}		
	(0.0291)	(0.0295)		
Mini-grid × post	-0.0350	-0.0873^{**}	-0.127	-0.237^{**}
	(0.0381)	(0.0400)	(0.101)	(0.117)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.0766	0.0840	0.122	0.129
N. Observations	885	885	885	885

Note: The outcome is a dummy equal to 1 if any children less than 5 years of age in the household had diarrhea within the last two weeks (and 0 otherwise). Linear probability models estimated by OLS using data from the three rounds of the DHS (1999, 2010, and 2015-2016) with standard errors clustered at region-year level. In all these columns we use the binary treatment approach, in which the variable "Mini-grid" is a dummy one defined as follows $MG_{c,r} = \mathbb{1}_{\{d_{c,r}<5\}}$ for all $d_{c,r} \in [0, 10]$, where $d_{c,r}$ is the distance (in km) between households in cluster c and the closest mini-grid. Column (1): full set of control variables —including head of household (log-) age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid (solar, hydro, biomass, hybrid or diesel)—, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Finally, we examine the impact of mini-grids on health outcomes. More precisely, we investigate whether the increase in refrigerator ownership induced by mini-grids (documented in Table 5) led to a lower incidence of infectious and viral diseases that are associated with poor food safety and preservation (Hoffmann et al., 2019). In particular, we focus on diarrhea, which is a particularly prevalent disease among children in developing countries with severe health consequences.[30] To this end, we estimate equation (3.1) again, using a dummy variable that equals 1 if any children less than 5 years of age in a household recently had diarrhea (and 0 otherwise) as our outcome of interest.

The results of this last empirical exercise using the DHS are included in Table 6. The point estimate obtained for the specification of our regression model that includes the full set of controls, region and time fixed effects, and region-specific trends shows that the incidence of this disease decreased by approximately 9% (significant at the 5% level). When we replace region fixed effect with cluster fixed effects, the estimated effect is higher (about 23%) and remains statistically significant at the 5% level. The same effect is also negative (albeit slightly lower in magnitude) but not statistically significant in the specifications that do not include the region time trends. Even though these results should be interpreted with caution due to the limited number of observations available on the incidence of diarrhea in the DHS, all in all, they provide suggestive evidence that the installation of mini-grids not only increased refrigerator ownership but also led to a lower prevalence of diarrhea among treated households.

Robustness checks. The results on the effects of mini-grids on the wealth-related and health-related outcomes explained above are robust to a battery of robustness checks, which can be found in Appendix B. Here, we provide a summary of the analysis performed in this Appendix.

First, we deal with the unbalanced sample problem in Appendix B.1 by showing that our estimates remain extraordinarily similar when we use the matching technique explained in Section 4.1 (Appendix B.1, and Tables B.4 and B.5). Second, we find the wealth- and health-related effects of mini-grids are not affected either after excluding from our sample households that are relatively close to the transmission lines of the national grid (Appendix B.2, Tables B.8-B.10). Third, these results also prove robust when we exclude from our sample diesel-fueled mini-grids (Appendix B.3, Tables B.12 and B.13) and also when we drop households that are likely affected by spillovers in the binary treatment approach (Appendix B.4, Tables B.16-B.18). Finally, the same is also true in Appendix B.5, where we re-estimate our main

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[30] According to Pruss-Ustun et al. (2008) and Jeuland et al. (2016), it is estimated that diarrheal diseases are responsible for about 6–7% of mortality (two million deaths annually), mostly among young children.

regression model using the DHS wealth index as the outcome of interest after redefining the variable *Post* to account for the potential impact on wealth of the investment phase (Table B.19 and Figure B.1).

5 Conclusion

Over the past few years, many international institutions and donors have committed billions of dollars to deploy mini-grids, which have become the mainstream "last-mile" infrastructure solution for electrifying entire villages in developing countries where national grid coverage is limited. This trend has been particularly marked in SSA, where about 4,000 mini-grids are planned for development — almost two in every three of the total planned globally (SEforALL, 2020). However, there is limited evidence on the effectiveness of mini-grids to promote the use of electricity among households, and consequently, little is known about their household welfare effects.

To the best of our knowledge, this is the first study to provide causal evidence on the economics of mini-grids. To do so, we take advantage of a policy reform implemented in Tanzania in 2008, which doubled the number of mini-grids across the country between that year and 2016. Using geo-localized data on the universe of mini-grids in this country, in combination with household-level data from two different sources —namely, four waves of the NPS and seven waves of the DHS— we study the impact of the construction of new mini-grids on the number of electricity connections, on the use of electricity as the main source of lighting, and on other wealth- and health-related outcomes. To do this, we exploit variation in the distance to mini-grids for households that are in proximity to them to compare the outcomes of those that are relatively close to a mini-grid and those that are relatively far from it. This methodology avoids including as "control" households that are too far away from the "treated" ones.

We find households that are relatively close to a mini-grid increase the probability of having a connection by about 16-23% after the construction of a mini-grid relative to households that are relatively far from them. Moreover, we document a similar positive effect on the DHS wealth index among treated households, in the probability with which treated households own selected electric-powered appliances. Therefore, our results speak directly to the implications of mini-grids for indoor pollution as we demonstrate that they decrease the use of some other fuels that are popular among households in SSA for lighting their homes. We also provide suggestive evidence of a decrease in the incidence of diarrhea among children.

Despite the pioneering work that we have conducted, we acknowledge several limitations of this paper driven mostly by data limitations. First, we could not conduct a technology-specific mini-grid analysis due to insufficient power. Therefore, and as a second limitation, we could not conduct a cost-benefit analysis (as the technologies that we consider in this study are widely heterogeneous in costs). Future researchers, thus, should take this into consideration.

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Online Appendix for “Household effects of electrification through mini-grids: Evidence from a nation-wide policy reform in Tanzania”

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Contents

Appendix A: Additional evidence on the geography of mini-grid locations

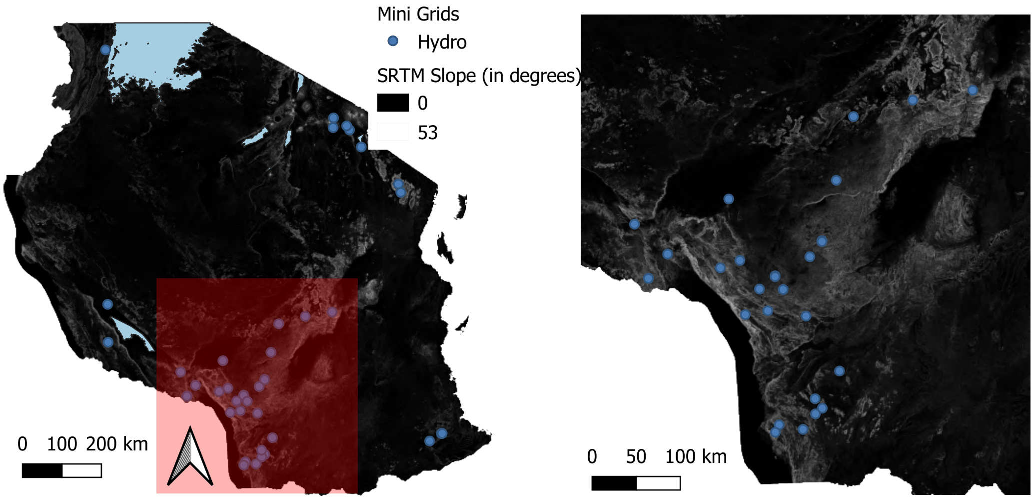
In this appendix, we offer additional detailed evidence supporting that, while the selection of communities in our sample for mini-grid installation was not random, the physical placement of the mini-grids within these communities was primarily determined by geographical and terrain-related factors. To demonstrate this, we provide several high-resolution maps below that document the (presumably exogenous) factors that primarily determined the placement of different types of mini-grids.

First, as discussed in Section 3.1 in the main text, the exact location of hydro-powered mini-grids is determined not only by the presence of a water source with an ample current (such as a river) but also by the terrain's topography (Okot, 2013). This is because the hydroelectricity is generated through an elevation difference: the mini-grid channels part of the stream that falls down a hillside through a powerhouse, after which the water rejoins the main river. Therefore, the speed of the flow, which is critical for the turbine to generate electricity, depends on the elevation of the terrain. As such, mini-grids must be constructed where there is a sufficiently steep slope (US Department of Energy, 2023).

This mechanism is in line with the evidence presented in the map in Figure A.1, which displays the location of all hydro-powered mini-grids in Tanzania included in our sample. This map also includes the elevation of the terrain —obtained from the Shuttle Radar Topography Mission (SRTM) digital elevation model—, where areas with lower slopes are shaded in a darker color and, conversely, those with higher slopes are shaded in a lighter color. To further examine the site selection of these mini-grids, we zoom in on a snapshot of the lower part of the map where a significant number of hydro-powered facilities are located. As evident from the map, the mini-grids are located in areas that are shaded in white or light gray, indicating the steepest slopes of the terrain. This is also consistent with the information in World Bank (2017), which has identified the specific areas in Tanzania that are most suitable for small hydro generators based on the characteristics of the terrain and water bodies. Thus, when installing a hydro-powered mini-grid in a community, the exact location in the premises of it is determined, to a large extent, by the gradient of the terrain.

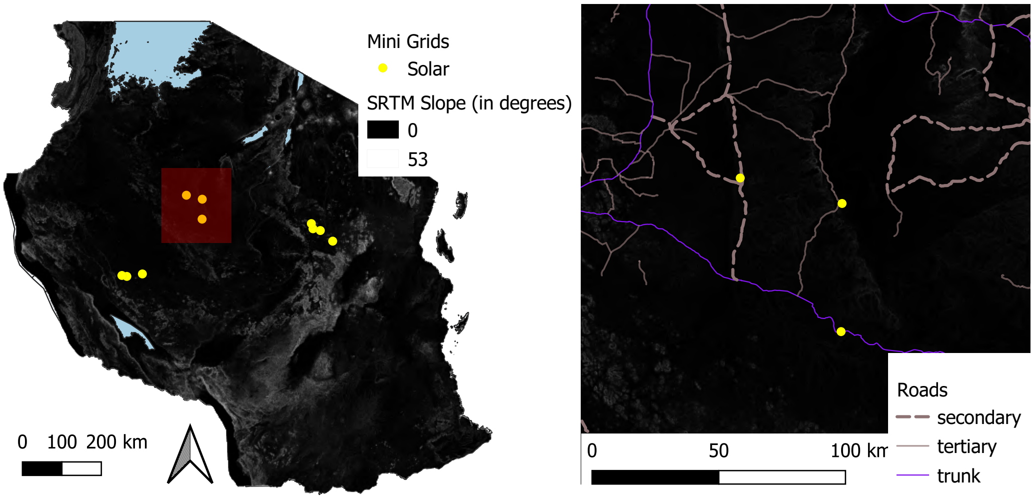
The opposite feature is observed when we turn to examine the location of solar mini-grids. For these mini-grids, location is primarily determined by solar radiance which, however, is relatively uniform across Tanzania, and has little variability within small areas (Moner-Girona et al., 2016; Zigah et al.,

Figure A.1. Map of the location of hydro-powered mini-grids and slope of the terrain in Tanzania



Note: This figure includes a map of all the hydro-powered mini-grids deployed in Tanzania up to 2017, indicated with blue circles. The image shows the topographic slope (in degrees) using a heatmap, in which darker means less slope, obtained from the Shuttle Radar Topography Mission (SRTM) digital elevation model (WorldPop, 2018). Areas shaded in black indicate that the terrain is flat, while areas shaded in white indicate that the slope reaches the maximum one (53 degrees). The bottom part of the map, where most of the hydro-powered mini-grids are located, was zoomed in to better appreciate the slope of the terrain there.

Figure A.2. Map of the location of solar-powered mini-grids, slope of the terrain, and roads in Tanzania



Note: This figure includes a map of all the solar-powered mini-grids deployed in Tanzania up to 2017, indicated with yellow circles. The image shows the topographic slope —in degrees— by a color ramp that goes from its minimum (flat terrain in black) to its maximum (53 degrees) in white (WorldPop, 2018). Secondary roads are indicated with a dashed, thin gray line, tertiary roads are indicated with a solid, thin gray line, and truck roads are indicated with a solid, thin purple line. The middle part of the map, where most of the solar-powered mini-grids are located, was zoomed in to better appreciate the slope of the terrain and the road access there.

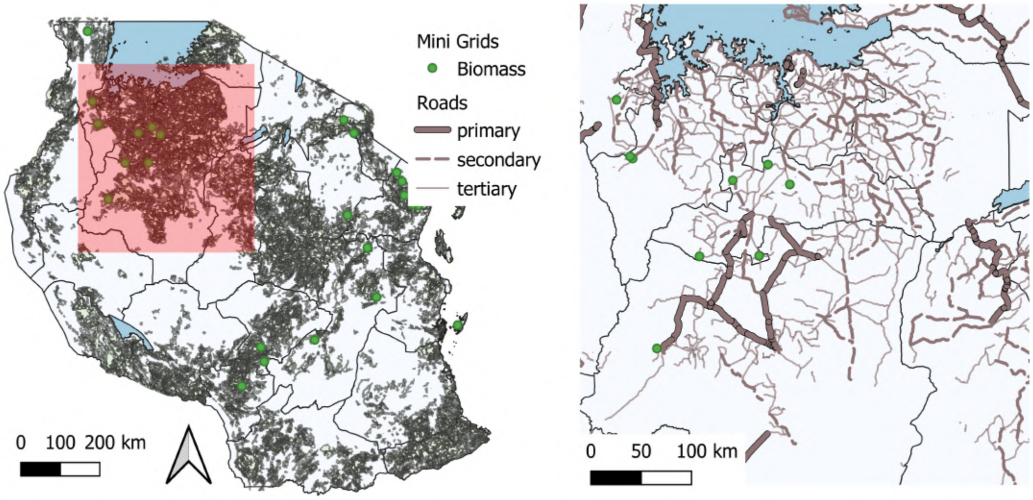
2023). Nevertheless, there are two additional key ingredients (besides solar radiance) that explain the exact location of a solar-powered mini-grid. First, the solar panels used to generate electricity must be installed where there is sufficiently ample flat terrain: it is estimated that a 1 megawatt (MW) solar generator (using photovoltaic panels) occupies around 5.5-6 acres or about 0.023-0.024 square kilometers (Kochendoerfer and Thonney, 2021; Abashidze and Taylor, 2022). Second, because solar PV panels are relatively heavy —the average weight per square meter of panel is about 33 pounds or 15 kilograms (Wu et al., 2017)—, they must also be located in a field that is connected to a road in order to facilitate their transportation and replacement (in case of damage).

These observations are supported by the information presented in Figure A.2, which displays a map containing all of the solar mini-grids included in our sample. As with the previous map, we show again the slope of the terrain and also include the roads in Tanzania in the zoomed-in portion to the right. In this map, it is fairly evident that the solar mini-grids in our sample are located in areas that are essentially flat, indicated on the map by black shading. Additionally, all these mini-grids are located near an existing road, be it a primary, a secondary, or a tertiary road (Chen et al., 2021).

Next, we turn to investigate the geographical distribution of biomass-powered mini-grids. These systems utilize agricultural waste, such as residues or wood, and share some similarities with the previously discussed mini-grids. Specifically, their location is not only constrained by the availability of biomass materials but also (as is the case for solar mini-grids) by the transportation logistics of the relatively heavy waste. Consequently, they tend to be located in areas with substantial agricultural activity and convenient access to major roads for transportation (Felix and Gheewala, 2011). Consistently, as shown in Figure A.3, the location of all biomass mini-grids in our sample corresponds to areas with agricultural land cover, indicated by light green shading on the map —this information was obtained from FAO (2002). Moreover, we can see in the zoomed-in portion of the map to the right that all of them are easily accessed by either a primary road, a secondary road, or a tertiary road.

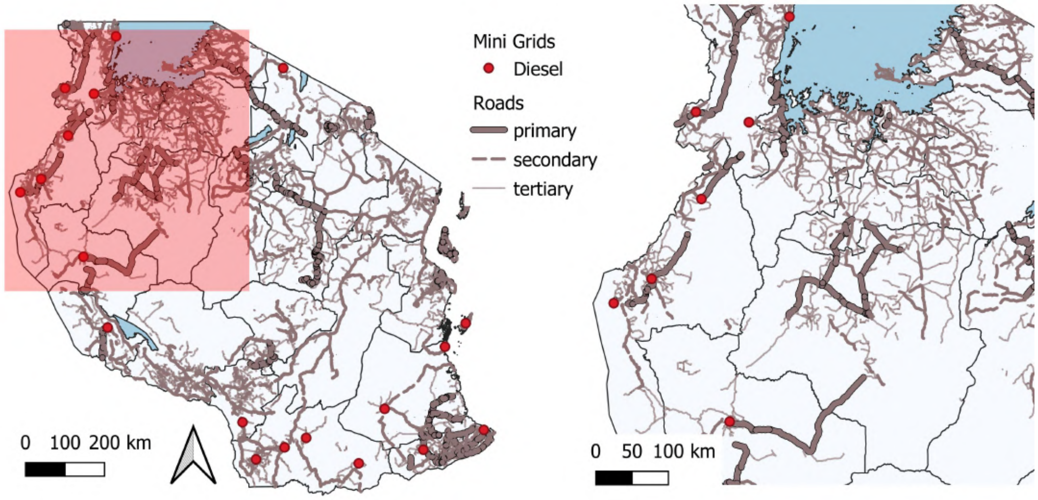
Finally, something similar occurs with diesel-fueled mini-grids: they also require proximity to primary (truck-accessible) roads that can be accessed by tank trucks for the delivery of diesel, as there are no pipelines in Tanzania for transporting this fuel Szabo et al. (2011). Again, we can observe in the map provided in Figure A.4 that all the diesel mini-grids in our sample are located nearby primary roads.

Figure A.3. Map of the location of biomass-powered mini-grids, agricultural land cover, and roads in Tanzania



Note: This figure includes a map of all the biomass-powered mini-grids deployed in Tanzania up to 2017, indicated with green circles. Agricultural land cover (FAO, 2002) is indicated in light green. Primary roads are indicated with a solid, thick gray line; secondary roads are indicated with a dashed, thin gray line, and tertiary roads are indicated with a solid, thin gray line. The solid, thin black lines represent the boundaries of the regions. The top-right part of the map, where most of the biomass-powered mini-grids are located, was zoomed in to better appreciate the road access and the agricultural land cover there.

Figure A.4. Map of the location of diesel-powered mini-grids and roads in Tanzania



Note: This figure includes a map of all the diesel-powered mini-grids deployed in Tanzania up to 2017, indicated with red circles. Primary roads are indicated with a solid, thick gray line; secondary roads are indicated with a dashed, thin gray line, and tertiary roads are indicated with a solid, thin gray line. The solid, thin black lines represent the boundaries of the regions. The top-right part of the map, where most of the diesel-powered mini-grids are located, was zoomed in to better appreciate the road access there.

Appendix B: Robustness checks

Even though the empirical strategy explained in Section 3 in the main text is well-founded to support the causal interpretation of our estimates, we acknowledge that there are alternative procedures to estimate the effect of the installation of a mini-grid on households, other definitions of the treatment and control groups, and also alternative samples that we could have been employed instead. Hence, this appendix presents an extensive procedure of robustness checks to confirm that our results are not sensitive to the choices used throughout the paper.

B.1 Matching

We first recognize that there is an imbalance in some observable characteristics across the different subsets of households in our sample. For example, Table 1 in the main text indicates that the dummy capturing the education level of the head of household is not well-balanced across the treated and the control groups (as defined in the binary treatment approach) both in the DHS and in the NPS. Moreover, Table B.1 (Panel A), in which we include the mean value of selected variables for both the treated and the control cohorts —and also the p-value of the test under the null hypothesis that the difference between them is equal to zero—, shows that there are also minor imbalances in some characteristics, such as in the age of the head of households. Therefore, one may be concerned that these differences might also explain the empirical results that we obtain.

To address this potential concern, we use a matching technique that can help resolve the unbalanced sample problem before implementing our estimation methodology. In particular, we proceed as follows. First, we estimate the propensity score of being in the treatment group (i.e., less than 5 km far from a mini-grid) using the observable characteristics of the head of the household (age, education, and sex), and also a dummy that captures whether the household lives in a rural setting.[1] Then, we match treated and control households based on the propensity score. Finally, we re-estimate our regression model using the subset of households that have been matched

In Table B.1 (Panel B) we examine the quality of the matching by comparing the mean of the variables above for treated and control households after the matching. Again, this table includes the p-value of

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[1] As indicated in Table B.1, this dummy variable is also not well-balanced across the two subsets of households considered (note that, due to the presence of cluster fixed effects, it cannot be included in our main regression model).

Table B.1. Balance of household characteristics before and after matching

	Panel A: Before matching					
	DHS dataset			*NPS dataset*		
	Mean in treated	Mean in untreated	Difference (p-value)	Mean in treated	Mean in untreated	Difference (p-value)
	(1)	(2)	(3)	(4)	(5)	(6)
(log-) Age of Hoh	3.787	3.698	-0.088***	3.818	3.735	-0.084***
	(0.356)	(0.350)	(0.000)	(0.329)	(0.346)	(0.000)
Hoh primary educ (d)	0.784	0.863	0.079***	0.567	0.690	0.123***
	(0.412)	(0.344)	(0.000)	(0.496)	(0.463)	(0.000)
Hoh sex (d)	0.748	0.731	-0.017	0.738	0.703	-0.035
	(0.434)	(0.443)	(0.169)	(0.440)	(0.457)	(0.197
Rural (d)	0.823	0.386	-0.437***	0.890	0.339	-0.550***
	(0.382)	(0.487)	(0.000)	(0.313)	(0.474)	(0.000)
N. Observations	2,254	2,803	5,057	527	545	1,072

	Panel B: After matching					
	DHS dataset			*NPS dataset*		
	Mean in treated	Mean in untreated	Difference (p-value)	Mean in treated	Mean in untreated	Difference (p-value)
(log-) Age of Hoh	3.725	3.726	0.000	3.722	3.731	0.009
	(0.345)	(0.348)	(0.978)	(0.337)	(0.342)	(0.770)
Hoh primary educ (d)	0.828	0.826	-0.003	0.674	0.682	0.008
	(0.377)	(0.380)	(0.870)	(0.470)	(0.467)	(0.846)
Hoh sex (d)	0.765	0.755	-0.010	0.760	0.744	-0.017
	(0.424)	(0.430)	(0.562)	(0.428)	(0.437)	(0.674)
Rural (d)	0.751	0.751	-0.000	0.760	0.760	0.000
	(0.433)	(0.433)	(1.000)	(0.428)	(0.428)	(1.000)
N. Observations	1,176	1,176	2,352	242	242	484

Note: Balance of selected household characteristics. Panel A: before the matching procedure. Panel B: after the matching procedure. Columns (1) and (4): means for the subgroups of households within a radius of 0-5 km to the closest mini-grid (treated households in the binary treatment approach) in the DHS and in the NPS respectively. Columns (2) and (5): means for the subgroups of households within a radius of 5-10 km to the closest mini-grid (control households in the binary treatment approach) in the DHS and in the NPS respectively. The standard deviation of each variable is displayed in parentheses. Columns (3) and (6): difference in means and the p-value (in parenthesis) of a simple t-test in means difference. The significance levels of this test are as follows: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All dummy variables are indicated with a (d).

the test under the null hypothesis that this difference equals zero —see columns (3) and (6). As we can see, no imbalances remain in these variables after implementing the matching methodology both in the DHS and in the NPS (although this lack of imbalances comes at the cost of losing approximately half of our sample).

Finally, we provide the same set of empirical results that we present in the main text (Tables 2-5) using our matched sample of households. These results are included in Tables B.2-B.5 respectively.[2] Regarding the coefficients obtained using the DHS, all of them remain positive, significant at least at the 10% level —except for that in Table B.4, column (2), and that in Table B.5, Panel B1, column (2)— and

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[2] Note that, due to the lack of observations, we cannot estimate the impact of mini-grids on the incidence of diarrhea using the matched sample (i.e., we do not have sufficient statistical power to replicate Table 6).

similar in magnitude to those included in the analog tables in the main text. This is also the case for most of the coefficients obtained using the NPS dataset. However, the reader should be aware that in some cases the estimated coefficients lose significance (particularly in the model specifications that include cluster fixed effects), likely due to the lack of observations and statistical power to estimate them; see columns (3)-(4) and (7)-(8) in Tables B.2, B.3, and also columns (3)-(4), Panels A2 and B2, in Table B.5. Overall, these results offer additional evidence that the deployment of mini-grids positively impacted the uptake of electricity connections, the use of electricity as the main source of lighting, the DHS wealth index, and the probability of having appliances among nearby households.

Table B.2. Impact of mini-grids on household probability of having an electricity connection using a matching procedure

	Binary treatment approach				*Continuous treatment approach*			
	Panel A. DHS dataset							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	0.00182	0.0282			0.0451	0.0841		
	(0.0474)	(0.0432)			(0.0936)	(0.0895)		
Mini-grid × post	0.160***	0.130**	0.149**	0.170**	0.290***	0.238***	0.284**	0.307**
	(0.0506)	(0.0526)	(0.0581)	(0.0776)	(0.0762)	(0.0743)	(0.108)	(0.126)
R^2	0.207	0.244	0.431	0.457	0.225	0.258	0.432	0.458
N. Observations	2,351	2,351	2,351	2,351	2,351	2,351	2,351	2,351
	Panel B. NPS dataset							
Mini-grid	-0.0689	-0.0572			0.0643	0.0919		
	(0.0420)	(0.0483)			(0.0838)	(0.0878)		
Mini-grid × post	0.199***	0.194**	-0.0127	-0.0286	0.240*	0.236*	0.0106	-0.0499
	(0.0682)	(0.0746)	(0.0491)	(0.0686)	(0.121)	(0.140)	(0.0832)	(0.107)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.189	0.209	0.420	0.411	0.197	0.219	0.419	0.411
N. Observations	482	482	435	432	482	482	435	432

Note: The outcome is a dummy equal to 1 if the household has an electricity connection (and 0 otherwise). Linear probability models estimated by OLS using data from the DHS matched sample (Panel A) and from the NPS matched sample (Panel B) with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.3. Impact of mini-grids on household probability of using electricity as the main source of lighting using a matching procedure

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	-0.0684	-0.0580			0.0605	0.0850		
	(0.0422)	(0.0483)			(0.0850)	(0.0885)		
Mini-grid × post	0.189***	0.187**	-0.0127	-0.0286	0.226*	0.225	0.0106	-0.0499
	(0.0687)	(0.0749)	(0.0491)	(0.0686)	(0.122)	(0.140)	(0.0832)	(0.107)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.193	0.208	0.420	0.411	0.200	0.217	0.419	0.411
N. Observations	482	482	435	432	482	482	435	432

Note: The outcome is a dummy equal to 1 if the household uses electricity as the main source of lighting (and 0 otherwise). Linear probability models estimated by OLS using data from the NPS (matched sample) with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.4. Impact of mini-grids on the DHS wealth index using a matching procedure

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	2.212*	2.325			4.228	3.854		
	(1.309)	(1.509)			(2.987)	(3.403)		
Mini-grid × post	2.449*	2.710	5.084***	6.281***	4.607**	5.124**	7.489***	9.102***
	(1.442)	(1.780)	(1.606)	(2.107)	(2.061)	(2.333)	(2.214)	(2.657)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.247	0.274	0.428	0.446	0.252	0.275	0.426	0.444
N. Observations	2,135	2,135	2,135	2,135	2,135	2,135	2,135	2,135

Note: The outcome is the (log-) DHS wealth index. Linear regression models estimated by OLS using data from the DHS (matched sample) with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in Columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.5. Impact of mini-grids on household probability of owning selected appliances (refrigerator and television) using a matching procedure

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	-0.00200	-0.00560		
	(0.00912)	(0.00916)		
Mini-grid × post	0.0306^{***}	0.0413^{***}	0.0457^{**}	0.0894^{***}
	(0.0110)	(0.0132)	(0.0227)	(0.0318)
R^2	0.0773	0.108	0.154	0.184
N. Observations	2,348	2,348	2,348	2,348
	Panel A2. NPS dataset			
Mini-grid	-0.0240	-0.0226		
	(0.0184)	(0.0199)		
Mini-grid × post	0.0603^{**}	0.0622^{**}	0.0553	0.0437
	(0.0236)	(0.0261)	(0.0405)	(0.0344)
R^2	0.0561	0.0728	0.118	0.143
N. Observations	482	482	435	432

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.0169	0.0530		
	(0.0353)	(0.0389)		
Mini-grid × post	0.0827^{**}	0.0479	0.103^{**}	0.129^{**}
	(0.0392)	(0.0425)	(0.0407)	(0.0520)
R^2	0.172	0.200	0.301	0.321
N. Observations	2,350	2,350	2,350	2,350
	Panel B2. NPS dataset			
Mini-grid	-0.106^{**}	-0.103^{*}		
	(0.0473)	(0.0535)		
Mini-grid × post	0.243^{***}	0.246^{***}	0.00880	-0.0165
	(0.0728)	(0.0765)	(0.0442)	(0.0554)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.227	0.249	0.369	0.416
N. Observations	482	482	435	432

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS matched sample (Panels A1 and B1) and from the NPS matched sample (Panels A2 and B2) with standard errors clustered at region-year level. In all these columns we use the binary treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

B.2 Dropping households close to the grid transmission lines

As extensively explained in the main text, mini-grids are stand-alone networks that can operate autonomously without being connected to a centralized grid (Peskett, 2011; Franz et al., 2014). Hence, they are usually located where the centralized grid has not (yet) arrived. However, as can be seen in Figure 1, due to the evolution of the Tanzanian national grid, a few mini-grids in our sample are relatively close to existing high and medium-voltage transmission lines —they were either fully integrated into or built as part of the existing grid (Odarno et al., 2017). In fact Table 1 in the main text shows that some of the households in our sample already had an electricity connection before the deployment of the closest mini-grid. Consequently, one might be concerned that our findings are not arising from the installation of a mini-grid, but they might rather be explained by the presence of the national grid infrastructure.

To address this potential additional concern, we provide in this appendix (as an additional robustness check) our main set of empirical results after dropping the households that are relatively close to the national grid transmission lines. More precisely, and for the sake of consistency, we exclude from our sample households that are less than 10 km far from the existing transmission lines as of 2016 (see Figure 1).[3] The results of this additional empirical exercise are included in Tables B.6-B.10.

First, Table B.6 contains the results on the probability with which households are connected to electricity after the deployment of a mini-grid. The coefficient of the interaction "Mini-grid × post" in Panels A (using the DHS dataset) and B (using the NPS dataset) for all the model specifications considered are extraordinarily similar to those included in Table 2 in the main text. In all these cases the point estimates are positive and significant —except for that in column (2), Panel B—, suggesting that the deployment of mini-grids increased the uptake of electricity connections among the nearby households. The same pattern is observed in Table B.7, whose estimates are again very similar to those in the analog table in the main text (Table 3). These results confirm that mini-grids increased the use of electricity for lighting purposes while decreasing that of pollutant devices.

Next, we turn to present the results using the DHS wealth index as our outcome of interest. These results are included in Table B.8. Consistent with those in Table 4 in the main text, the estimates in columns (1)-(2) and (5)-(6) —obtained for the model specifications that include region-fixed effects using both the binary treatment approach and the continuous treatment approach— are not significant.

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[3] Data on the geographical expansion of the transmission lines for previous years is not available.

Table B.6. Impact of mini-grids on household probability of having an electricity connection (dropping households close to the grid transmission lines)

	Binary treatment approach				*Continuous treatment approach*			
	Panel A. DHS dataset							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	0.0772*	0.0965*			0.214***	0.237**		
	(0.0414)	(0.0570)			(0.0798)	(0.0946)		
Mini-grid × post	0.117**	0.107	0.142**	0.161**	0.196**	0.190**	0.308***	0.321***
	(0.0580)	(0.0716)	(0.0556)	(0.0751)	(0.0789)	(0.0941)	(0.0794)	(0.103)
R^2	0.228	0.247	0.303	0.326	0.245	0.264	0.308	0.329
N. Observations	2,963	2,963	2,963	2,963	2,963	2,963	2,963	2,963
	Panel B. NPS dataset							
Mini-grid	0.108**	0.0919**			0.255***	0.224***		
	(0.0443)	(0.0430)			(0.0733)	(0.0709)		
Mini-grid × post	0.143***	0.167***	0.0799**	0.110***	0.196**	0.244***	0.115*	0.174***
	(0.0520)	(0.0540)	(0.0361)	(0.0332)	(0.0776)	(0.0869)	(0.0629)	(0.0626)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.254	0.269	0.329	0.347	0.263	0.277	0.328	0.346
N. Observations	643	643	597	595	643	643	597	595

Note: The outcome is a dummy equal to 1 if the household has an electricity connection (and 0 otherwise). Linear probability models estimated by OLS using data from the DHS (Panel A) and from the NPS (Panel B) with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission lines. In Columns (1)-(4) we use the binary treatment approach, while in Columns (5)-(8) we use the continuous treatment approach. Column (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Column (2) and (6): same as the previous columns but also including region-specific linear time trends. Column (3) and (7): full set of control variables, cluster fixed effects, and year fixed effects. Column (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

However, all the coefficients obtained for the model specifications that include cluster fixed effects are positive, significant, and very similar to those in Table 4. The same pattern is observed in the appliance regressions, whose results are shown in Table B.9: the point estimates are again positive, while only a few of them are not significant (as is also the case in Table 5). All in all, these findings further suggest that mini-grids positively impact the uptake of electric-powered appliances.

Finally, Table B.10 displays the estimated impact of mini-grid deployment on the incidence of diarrhea among children using the binary treatment approach. Consistent with the results in Table 6 in the main text, the coefficient of interest for all the model specifications considered are negative, providing thus further evidence that mini-grids contributed to reducing the prevalence of such a disease. Moreover, contrary to the results in the aforementioned Table 6 —see columns (1) and (3)—, all the coefficients in Table B.10 are significant at least at the 10% level of significance.

Table B.7. Impact of mini-grids on household probability of using electricity as the main source of lighting (dropping households close to the grid transmission lines)

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	0.106**	0.0905**			0.251***	0.221***		
	(0.0443)	(0.0430)			(0.0729)	(0.0705)		
Mini-grid × post	0.137**	0.161***	0.0799**	0.110***	0.187**	0.233***	0.115*	0.174***
	(0.0516)	(0.0533)	(0.0361)	(0.0332)	(0.0774)	(0.0861)	(0.0629)	(0.0626)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.270	0.283	0.329	0.347	0.279	0.291	0.328	0.346
N. Observations	643	643	597	595	643	643	597	595

Note: The outcome is a dummy equal to 1 if the household uses electricity as the main source of lighting (and 0 otherwise). Linear probability models estimated by OLS using data from the NPS with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission lines. In Columns (1)-(4) we use the binary treatment approach, while in Columns (5)-(8) we use the continuous treatment approach. Column (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Column (2) and (6): same as the previous columns but also including region-specific linear time trends. Column (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Column (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.8. Impact of mini-grids on the DHS wealth index (dropping households close to the grid transmission lines)

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	6.438***	7.159***			12.38***	12.95***		
	(1.614)	(2.001)			(2.690)	(3.194)		
Mini-grid × post	0.184	-0.0431	5.654***	5.901***	1.734	1.816	9.588***	9.888***
	(1.613)	(1.873)	(1.568)	(2.053)	(1.954)	(2.129)	(1.823)	(2.234)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.388	0.421	0.481	0.501	0.406	0.434	0.482	0.503
N. Observations	2,754	2,754	2,754	2,754	2,754	2,754	2,754	2,754

Note: The outcome is the (log-) DHS wealth index. Linear regression models estimated by OLS using data from the DHS with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission line. In Columns (1)-(4) we use the binary treatment approach, while in Columns (5)-(8) we use the continuous treatment approach. Column (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Column (2) and (6): same as the previous columns but also including region-specific linear time trends. Column (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Column (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.9. Impact of mini-grids on household probability of owning selected appliances (refrigerator and television; dropping households close to the grid transmission lines)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	0.0160	-0.0138		
	(0.0117)	(0.0125)		
Mini-grid × post	0.0404**	0.0779***	0.121***	0.150***
	(0.0173)	(0.0208)	(0.0445)	(0.0452)
R^2	0.100	0.133	0.184	0.215
N. Observations	2,958	2,958	2,958	2,958
	Panel A2. NPS dataset			
Mini-grid	0.00524	0.00496		
	(0.0227)	(0.0248)		
Mini-grid × post	0.0616***	0.0609**	0.0433***	0.0333***
	(0.0216)	(0.0251)	(0.0136)	(0.0108)
R^2	0.105	0.122	0.140	0.208
N. Observations	643	643	597	595

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.0824***	0.102***		
	(0.0257)	(0.0329)		
Mini-grid × post	0.0507	0.0461	0.115**	0.141***
	(0.0314)	(0.0389)	(0.0443)	(0.0513)
R^2	0.192	0.208	0.253	0.270
N. Observations	2,962	2,962	2,962	2,962
	Panel B2. NPS dataset			
Mini-grid	0.0844*	0.0709		
	(0.0443)	(0.0449)		
Mini-grid × post	0.118*	0.138**	0.0357	0.0444
	(0.0592)	(0.0620)	(0.0324)	(0.0311)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.270	0.278	0.333	0.363
N. Observations	643	643	597	595

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS (Panels A1 and B1) and from the NPS (Panels A2 and B2) with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission line. In all these columns we use the binary treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.10. Impact of mini-grids on the incidence of diarrhea among children (less than 5 years old; dropping households close to the grid transmission lines)

	(1)	(2)	(3)	(4)
Mini-grid	0.0428*	0.0555*		
	(0.0249)	(0.0306)		
Mini-grid × post	-0.0858**	-0.101*	-0.182**	-0.340***
	(0.0346)	(0.0497)	(0.0770)	(0.00427)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.0819	0.0836	0.114	0.123
N. Observations	714	714	714	714

Note: The outcome is a dummy equal to 1 if any children less than 5 years of age in the household had diarrhea within the last two weeks (and 0 otherwise). Linear probability models estimated by OLS using data from the three rounds of the DHS (1999, 2010, and 2015-2016) with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission line. In all these columns we use the binary treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

B.3 Excluding diesel mini-grids

As explained in the main text, another concern might arise due to the potential endogenous location of some mini-grids. Recall that our empirical strategy rests on the assumption that, within relatively narrowly defined geographical areas (i.e., within a radius of 10 km), the exact location of a mini-grid is uncorrelated with factors affecting electricity access and other development outcomes of the households on their premises (conditional on the household characteristics and the battery of fixed effects that we consider) but is rather explained by other geographical factors (e.g., the roughness of the terrain, the slope of the nearest water body, and other features of the territory). Additional explanations and substantial evidence that support this assumption are provided in Appendix C, which contains several maps showing that the location of different types of mini-grids mostly responds to (exogenously given) geographical characteristics.[4]

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[4] In line with this idea, World Bank (2017) discusses the exact places in Tanzania where the characteristics of the terrain are appropriate for the installation of hydro-powered mini-grids (i.e., places in which the water body has a sufficiently steep slope

The assumption above presumably holds for all the mini-grids in our sample that depend on the availability of natural resources (such as hydro, solar, or hybrid). However, one could potentially argue that this assumption is not as likely to hold for the mini-grids that do not depend on the natural resources at hand and, by contrast, that are powered by a fuel that can be purchased in the market and that is relatively easily transportable (such as diesel-powered ones). Still, this type of mini-grids cannot be installed "anywhere" within these relatively narrowly defined geographical zones, as they must be located where there is easy and adequate road access for the tank trucks to deliver the fuel (there are no pipelines in Tanzania). Note moreover that, as explained by Dumas and Játiva (2020), the road density in Tanzania is very low in comparison with that of the adjacent countries (it was about 97 meters per square km back in 2008, whereas in Kenya and Uganda was about 300), and the few existing roads are in very poor conditions (only 36.63% of the road network was paved or sealed back in 2008).

Table B.11. Impact of non-diesel fueled mini-grids on household probability of having an electricity connection (DHS only)

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	-0.0285	-0.0298			-0.108	-0.160		
	(0.0467)	(0.0343)			(0.0951)	(0.111)		
Mini-grid × post	0.183^{***}	0.183^{**}	0.188^{**}	0.340^{**}	0.364^{***}	0.419^{***}	0.310^{*}	0.343^{*}
	(0.0622)	(0.0728)	(0.0909)	(0.165)	(0.0947)	(0.116)	(0.173)	(0.202)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.197	0.221	0.468	0.510	0.208	0.234	0.466	0.505
N. Observations	2,176	2,176	2,176	2,176	2,176	2,176	2,176	2,176

Note: The outcome is a dummy equal to 1 if the household has an electricity connection (and 0 otherwise). Linear probability models estimated by OLS using data from the DHS (dropping all the households that are less than 10 km far from a diesel mini-grid) with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Nevertheless, in order to address the concern arising due to the potential endogenous location of non-renewable resource-based mini-grids, we estimate our main regression model excluding the diesel-fueled ones in this appendix. The reader should be aware, though, that we can do so using just the DHS dataset but not the NPS dataset. In the latter case, due to the lack of observations, we do not have

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or the current is adequate and ample).

sufficient statistical power to estimate our regression model after dropping the diesel-fueled mini-grids from our sample. Our main empirical results are included in Tables B.11-B.13.

First, Table B.11 includes the estimated impact of mini-grid deployment on the likelihood of having an electricity connection at home for nearby households. On the one hand, the coefficients across columns (1)-(4) (i.e., those obtained using the binary treatment approach) are extremely similar to those in Table 2 (Panel A) in the main text. On the other hand, those included in columns (5)-(8) (i.e., using the continuous treatment approach) are slightly higher in magnitude (about 0.1 points higher) relative to the analog ones included in Table 2. In both cases, these results further suggest that the installation of mini-grids positively impacted the uptake of electricity connections among nearby households.

Table B.12. Impact of non-diesel fueled mini-grids on the DHS wealth index

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	1.755	0.834			2.070	-1.310		
	(1.395)	(1.818)			(3.671)	(5.637)		
Mini-grid × post	1.425	3.112	6.331^{**}	24.96^{***}	2.151	6.427	5.097	19.05^{*}
	(2.487)	(3.440)	(3.095)	(3.986)	(3.968)	(5.408)	(4.749)	(10.88)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.198	0.216	0.368	0.397	0.192	0.211	0.362	0.381
N. Observations	1,988	1,988	1,988	1,988	1,988	1,988	1,988	1,988

Note: The outcome is the (log-) DHS wealth index. Linear regression models estimated by OLS using data from the DHS (dropping all the households that are less than 10 km far from a diesel mini-grid) with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in Columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Then, Table B.12 shows the point estimates associated with the DHS wealth index. These estimates are again positive and similar in magnitude to those displayed in Table 4 in the main text for the model specifications included in columns (1)-(3) and (5)-(7) (in some cases they are not significant at the 10% level though). However, for the two specifications that include cluster fixed effects and region-specific time trends —see columns (4) and (8)—, the magnitude of the coefficient of interest is above that obtained in Table 4, suggesting that these coefficients are likely overestimated in these two cases when we drop the diesel mini-grids. Still, our main conclusion qualitatively holds, as we see that the installation of mini-grids is associated with a higher DHS wealth index.

Table B.13. Impact of non-diesel fueled mini-grids on household probability of owning selected appliances (refrigerator and television; DHS only)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
Mini-grid	-0.00152	0.00214		
	(0.00885)	(0.00644)		
Mini-grid × post	0.0132	0.0121	0.0240	0.0616
	(0.0127)	(0.0127)	(0.0207)	(0.0369)
R^2	0.0263	0.0333	0.0560	0.0660
N. Observations	2,174	2,174	2,174	2,174
	Panel B. Outcome: has a television?			
Mini-grid	0.0115	0.0383		
	(0.0334)	(0.0290)		
Mini-grid × post	0.0585	0.0291	0.0856	0.206
	(0.0547)	(0.0593)	(0.0752)	(0.144)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.147	0.162	0.269	0.291
N. Observations	2,176	2,176	2,176	2,176

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS (dropping all the households that are less than 10 km far from a diesel mini-grid) with standard errors clustered at region-year level. In all these columns we use the binary treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Something similar is observed in Table B.13, which contains the results for the appliance regressions. Panels A and B, in which we include the impact that the deployment of a mini-grid had on the probability of owning a refrigerator and a television (respectively), show that all the point estimates are again positive but slightly lower in magnitude than those in Table 5 (Panels A1 and B1) in the main text. There are two main reasons that explain this pattern in our empirical results. First, the fact that non-diesel-powered mini-grids are generally less reliable than those powered by diesel (which are excluded from the sample here) due to the intermittency problem (Borenstein, 2012; Gowrisankaran et al., 2016; Liebensteiner and Wrienz, 2020). Second, because the capacity (in MW) of the former is also on average lower than the capacity of diesel-powered mini-grids and, thus, they are presumably less appropriate to power higher voltage appliances, such as refrigerators and televisions. All in all, even though these estimates are not significant at the 10%, their sign still provides suggestive evidence that mini-grids positively impacted the uptake of these appliances.

B.4 Dropping potential spillovers

In the main text, we present two different approaches to estimate our regression model, namely, the binary treatment approach and the continuous treatment approach. The former, for which we define treated and control households in our sample using the 5 km threshold following the information in Figures 4 and 5, allows us to implement a standard generalized *DiD* regression based on a binary treatment. However, this threshold creates a sharp break between the treated cohort (0-5 km) and the control cohort (5-10 km) for all the mini-grids in our sample, regardless of their generation capacity (in MW). Thus, one may have the potential concerns that this threshold is not the appropriate one for all the mini-grids in our sample, as some of them (say, those with higher capacity) may have an impact on households slightly beyond the 5 km threshold and, conversely, some others (say, those with lower capacity) may not have an impact on households located just below the 5 km threshold. In these cases, the treated and the control group would contaminate (bias) our estimates.

To address this potential concern, we follow Benshaul-Tolonen (2019) and estimate again our main regression model (using the binary treatment approach) taking potential spillovers into account by dropping from our sample all the households that are within 4-6 km far from a mini-grid. The empirical results of this additional robustness check are included in Tables B.14-B.18.

To begin with, Table B.14 includes the estimated effect of mini-grid deployment on households' likelihood of having an electricity connection. The estimates across the four model specifications obtained using both the DHS (Panel A) and the NPS (Panel B) are positive, significant at least at the 5% level —except for the model specification in column (3) in Panel B—, and comparable in magnitude to those obtained in the first four columns in Table 2 in the main text. Something similar is observed in Table B.15 (the analog of Table 3), which displays the estimated impact of mini-grids on the probability of using electricity (rather than fossil fuel-based devices) as the main source of lighting (recall that this

Table B.14. Impact of mini-grids on household probability of having an electricity connection (dropping spillovers in the binary treatment approach)

	Panel A. DHS dataset			
	(1)	(2)	(3)	(4)
Mini-grid	0.0460 (0.0456)	0.0436 (0.0586)		
Mini-grid × post	0.196*** (0.0568)	0.191*** (0.0671)	0.161** (0.0632)	0.224** (0.0894)
R^2	0.221	0.232	0.333	0.350
N. Observations	3,221	3,221	3,221	3,221
	Panel B. NPS dataset			
Mini-grid	0.167*** (0.0458)	0.128*** (0.0427)		
Mini-grid × post	0.145** (0.0641)	0.199*** (0.0638)	0.0768 (0.0495)	0.147*** (0.0398)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.278	0.293	0.352	0.378
N. Observations	880	880	813	812

Note: The outcome is a dummy equal to 1 if the household has an electricity connection (and 0 otherwise). Linear probability models estimated by OLS using data from the DHS (Panel A) and from the NPS (Panel B) with standard errors clustered at region-year level, using the binary treatment approach, and excluding households within 4-6 km far from a mini-grid. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous columns but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

information is available in the NPS dataset only). The same pattern is also observed in Tables B.16, B.17, and B.18, in which the effect of mini-grid deployment on the DHS wealth index, on the ownership of appliances, and on the incidence of diarrhea among children are qualitatively and quantitatively similar to those included in Tables 4, 5, and 6 in the main text, respectively. A few exceptions are worth noting, though.

First, the coefficient on interest in columns (1) and (2) in Table B.16, where the dependent variable is the DHS wealth index, are positive but not significant. Notice, though, that they were not significant either in Table 4 in the main text (additional explanations on this result are provided in Section 4.2). This is also the case in Table B.17, Panel B2, columns (3)-(4), regarding the impact of mini-grids on the

Table B.15. Impact of mini-grids on household probability of using electricity as the main source of lighting (dropping spillovers in the binary treatment approach)

	(1)	(2)	(3)	(4)
Mini-grid	0.164***	0.126***		
	(0.0458)	(0.0429)		
Mini-grid × post	0.143**	0.197***	0.0793	0.150***
	(0.0638)	(0.0634)	(0.0494)	(0.0402)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.280	0.294	0.352	0.377
N. Observations	880	880	813	812

Note: The outcome is a dummy equal to 1 if the household uses electricity as the main source of lighting (and 0 otherwise). Linear probability models estimated by OLS using data from the NPS with standard errors clustered at region-year level, using the binary treatment approach, and excluding households within 4-6 km far from a mini-grid. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous columns but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.16. Impact of mini-grids on the DHS wealth index (dropping spillovers in the binary treatment approach)

	(1)	(2)	(3)	(4)
Mini-grid	4.627**	5.236*		
	(2.088)	(2.675)		
Mini-grid × post	3.042	2.124	6.833***	6.819***
	(2.080)	(2.576)	(1.484)	(1.847)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.359	0.380	0.478	0.488
N. Observations	3,015	3,015	3,015	3,015

Note: The outcome is the (log-) DHS wealth index. Linear regression models estimated by OLS using data from the DHS with standard errors clustered at region-year level, using the binary treatment approach, and excluding households within 4-6 km far from a mini-grid. Column (1) and: full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous columns but also including region-specific linear time trends. Column (3): full set of control variables, DHS cluster fixed effects, and year fixed effects. Column (4): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B.17. Impact of mini-grids on household probability of owning selected appliances (refrigerator and television; dropping spillovers in the binary treatment approach)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	-0.0101	-0.0277**		
	(0.0112)	(0.0124)		
Mini-grid × post	0.0703***	0.0818***	0.135***	0.134***
	(0.0233)	(0.0204)	(0.0373)	(0.0384)
R^2	0.0914	0.118	0.197	0.216
N. Observations	3,218	3,218	3,218	3,218
	Panel A2. NPS dataset			
Mini-grid	0.0313**	0.0333**		
	(0.0149)	(0.0157)		
Mini-grid × post	0.0698***	0.0696***	0.0629***	0.0440***
	(0.0220)	(0.0248)	(0.0170)	(0.0135)
R^2	0.111	0.119	0.129	0.174
N. Observations	880	880	813	812

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.0326	0.0441		
	(0.0285)	(0.0375)		
Mini-grid × post	0.115***	0.0961**	0.113**	0.134**
	(0.0332)	(0.0384)	(0.0492)	(0.0590)
R^2	0.183	0.190	0.262	0.272
N. Observations	3,222	3,222	3,222	3,222
	Panel B2. NPS dataset			
Mini-grid	0.170***	0.129***		
	(0.0344)	(0.0219)		
Mini-grid × post	0.115*	0.170***	0.0265	0.0666
	(0.0607)	(0.0533)	(0.0478)	(0.0422)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.280	0.295	0.325	0.373
N. Observations	880	880	813	812

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS (Panels A1 and B1) and from the NPS (Panels A2 and B2) with standard errors clustered at region-year level, using the binary treatment approach, and excluding households within 4-6 km far from a mini-grid. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

uptake of televisions (interested readers may refer to Section 4.2 for further details). Second, the sign of the coefficient in the last column of Table B.18 (which displays the estimated impact on the incidence of diarrhea) is the opposite of that included in the same column of Table 6 in the main text. Moreover, bearing in mind that we are estimating a linear probability model, its magnitude is also implausibly large. These two ingredients suggest that the model specification in this column (including year and cluster fixed effects, and also region-specific time trends) is not an appropriate one, considering also the limited number of observations that we have in the NPS dataset (and that is further reduced once we exclude households within 4-6 km far from a mini-grid).

Table B.18. Impact of mini-grids on the incidence of diarrhea among children (less than 5 years old; dropping spillovers in the binary treatment approach)

	(1)	(2)	(3)	(4)
Mini-grid	0.00147	0.0344		
	(0.0270)	(0.0224)		
Mini-grid × post	-0.0419	-0.0723**	-0.0886	1.142***
	(0.0365)	(0.0271)	(0.101)	(0.0574)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.0962	0.0996	0.136	0.140
N. Observations	703	703	703	703

Note: The outcome is a dummy equal to 1 if any children less than 5 years of age in the household had diarrhea within the last two weeks (and 0 otherwise). Linear probability models estimated by OLS using data from the three rounds of the DHS (1999, 2010, and 2015-2016) with standard errors clustered at region-year level, using the binary treatment approach, and excluding households within 4-6 km far from a mini-grid. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Overall, we can confirm that the results obtained taking potential spillovers into account by excluding from our sample all the households within 4-6 km far from a mini-grid are extremely similar to those obtained using the full sample of households. Thus, we find evidence once again that mini-grids positively impacted the uptake of electricity connections and the use of electricity at home, and also suggestive evidence of a lower incidence of infectious diseases that are associated with poor food safety and preservation.

B.5 Estimates of the DHS wealth index taking into account the investment phase

In order to confirm the validity of our empirical strategy, Figure 7 in the main document tests whether there are pre-trends in the evolution of the DHS wealth index prior to the installation of a mini-grid among treated households. To do so we extend our main regression model with leads of the binary treatment variable (see Section 4.2 for further details). Although the coefficients included in this Figure rule out the possibility that the estimated increase in the wealth index shown in Table 4 is stemming from a previously existing trend, we observe nevertheless that the coefficient of the lead variable at $t-1$ is positive and significant at the 1% level. This result, which suggests a slight anticipation effect in the wealth index the year before the installation of a mini-grid, is also consistent with the findings by Benshaul-Tolonen (2019): she documents that divergence from the pre-trend during the investment period usually occurs in capital-intensive investments (as they generate employment at the local level and, thus, wealth).

Table B.19. Impact of mini-grids on the DHS wealth index (taking into account investment phase)

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	3.378**	3.220*			8.034***	7.274**		
	(1.621)	(1.889)			(2.742)	(3.125)		
Mini-grid × post	2.916	3.443*	6.358***	6.914***	3.673*	4.780**	8.285***	9.006***
	(1.763)	(1.991)	(1.373)	(1.818)	(2.156)	(2.366)	(1.853)	(2.190)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.316	0.339	0.456	0.468	0.325	0.345	0.451	0.464
N. Observations	3,691	3,691	3,691	3,691	3,691	3,691	3,691	3,691

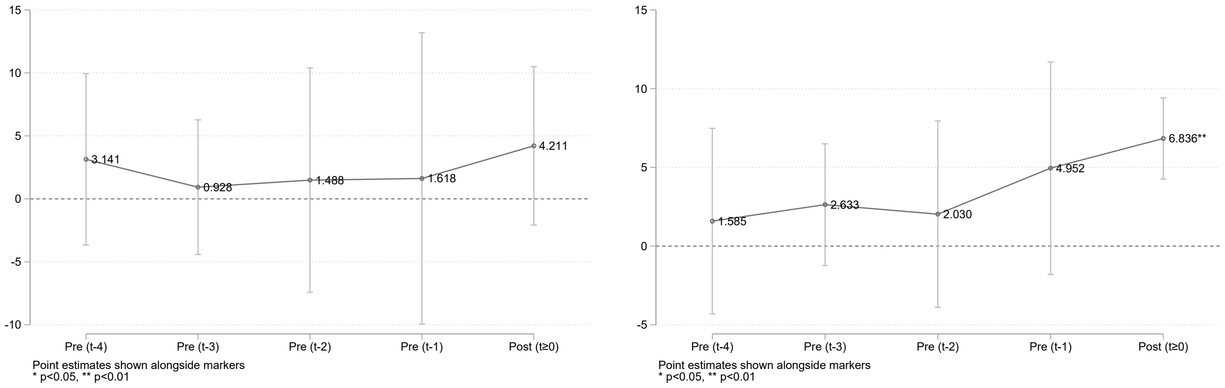
Note: The outcome is the (log-) DHS wealth index. Linear regression models estimated by OLS using data from the DHS with standard errors clustered at region-year level. The variable *Post* was modified to accommodate the investment phase (the year before the deployment of the corresponding mini-grid). In Columns (1)-(4) we use the binary treatment approach, while in Columns (5)-(8) we use the continuous treatment approach. Column (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Column (2) and (6): same as the previous columns but also including region-specific linear time trends. Column (3) and (7): full set of control variables, DHS cluster fixed effects, and year fixed effects. Column (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Therefore, in this appendix, we present the same set of results that are included in Table 4 and in

Figure 7 in the main text by taking into account the anticipation effect that occurs in the investment phase at $t-1$ (i.e., the year before the installation of a mini-grid). To do so, we modify the variable *Post* in equation (3.1) and define it instead as a dummy variable that equals 1 from the year before the deployment of the corresponding mini-grid and on, and 0 otherwise. The results obtained using this alternative definition of the variable *Post* are included in Table B.19 and in Figure B.1.

To begin with, all the estimates of interest included in Table B.19 remain positive, which suggests that the mini-grids positively impacted the DHS wealth index in the post-period (including $t-1$). Moreover, some of the coefficients that were not significant in Table 4 in the main document are now significant at least at the 10% —see, for example, that in column (2)—, suggesting that the new definition of the variable *Post* is presumably better reflecting the effect that the deployment of a mini-grid (and the prior investment phase) had on the DHS wealth. Finally, Figure B.1 (which is the analog of Figure 7 in the main text) shows that the pre-trend at $t-1$ does not occur anymore, while the point estimate of the variable *Post* remains positive and significant at the 1% level for the model specification that includes cluster fixed effects —see Figure B.1(B).

Figure B.1. Estimated impact on the DHS wealth index for treated households (as defined using the binary treatment approach) relative to the time of installation of the mini-grids



(A) Model specification with Region FE

(B) Model specification with Cluster FE

Note: The figures capture the impact that the deployment of the mini-grids in our sample had on the (log-) DHS wealth index among treated households —as defined in the binary treatment approach— using the DHS dataset. The variable *Post* was modified to accommodate the investment phase (the year before the deployment of the corresponding mini-grid). We consider the impact four years before the year in which the mini-grids in our sample were deployed. Estimates in Figure B.1(A) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables, region fixed effects, and year fixed effects. Estimates in Figure B.1(B) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables, cluster fixed effects, and year fixed effects. Standard errors are clustered at the region-year level. Vertical bands represent 95% confidence intervals for the point estimates.

Appendix C: Additional empirical results

C.1 Main estimates for appliances/diarrhea incidence (continuous treatment approach)

For the sake of clarity of exposition, in Section 4.2 in the main text we present the empirical results of the impact of mini-grid deployment on appliance (refrigerator and television) ownership and on the incidence of diarrhea among less than 5-year-old children using just the binary treatment approach — see Tables 5 and 6 respectively. However, for the sake of completeness, in this appendix we include the same set of empirical results using the continuous treatment approach to confirm that our results remain consistent if we use this alternative approach instead. These results are included in Tables C.1 and C.2.

First, Panel A in Table C.1 displays the estimates using the "refrigerator" dummy as the outcome variable. The coefficient of interest across all the model specifications included in this panel are positive and significant at the 1% level when we use both the DHS dataset (Panel A1) and the NPS dataset (Panel A2). In the former case, this coefficient is between 0.08 and 0.16, which implies that the probability of having a refrigerator in the "post" period for a household located 2.5 km far from a mini-grid (the household "in the middle" among those in the treated group, as defined by the binary treatment variable) increases by about 6-12%. These figures coincide with the estimated (average) effect obtained using the binary treatment approach displayed in Table 5 (Panel A1). Extremely similar results are obtained when we use the NPS dataset instead, as can be seen in Table C.1 (Panel A2) and in Table 5 (Panel A2) in the main document.

The same pattern is also observed in Panel B in Table C.1, which contains the estimated effect of mini-grids on the uptake of televisions for households that are increasing far from them. All the point estimates are again positive, and most of them are significant at the 1% level. However, as is also the case in Table 5 (Panel B2) in the main text, the coefficient of interest for the model specifications that include cluster fixed effect obtained using the NPS dataset are close to zero and not significant —see Panel B2, columns (3)-(4). For all the other cases, this coefficient is between 0.13 and 0.28, which implies that the likelihood of having a television after the installation of a mini-grid for a household located 2.5 km far from it (the household "in the middle" among those in the treated group) increases by about 10-21%. These figures are again extraordinarily similar to those included in Table 5 (Panel B), obtained using the binary treatment approach.

Table C.1. Impact of mini-grids on the household probability of owning selected appliances (refrigerator and television; continuous treatment approach)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	0.0125	-0.0109		
	(0.0194)	(0.0212)		
Mini-grid × post	0.0791***	0.101***	0.160***	0.141***
	(0.0278)	(0.0271)	(0.0397)	(0.0341)
R^2	0.0878	0.116	0.162	0.185
N. Observations	3,987	3,987	3,987	3,987
	Panel A2. NPS dataset			
Mini-grid	0.0420*	0.0339		
	(0.0225)	(0.0244)		
Mini-grid × post	0.111***	0.122***	0.0735***	0.0633***
	(0.0253)	(0.0279)	(0.0250)	(0.0172)
R^2	0.114	0.121	0.137	0.180
N. Observations	1,053	1,053	976	973

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.103*	0.113*		
	(0.0562)	(0.0598)		
Mini-grid × post	0.136***	0.126***	0.186***	0.193***
	(0.0452)	(0.0474)	(0.0592)	(0.0679)
R^2	0.181	0.194	0.257	0.269
N. Observations	3,991	3,991	3,991	3,991
	Panel B2. NPS dataset			
Mini-grid	0.184***	0.148***		
	(0.0539)	(0.0513)		
Mini-grid × post	0.226***	0.279***	-0.000557	-0.00226
	(0.0789)	(0.0805)	(0.0527)	(0.0534)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.268	0.283	0.351	0.389
N. Observations	1,053	1,053	976	973

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS (Panels A1 and B1) and from the NPS (Panels A2 and B2) with standard errors clustered at region-year level. In all these columns we use the continuous treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Finally, the estimates of the effect of mini-grid deployment on the incidence of diarrhea among children using the continuous treatment approach are included in Table C.2. Consistent with the results obtained using the binary treatment approach displayed in Table 6 (main text), the coefficient of interest is negative across all the model specifications, except for that included in column (3) (which is close to zero). However, while this coefficient is significant at the 5% level in Table 6 for the specifications of the model that include region-specific time trends —see columns (2) and (4)—, they are significant only at a level of confidence slightly above 10% in Table C.2. The reader should be aware, though, that the relatively low number of observations in the NPS dataset may particularly contribute to generating these deviations in the level of significance of the coefficients when using different specifications and estimation approaches.

Table C.2. Impact of mini-grids on the incidence of diarrhea among children (continuous treatment approach)

	(1)	(2)	(3)	(4)
Mini-grid	-0.0254	0.0190		
	(0.0604)	(0.0826)		
Mini-grid × post	-0.0150	-0.0661	0.00790	-0.0531
	(0.0678)	(0.0893)	(0.166)	(0.507)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.0768	0.0840	0.120	0.125
N. Observations	885	885	885	885

Note: The outcome is a dummy equal to 1 if any children less than 5 years of age in the household had diarrhea within the last two weeks (and 0 otherwise). Linear probability models estimated by OLS using data from the three rounds of the DHS (1999, 2010, and 2015-2016) with standard errors clustered at region-year level. In all these columns we use the continuous treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

C.2 Robustness checks for appliances/diarrhea incidence (continuous treatment approach)

Next, we include in the present appendix the same set of robustness checks that we consider in Appendix A for the appliance regression and for the diarrhea incidence regression using the continuous

Table C.3. Impact of mini-grids on household probability of owning selected appliances using a matching procedure (refrigerator and television; continuous treatment approach)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	0.00851	-0.00834		
	(0.0173)	(0.0168)		
Mini-grid × post	0.0655***	0.0807***	0.139***	0.162***
	(0.0194)	(0.0200)	(0.0357)	(0.0377)
R^2	0.0846	0.113	0.160	0.186
N. Observations	2,348	2,348	2,348	2,348
	Panel A2. NPS dataset			
Mini-grid	0.0843	0.0616		
	(0.0578)	(0.0610)		
Mini-grid × post	0.0723	0.101	0.0947	0.0777
	(0.0546)	(0.0604)	(0.0686)	(0.0477)
R^2	0.116	0.170	0.160	0.245
N. Observations	482	482	435	432

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.0389	0.0714		
	(0.0753)	(0.0815)		
Mini-grid × post	0.167***	0.123**	0.230***	0.253***
	(0.0562)	(0.0604)	(0.0731)	(0.0845)
R^2	0.180	0.204	0.304	0.323
N. Observations	2,350	2,350	2,350	2,350
	Panel B2. NPS dataset			
Mini-grid	0.0608	0.0432		
	(0.0845)	(0.0982)		
Mini-grid × post	0.235**	0.279**	0.0166	-0.0607
	(0.113)	(0.132)	(0.0898)	(0.0998)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.232	0.254	0.353	0.406
N. Observations	482	482	435	432

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS matched sample (Panels A1 and B1) and from the NPS matched sample (Panels A2 and B2) with standard errors clustered at region-year level. In all these columns we use the continuous treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

treatment approach. Note that the tables in Appendix A include the robustness checks for these regressions using only the binary treatment approach in order to make them consistent with the format of the analog tables in the main text (i.e., to facilitate the visual comparison between the tables in the main text and those in Appendix A).

First, we provide estimates of the impact of mini-grids on appliance ownership using our matched sample of households (see Appendix A.1 for further details on the matching procedure). These results are included in Table C.3. The estimated coefficient of interest across all the model specifications in Panel A (refrigerator ownership) and Panel B (television ownership) using both the DHS dataset and the NPS dataset are extraordinarily similar in magnitude to those included in Table B.5. The only difference is that, while the estimates for refrigerator ownership using the DHS-matched sample in columns (1) and (2) are significant at the 5% level in Table B.5, they are significant only at a level of confidence slightly above 10% when using the continuous treatment approach —see Table C.3, Panel A2.

Second, we present the results obtained after dropping from our sample the households that are relatively close to (i.e., less than 10 km far from) the national grid transmission lines. On the one hand, Table C.4 displays the estimated impact on appliance ownership using the continuous treatment approach. The point estimates of the coefficient of interest across all the model specifications are positive and significant at least at the 10% level —except for those obtained using "television ownership" as the outcome variable in Panel B2, columns (3) and (4). The magnitude of them is again consistent with that of those in Table B.6 (obtained using the binary treatment approach). On the other hand, the estimates of the effect of mini-grid deployment on the incidence of diarrhea among children are included in Table C.5. Likewise, the estimated impact on this outcome across all the model specifications considered is similar to that found in Table B.10. However, this effect is not significant at the 10% level using the continuous treatment approach; this is likely due to the relatively low number of observations (which, as discussed above, contributes to generating deviations in the level of significance when using different estimation approaches).

Finally, we provide the estimates for the appliance regression using the DHS dataset after excluding from our sample the diesel-fueled mini-grids. These empirical results are included in Table C.6. Once again, the coefficient of interest across all the columns in this table are positive and comparable in magnitude to those included in the analog table in Appendix A (see Table B.13). However, as it also occurs

Table C.4. Impact of mini-grids on household probability of owning selected appliances (refrigerator and television; dropping households close to the grid transmission lines; continuous treatment approach)

	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
	Panel A1. DHS dataset			
Mini-grid	0.0399*	-0.00123		
	(0.0234)	(0.0259)		
Mini-grid × post	0.0845**	0.125***	0.207***	0.196***
	(0.0322)	(0.0330)	(0.0482)	(0.0495)
R^2	0.108	0.139	0.186	0.211
N. Observations	2,958	2,958	2,958	2,958
	Panel A2. NPS dataset			
Mini-grid	0.0325	0.0338		
	(0.0304)	(0.0326)		
Mini-grid × post	0.0978***	0.0952***	0.0733***	0.0577***
	(0.0290)	(0.0338)	(0.0210)	(0.0182)
R^2	0.110	0.126	0.139	0.208
N. Observations	643	643	597	595

	Panel B. Outcome: has a television?			
	(1)	(2)	(3)	(4)
	Panel B1. DHS dataset			
Mini-grid	0.178***	0.192***		
	(0.0551)	(0.0594)		
Mini-grid × post	0.102**	0.105*	0.228***	0.240***
	(0.0464)	(0.0550)	(0.0648)	(0.0763)
R^2	0.201	0.215	0.256	0.271
N. Observations	2,962	2,962	2,962	2,962
	Panel B2. NPS dataset			
Mini-grid	0.234***	0.206***		
	(0.0596)	(0.0561)		
Mini-grid × post	0.170*	0.215**	0.0253	0.0391
	(0.0898)	(0.0975)	(0.0540)	(0.0577)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.291	0.300	0.333	0.363
N. Observations	643	643	597	595

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS (Panels A1 and B1) and from the NPS (Panels A2 and B2) with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission line. In all these columns we use the continuous treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

in the latter, the estimated effect is frequently not significant. This is because, as explained in Appendix A.3, the non-diesel powered mini-grids in our sample are presumably less appropriate to power higher voltage appliances (see that appendix for further details). Overall, the empirical results in Tables C.3-C.6 further confirm that our estimates obtained using the continuous treatment approach are consistent with those obtained using the binary treatment approach for both the appliance regression and for the diarrhea incidence regression.

Table C.5. Impact of mini-grids on the incidence of diarrhea among children (less than 5 years old; dropping households close to the grid transmission lines; continuous treatment approach)

	(1)	(2)	(3)	(4)
Mini-grid	-0.0234	-0.0854		
	(0.0489)	(0.0956)		
Mini-grid × post	-0.0612	-0.0187	-0.0655	-0.321
	(0.0562)	(0.0966)	(0.171)	(0.657)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.0817	0.0840	0.109	0.115
N. Observations	714	714	714	714

Note: The outcome is a dummy equal to 1 if any children less than 5 years of age in the household had diarrhea within the last two weeks (and 0 otherwise). Linear probability models estimated by OLS using data from the three rounds of the DHS (1999, 2010, and 2015-2016) with standard errors clustered at region-year level, and excluding households within 10 km far from the grid transmission line. In all these columns we use the continuous treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table C.6. Impact of non-diesel fueled mini-grids on household probability of owning selected appliances (refrigerator and television; continuous treatment approach; DHS only)

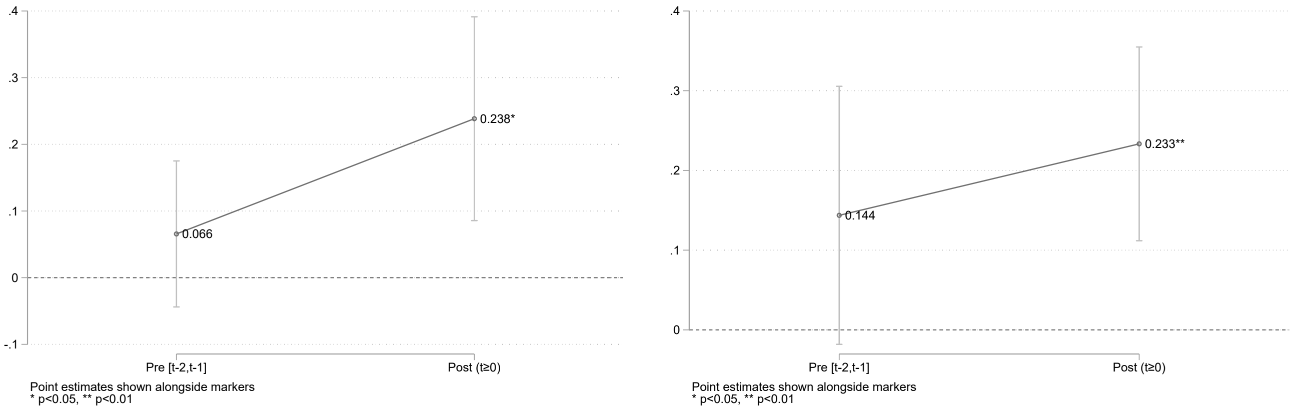
	Panel A. Outcome: has a refrigerator?			
	(1)	(2)	(3)	(4)
Mini-grid	-0.00719	-0.00477		
	(0.0165)	(0.0199)		
Mini-grid × post	0.0257	0.0279	0.0595	0.0630
	(0.0190)	(0.0212)	(0.0358)	(0.0446)
R^2	0.0265	0.0335	0.0570	0.0649
N. Observations	2,174	2,174	2,174	2,174
	Panel B. Outcome: has a television?			
Mini-grid	-0.0275	-0.0155		
	(0.0766)	(0.100)		
Mini-grid × post	0.136^{*}	0.126	0.167	0.219
	(0.0787)	(0.0994)	(0.125)	(0.147)
Full set of controls	✓	✓	✓	✓
Region FE	✓	✓		
Cluster FE			✓	✓
Year FE	✓	✓	✓	✓
Region-specific time-trend		✓		✓
R^2	0.147	0.162	0.270	0.290
N. Observations	2,176	2,176	2,176	2,176

Note: The outcome is a dummy equal to 1 if the household owns a refrigerator (and 0 otherwise) in Panel A, while it is a dummy equal to 1 if the household owns a television (and 0 otherwise) in Panel B. Linear probability models estimated by OLS using data from the DHS dataset (dropping all the households that are less than 10 km far from a diesel mini-grid) with standard errors clustered at region-year level. In all these columns we use the continuous treatment approach. Column (1): full set of control variables, region fixed effects, and year fixed effects. Column (2): same as the previous column but also including region-specific linear time trends. Column (3): full set of control variables, cluster fixed effects, and year fixed effects. Column (4): same as the previous column but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

C.3 Additional validity figures (pre-trends)

In Section 4 in the main text, right after providing our main empirical results, we test for the existence of differential trends in the uptake of electricity connections (Figure 6) and in the evolution of the DHS wealth index (Figure 7) prior to the installation of a mini-grid among treated households. To do so, we augment equation (3.1) by including several leads of the treatment variable. Our goal is to rule out that the positive impact of mini-grids on electricity connections and on the wealth index that we document is stemming from a pre-existing trend and, thus, to confirm the validity of our identifying strategy. However, for the sake of brevity, we performed this pre-trends sanity check only for these two outcomes. In this appendix we include the same analysis on pre-trends for all the other outcomes considered in the main text —except for the incidence of diarrhea, for which we cannot estimate the augmented regression model due to the relatively low number of observations (recall that this information is only available for three rounds of the DHS).

Figure C.1. Estimated impact on household probability of using electricity as the main source of lighting for treated households (as defined using the binary treatment approach) relative to the time of installation of the mini-grids



(A) Model specification with Region FE

(B) Model specification with Cluster FE

Note: The figures capture the impact that the deployment of the mini-grids in our sample had on the use of electricity as the main source of lighting among treated households —as defined in the binary treatment approach, i.e., those within 5 km from a mini-grid— using the NPS dataset. We consider the impact two years before the year in which these mini-grids were deployed. Estimates in Figure C.1(A) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables (head of household age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid), region fixed effects, and year fixed effects. Estimates in Figure C.1(B) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables, cluster fixed effects, and year fixed effects. Standard errors are clustered at the region-year level. Vertical bands represent 95% confidence intervals for the point estimates.

To begin with, Figure C.1 provides the results obtained by estimating the aforementioned augmented regression model on the dummy that captures the use of electricity as the main source of lighting (recall that this information is only available in the NPS dataset). The results using the model specification that includes region fixed effects —see Figure C.1(A)— suggest that the increase in that outcome in the post period is not stemming from an existing trend, as we do not observe a positive impact on it two years prior to the installation of the corresponding mini-grid. The same conclusion holds if we use instead the model specification that includes cluster fixed effects —see Figure C.1(B).

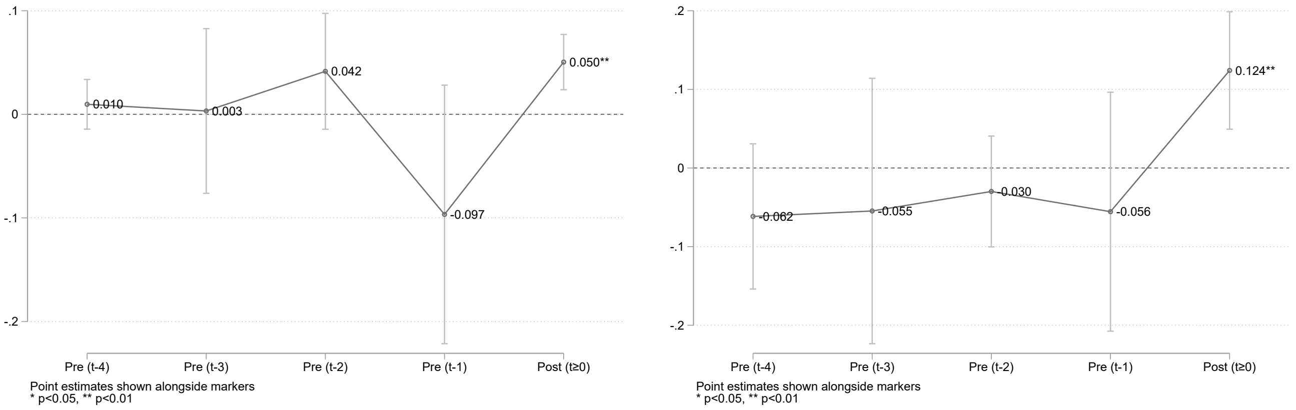
The results for the same pre-trends empirical test using the dummies that capture the ownership of selected appliances as the outcome variable are included in Figure C.2 —these results were obtained using the DHS dataset; similar conclusions holds if we use instead the NPS. First Panel A displays the evolution on the impact of mini-grid deployment on the probability of having a refrigerator among treated households. This panel shows that, either if we use the model that includes region fixed effect —Figure C.2(A)— or the one that includes cluster fixed effects —Figure C.2(B)—, the estimated coefficients for up to four years before the installation of a mini-grid are frequently close to zero (they are sometimes positive and sometimes negative) and all of them are not significant. However, the "post" coefficient is positive and significant at the 1% level. These results suggest that the increase in the uptake of refrigerator is unlikely driven by a pre-existing trend among treated households. The exact same pattern is observed in Panel B, in which the outcome considered is the probability of having a television. As can be seen both in Figure C.2(C) (model specification with region fixed effects) and in Figure C.2(D) (model specification with cluster fixed effects), most the "pre-" coefficients are not significant, while the "post" coefficients are positive and strongly significant. Again, we find evidence suggesting that the positive impact on television ownership is not stemming from a previously existing trend.

C.4 Falsification (placebo) tests

In this final appendix, we perform a sensitivity analysis by estimating two different placebo tests using outcomes that are unlikely to be affected by the installation of a mini-grid. Specifically, we use a dummy variable indicating whether a household owns a bicycle (obtained from the DHS), which is an asset that does not require electricity and is likely not affected by income shocks —even poor households may own one (Aggarwal, 2018; Nakanwagi et al., 2021). Additionally, we use information from the DHS on whether any adult (aged 15-49) in the household tested positive for HIV, which is a disease in

Figure C.2. Estimated impact on household probability of owning selected appliances (refrigerator and television) for treated households (as defined using the binary treatment approach) relative to the time of installation of the mini-grids

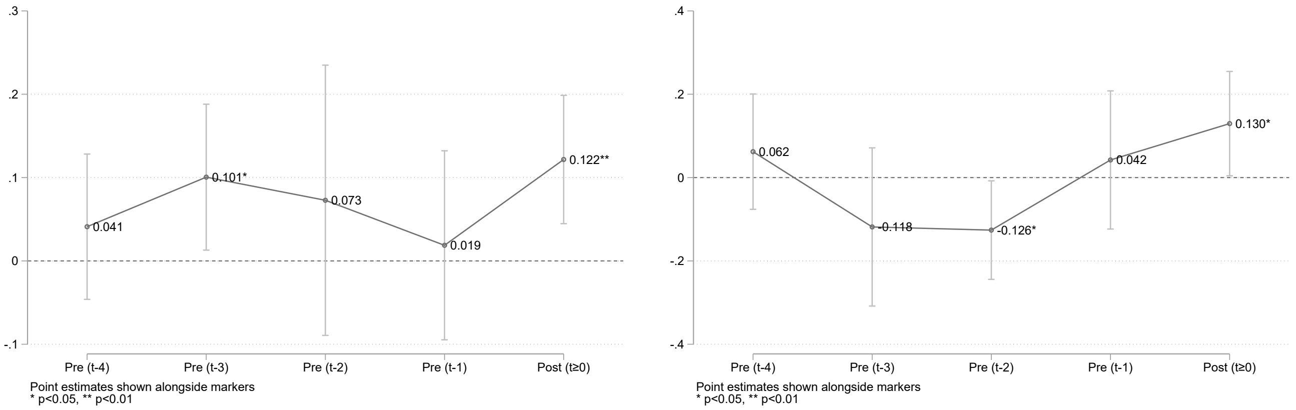
Panel A: Household has a refrigerator



(A) Model specification with Region FE

(B) Model specification with Cluster FE

Panel B: Household has a television



(C) Model specification with Region FE

(D) Model specification with Cluster FE

Note: The figures capture the impact that the deployment of the mini-grids in our sample had on household probability of owning a refrigerator (Panel A) and a television (Panel B) among treated households —as defined in the binary treatment approach, i.e., those within 5 km from a mini-grid— using the DHS dataset. We consider the impact four years before the year in which the mini-grids in our sample were deployed. Estimates in Figures C.2(A) and C.2(C) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables (head of household age, head of household education, head of household sex, and dummy variables indicating the technology of the closest mini-grid), region fixed effects, and year fixed effects. Estimates in Figures C.2(B) and C.2(D) are obtained using the specification of our regression model (binary treatment approach) including the full set of control variables, cluster fixed effects, and year fixed effects. Standard errors are clustered at the region-year level. Vertical bands represent 95% confidence intervals for the point estimates principle unrelated to electricity access.[5] The rationale behind these tests is that we do not expect to observe differences between treated and control groups, as the outcomes considered are unlikely to be affected by the installation of a mini-grid nearby. Therefore, any estimates significantly different from zero would support the validity of our research design.

We present the results of the placebo tests in Tables C.7 and C.8. In both cases, the coefficient of the "Mini-grid × post" interaction term is not statistically significant and is close to zero (with no consistent positive or negative effect observed) across all model specifications using both the binary treatment approach —columns (1)-(4)—- and continuous treatment approach —columns (5)-(8). These results provide further support for the validity of our research design, as we find no evidence of treatment effects on outcomes that are unlikely to be influenced by the installation of a mini-grid.

Table C.7. Impact of mini-grids on household probability of owning a bicycle

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	-0.00869 (0.0488)	-0.00644 (0.0580)			-0.117 (0.0789)	-0.138 (0.0895)		
Mini-grid × post	-0.0241 (0.0459)	-0.0186 (0.0493)	-0.00733 (0.0317)	-0.00714 (0.0319)	0.00725 (0.0633)	0.0347 (0.0654)	-0.0677 (0.0554)	-0.0755 (0.0588)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.154	0.164	0.230	0.235	0.156	0.166	0.230	0.236
N. Observations	3,990	3,990	3,990	3,990	3,990	3,990	3,990	3,990

Note: The outcome is a dummy equal to 1 if the household owns at least one bicycle (and 0 otherwise). Linear regression models estimated by OLS using data from the DHS with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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[5] This data is based on blood sample test provided by the survey respondents, and is available only for three rounds of the DHS: 2003-2004; 2007-2008; and 2011-2012.

Table C.8. Impact of mini-grids on HIV incidence at household level

	Binary treatment approach				*Continuous treatment approach*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mini-grid	0.0385	0.0481			0.0886	0.116^{*}		
	(0.0406)	(0.0427)			(0.0696)	(0.0674)		
Mini-grid × post	0.0244	0.0301	-0.0273	-0.00586	0.0216	0.0187	-0.0410	-0.0209
	(0.0422)	(0.0429)	(0.0386)	(0.0621)	(0.0509)	(0.0506)	(0.0679)	(0.0699)
Full set of controls	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓			✓	✓		
Cluster FE			✓	✓			✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Region-specific time-trend		✓		✓		✓		✓
R^2	0.0561	0.0634	0.116	0.121	0.0560	0.0634	0.116	0.121
N. Observations	1,712	1,712	1,712	1,712	1,712	1,712	1,712	1,712

Note: The outcome is a dummy equal to 1 if any member of the household (15-49 years) is HIV positive (and 0 otherwise). Linear regression models estimated by OLS using data from the DHS with standard errors clustered at region-year level. In columns (1)-(4) we use the binary treatment approach, while in columns (5)-(8) we use the continuous treatment approach. Columns (1) and (5): full set of control variables, region fixed effects, and year fixed effects. Columns (2) and (6): same as the previous columns but also including region-specific linear time trends. Columns (3) and (7): full set of control variables, cluster fixed effects, and year fixed effects. Columns (4) and (8): same as the previous columns but also including region-specific linear time trends. The significance levels are as follows: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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