Nov, 2025
GRINS DISCUSSION PAPER SERIES DP N° 66/2025 ISSN 3035-5576

GRINS

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KEYWORDS

Energy poverty | children | education | women | employment | Ethiopia

JEL CODE

I21, I39, J13, J16, J22, J24

ACKNOWLEDGEMENTS

This study was funded by the European Union - NextGenerationEU, in the framework of the GRINS - Growing Resilient, INclusive and Sustainable project (GRINS PE00000018). The views and opinions expressed are solely those of the authors and do not necessarily reflect those of the European Union, nor can the European Union be held responsible for them.

We thank Enrico Bernardini, Ivan Faiella, Nisan Gorgulu, Patrizio Pagano, Massimo Tavoni and comments provided by participants at the 8th AIEE Energy Symposium on Energy Security, held in November 2024, Padova, Italy. The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views or positions of Banca d'Italia.

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Author(s): Luciano Lavecchia, Abreham Adera, Raffaele Miniaci. Title: The effects of Grid and off-Grid Electrification on Child Education: Evidence from Rural Ethiopia. Publication Date: 2025.

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The results show that rural electrification significantly enhances children's education by 4-11 months of additional schooling. Grid connectivity has, in the short run, a stronger effect than off-grid solutions.
Our findings show that electrification reduces the burden of housework on children, and, in particular, firewood collection, allowing them to focus more on their education.
We find some evidence of a reduction in farming activities among men and no evidence of shifts toward either farm or non-farm activities for women, indicating that the primary benefits of electrification are channeled through reduced child labor rather than through structural changes in adult employment.
These results highlight the broader welfare implications of rural electrification for children and

underscore the urgent need for targeted strategies to address rural energy poverty—an essential step toward inclusive and sustainable development.

The effects of Grid and off-Grid Electrification on Child Education: Evidence from Rural Ethiopia *

Abreham Adera† Raffaele Miniaci ‡ Luciano Lavecchia §

This version: November 17, 2025

Abstract

This paper examines the impact of grid and off-grid electrification on children's educational attainment in rural Ethiopia. The study employs a difference-in-differences strategy, complemented by an event study framework that leverages the natural experiment arising from the staggered rollout of electricity adoption. The results show that rural electrification significantly enhances children's education by 4-11 months of additional schooling. Grid connectivity has, in the short run, a stronger effect than off-grid solutions. Our findings show that electrification reduces the burden of housework on children, and, in particular, firewood collection, allowing them to focus more on their education. We find some evidence of a reduction in farming activities among men and no evidence of shifts toward either farm or non-farm activities for women, indicating that the primary benefits of electrification are channeled through reduced child labor rather than through structural changes in adult employment. These results highlight the broader welfare implications of rural electrification for children and underscore the urgent need for targeted strategies to address rural energy poverty—an essential step toward inclusive and sustainable development.

Keywords: Energy poverty, children, education, women, employment, Ethiopia

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JEL Codes: I21,I39, J13, J16, J22, J24

1 Introduction

Those pylons and poles that carried electricity into the countryside were greeted with applause, as one greets a great gift. To understand this, we have to go back to the stories of our grandparents who were farmers, to the day when they flipped the first switch and everything in the house suddenly lit up. Many, that evening, said a prayer in gratitude for that "miracle" that improved their lives, that allowed their children to study better and everyone to bathe in hot water.

Pope Francis
Vatican City, 31 August 2024

Goal 7 of the United Nations Sustainable Development Goals (SDGs) aims to "ensure access to affordable, reliable, sustainable, and modern energy for all." In pursuit of this objective, the World Bank Group has committed to achieving universal electricity access by 2030 under the "Sustainable Energy for All" (SE4All) initiative (IEG, 2015). Progress has been made, with the share of the world's population without access to electricity falling from 13 percent in 2015 to 9 percent in 2022 (IEG, 2024). Nevertheless, the 2024 edition of Tracking SDG 7: The Energy Progress Report warns that current efforts are insufficient to meet SDG 7 by 2030. This is particularly critical in Sub-Saharan Africa, where more than four out of five people worldwide (or 600 million individuals) without electricity access live (IEG, 2024). Based on the argument that electrification improves education, welfare, and economic opportunities, concerned entities are calling for an urgent mission to increase energy access.

As His Holiness Pope Francis remarks, "*Even today, in certain villages in Africa, Asia, and Latin America, one sees clusters of young people at night under the few street lamps studying, because they do not have electricity in their homes,*"[1]. One observation here is

[1] Address of His Holiness Pope Francis to Managers and Employees of the Terna Group, Clementine Hall, Vatican City, 31 August 2024.

that electrification should improve child education. Yet, little research has been done on the impact of rural electrification on child education in Africa , nor is the evidence on its impacts on other outcomes conclusiveBernard (2012). Electrification may improve child enrollment but does it help keep children in school (improve attainment)? And if, how so? This paper aims to address this question by focusing on Ethiopia where, despite 94% electrification rate in urban areas, 47% of the population, almost 60 million Ethiopians, predominantly in rural areas, still live without access to electricity.

In the global South, children may enroll in school, but many struggle to complete their education, either by failing to progress through the grades or by leaving school before completion. Can electrification help addressing the challenges of low educational attainment? We attempt to provide an answer to this question by focusing on Ethiopia. At least two reasons make Ethiopia a compelling case for this inquiry. While it has made notable achievements in increasing enrollment rates, it still grapples with high school dropout rates and low completion rates (Woldehanna et al., 2021), especially in rural areas (Sileshi et al., 2024). These challenges are critical barriers, potentially hindering the nation from reaching SDG goal 4: 'ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all.' Concurrently, Ethiopia made progress in electrification. In 2000, it could generate only 1.7 TWh of electricity. However, by 2016, this rose sevenfold to 12.5 TWh and further reached 18.2 TWh in 2023 [2]. The Grand Ethiopian Renaissance Dam (GERD) project, which was inaugurated on September 9th, 2025, should add 15 TWh. Also, the electrification rate stood at 30.8% in 2013 but almost doubled to 54.3% in 2023[3]. At this juncture, if electrification can effectively support children education —e.g., by enabling children to study at night or allowing mothers to shift time from household chores to support their children's education[4]—these impacts should be observable in Ethiopia. However, there is still limited understanding of how Ethiopia's electrification progress has influenced child welfare. Our paper fills this gap by studying the relationship between rural electrification and child education, while also exploring the mechanisms that drive these effects.

The study utilizes panel data from the Ethiopian Socio-Economic Survey (ESS), conducted between 2011 and 2016. We consider two definitions of electrification: households are classified as electrified if either have a solar power system or are connected to the electrical grid. To identify the impact of the different types of electrification, we leverage the

[2] Ember, Electricity data explorer, last access: 19 August, 2025.

[3] IEA, SDG7 Data and Projections. Access to electricity, last access 19 September, 2025

[4] Lighting Up Eastern Africa: How Greater Access to Energy is Creating Jobs and Improving Public Services in Rural Ethiopia, last access 19 September 2025.

variation in household electrification status during the period covered by the ESS survey. Specifically, we track households that were not electrified in 2011/12 and check whether they were electrified by 2016. Using a difference-in-differences methodology, we compare the outcomes of households that remained without electricity with those that newly adopted electricity by 2016.

The results indicate that rural electrification improves children's education measured in additional years of schooling. We find that connecting to the grid has stronger effects in the short run but it's later matched by off-grid solutions such as photovoltaics (PV). Children in households that gained access to either solar or grid electricity by 2016 experienced after two years, on average, 0.74 more years of education compared to those who did not gain access to electricity during the same period.

The results are robust across a broad range of alternative specifications, including a conservative analysis that focuses only on switchers—i.e., households in areas where at least one household transitioned from being not electrified in 2011 to being electrified by 2016—and an event study design. The event study estimates show no significant pre-trends for children in the pre-treatment period. Interestingly, the event study estimates indicate positive post-treatment effects for treated children, along with a rise in the estimated effect over time.

Lastly, we explore pathways through which electrification affects children's educational attainment. We find evidence that electrification significantly decreases children's involvement in firewood collection and, in the case of grid electrification, non-farm labor. This suggests that electrification reduces the burden of household labor on children, allowing them to focus more on their education. For adults (women and men), we find evidence that electrification reduces fire wood collection and little evidence that electrification leads to increased paid employment or shifts labor toward farm or non-farm employment. These indicates that the primary benefits of electrification are channeled through reduced child labor rather than structural changes in adult employment. Also, with grid electrification, children may have more time to study in the evening. This highlights the relevance of interventions that specifically target rural energy poverty to foster positive outcomes for children in these areas.

To our knowledge, this is the first paper to examine the impact of Ethiopia's multi-decade efforts to electrify its rural areas on child education and the underlying mechanisms. The rural electrification in Ethiopia has been previously studied by Fried and Lagakos (2021), who have demonstrated that it has led to structural change and altered migration patterns of villages, and Terefe Gashaye et al. (2025) who have documented its positive impact on household income. Our paper complements this literature by shifting the focus from households and villages to children, highlighting how access to electricity translates into educational gains and human capital development. Outside Ethiopia, our findings resonate with research that documents the benefits of electrifying rural households for child education, as seen in Ghana (Akpandjar and Kitchens, 2017), Madagascar (Daka and Ballet, 2011), and India (Khandker et al., 2014). It also adds to research that documents the impact of rural electrification on female employment (Rathi and Vermaak, 2018; Grogan and Sadanand, 2013; Dinkelman, 2011) and contributes to the debate on the impact of maternal employment on child education (Brauner-Otto et al., 2022).

Our estimates of the impact of electrification on children's education can be compared with the educational impacts of other social programs in Ethiopia. A directly comparable study is the recent work by Gebremariam et al. (2024), who find that the Productive Safety Net Program (PSNP) increased children's educational attainment by approximately 0.35 years (about 4.2 months). Remarkably, our estimated educational gain from rural electrification is comparable to, and potentially larger than, the impact of the PSNP.

In addition to the PSNP, the School Feeding Program (SFP) represents a major policy intervention aimed at improving child education. However, empirical evidence on the impacts of the SFP in Ethiopia remains limited, focusing primarily on school absenteeism (Mideksa et al., 2024) rather than educational attainment, and often confined to specific locations such as Addis Ababa or the Sidama region (Destaw et al., 2022; Desalegn et al., 2021; Zenebe et al., 2018).

The rest of this paper is organized as follows: Section 2 discusses the proposed mechanism through which rural electrification impacts children's educational attainment. Section 3 describes the data. Section 4 presents the identification strategy. Section 5 presents the results. Section 6 concludes the paper.

2 Theoretical background

Through what channels does rural electrification influence child education? Drawing on existing research, this section discusses the potential mechanisms.

There is a geographic bias in electrification research, with sub-Saharan Africa being underrepresented (Bayer et al., 2020; Hamburger et al., 2019), while most evidence comes from Asia and Latin America (Chhay and Yamazaki, 2021; Gibson and Olivia, 2010; Grogan and Sadanand, 2013; Khandker et al., 2014, 2013; Sedai et al., 2021). The few studies that evaluate the impact of electricity access in Africa remains inconclusive (Lenz et al., 2017; Peters and Sievert, 2016). Dinkelman (2011) finds that electrification in South Africa enabled greater female employment, while more recent work by Rathi and Vermaak (2018) suggests that the employment benefits of electrification in South Africa are limited due to the economy's inability to absorb additional labor. Upon evaluating the Rwandan Electricity Access Roll-Out Program (EARP), Lenz et al. (2017) finds only weak evidence for impacts on household poverty, whereas Adom and Nsabimana (2022) recently finds that rural electrification in Rwanda improves consumption and labor force participation. For Nigeria, Salmon and Tanguy (2016) finds that electrification increases the working hours of spouses, whereas Pelz et al. (2023) recently shows that there is little effect on employment. Given these gaps, scholars are calling for more research on the impact of electricity access in Africa (Lenz et al., 2017; Hamburger et al., 2019; Bayer et al., 2020).

2.1 Child labor channel

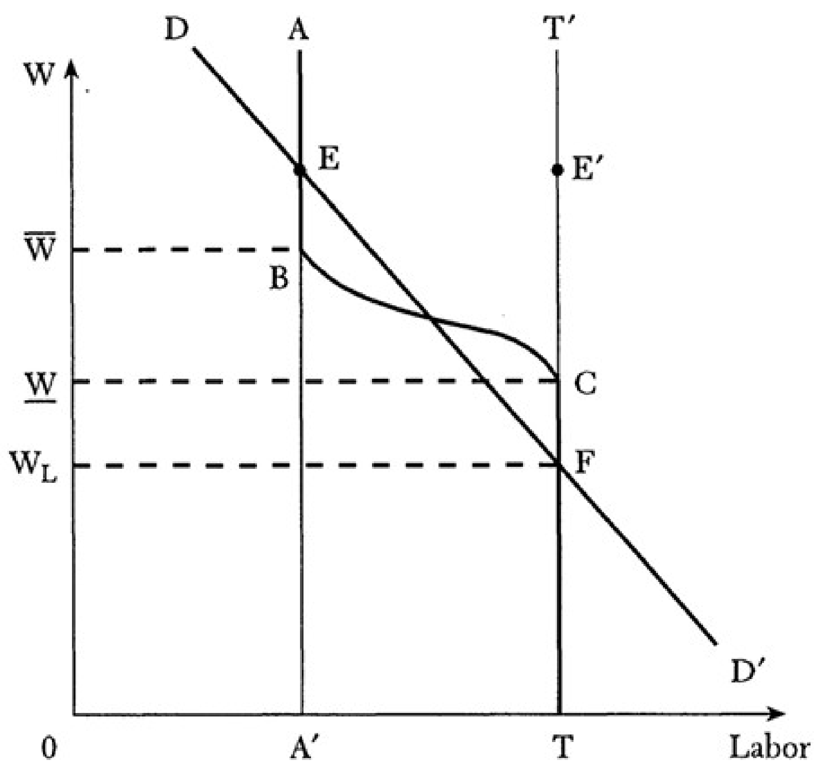
Child labor reduces children's educational attainment in Ethiopia, especially in rural areas (Haile and Haile, 2012; Woldehanna et al., 2021). On average, an Ethiopian child spends 2 hours a day collecting firewood to meet their household's needs. Therefore, rural electrification may also impact child education by affecting child labor supply.

First, by creating structural changes and new opportunities, rural electrification may either incentivize parents to prioritize their children's education over labor or impede child education by incentivizing child labor. Parents may prefer to enroll their children in school rather than engage them in work when they anticipate that education will lead to access to better opportunities. Conversely, if new opportunities are mainly low-skilled, this may discourage schooling and increase child labor, as the opportunity cost of schooling becomes higher (Shah and Steinberg, 2017). In Ethiopia, where most child labor occurs in agriculture, the new job opportunities facilitated by electrification are more likely to be low-skilled, potentially increasing the opportunity cost of schooling and thereby impeding school completion.

Secondly, rural electrification can affect child education by reducing the burden of domestic chores, which, as Putnick and Bornstein (2015) notes, is another form of child labor. In developing countries, children often spend significant time on domestic tasks, such as gathering wood for cooking and heating. For instance, rural households, and especially children, in Ethiopia allocate significant labor hours to firewood collection. As has been the case in Vietnam (O'Brien et al., 2021), using fuel wood as the primary energy source reduces child education. Thus, electrification may help to reallocate children's time from domestic chores to education. For India, Khandker et al. (2014) find that rural electrification reduces the time children spend collecting fuel wood and increases the time they allocate to studying. In Ghana, Akpandjar and Kitchens (2017) discover that households with electricity are more likely to adopt labor-saving electric stoves, which reduce their use of wood fuel for cooking and thereby provide children with more free time.

2.2 Adult labor channel

Figure 1: Adult labor and child labor



Note: This figure is borrowed from Basu (1999). AA' is adult labor supply; TT' is adult plus child labor supply; DD' is aggregate labor demand.

To explain how adult labor is related to child labor, we draw on the simple model from Basu (1999), as illustrated in Figure 1. Assuming that no household would send their children to work if its income from non-child labor were high enough (the so called 'luxury assumption'), the aggregate labor supply function could be constructed as follows. AA' represents the inelastic adult labor supply curve, while TT' denotes the maximum potential labor supply, given by the sum of AA' and the amount of labor children can supply. As long as the wage is above $\overline{W}$, the supply curve is the trait AB (only the adults work); if the wage is below $\underline{W}$, it follows CT (all adults and children work). In between, it traces an S-shaped curve BC connecting the two vertical segments (all adults and some children work). As the wage rises from $\underline{W}$ to $\overline{W}$, households gradually withdraw their children from the labor force. If the market wage exceeds $\overline{W}$, no child is sent to work. However, if the market wage is below $\underline{W}$, all children are sent to work.

Let DD' be the aggregate labor demand curve in the economy. According to Basu (1999) model, there are two stable equilibria (points E and F), with F representing the "bad" equilibrium with child labor. Electrification can expands employment opportunities, shifting DD' upward to a level such that the demand function cuts the supply curve only at a level above $\overline{W}$. This would reduce households' reliance on child labor, with families withdrawing their children from the labor market to keep them in school.

When it comes to adult employment, female employment is especially crucial for children's education. Theoretically, the effects of female employment on children's education can be either positive or negative. Maternal employment may enhance children's schooling through several mechanisms (see Brauner-Otto et al., 2022, for a review on these mechanisms).

First, maternal employment can lead to greater maternal autonomy, empowering mothers to influence household decisions and allocate resources toward their children's education (Allendorf, 2007; Wiig, 2013; Gebremedhin and Mohanty, 2016).

Second, maternal employment can reduce the need for child labor. In low-income settings, child labor often contribute significantly to household income (Todaro and Smith, 2009). However, as mothers' earnings increase due to electrification, the reliance on child labor may decrease and children are more likely to stay in school longer (Basu and Van, 1998).

Third, maternal employment may provide an information channel. Mothers participating in non-family activities outside the home are exposed to new ideas, including the value of education, which can motivate them to prioritize their children's schooling.

Finally, maternal employment creates a role model effect (Johnston et al., 2014). Mothers engaged in non-family labor may serve as role models for their children. Children who observe their mothers working in low-status, such as, manual-labor jobs may be motivated to stay in school to avoid similar circumstances. Similarly, witnessing mothers in desirable positions can inspire children to pursue similar career paths.

Conversely, maternal employment may reduce child education attainment. This may occur for at least two reasons. First, increased maternal employment outside the home reduces the time mothers can dedicate to their children (Cawley and Liu, 2012; Basu and Basu, 1991). This reduction in parental involvement may lower the likelihood of children completing their education. Second, when mothers join the workforce, the need for someone to manage household tasks may arise. Consequently, children might be withdrawn from school to fulfill these responsibilities, adversely affecting their educational attainment.

As discussed earlier, electrification may improve child education by enhancing adult employment opportunities. However, does electrification have an impact on adult labor supply in the first place? There are at least three reasons why this can happen. First, electrification leads to the adoption of electric appliances, which enables women to reallocate time from domestic chores (especially fire wood collection - Sedai et al. 2022) to income-generating activities (Dinkelman, 2011; Rathi and Vermaak, 2018). Research by Grogan and Sadanand (2013) in rural Nicaragua reveals that electrified households spend less time collecting firewood, with women using the increased income to purchase firewood. As such, rural electrification can enhance women's employment opportunities, even in the absence of labor-saving appliances.

Second, rural electrification may stimulate the establishment of new local businesses and create additional employment opportunities (Chhay and Yamazaki, 2021; Akpandjar and Kitchens, 2017). For example, Fried and Lagakos (2021) finds that electrified villages in Ethiopia experienced higher in-migration rates, lower out-migration rates, improved irrigation and agricultural yields (and therefore farming productivity), and increased non-agricultural business activity.

Nevertheless, empirical evidence on the impact of rural electrification on adult employment remains mixed. In India, Van de Walle et al. (2017) find no significant effects of electrification on women's self-employment in either agricultural or non-agricultural sectors, whereas Rathi and Vermaak (2018) report increased paid employment opportunities for women. In South Africa, Dinkelman (2011) document significant positive effects of rural electrification on female employment, while Rathi and Vermaak (2018) note that these benefits are negligible.

In contrast, several studies find more consistently positive effects. Chhay and Yamazaki (2021) show that access to electricity in Cambodia significantly increases the likelihood of non-agricultural self-employment for both men and women. In Ghana, Akpandjar and Kitchens (2017) find that electrified households—especially women—are more likely to operate non-agricultural small businesses, engage in wage employment, and move into higher-skilled occupations. Similarly, Grogan and Sadanand (2013) find that electricity access increases the likelihood of rural Nicaraguan women working outside the home, though it has no significant effect on male employment. In Peru, Dasso and Fernandez (2015) find that rural electrification increases employment for both women and men. In India, Khurana and Sangita (2022) observe positive effects of electrification on non-farm entrepreneurship and household income. Likewise, in rural Indonesia, Gibson and Olivia (2010) report that electricity access is positively associated with non-farm entrepreneurship.

3 Data

The Ethiopian Socio-economic Survey (ESS) is a collaborative project between the Ethiopian Statistical Service (formerly, Central Statistics Agency) and the World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) team. ESS refers to the survey in general, ESS1 to the first wave carried out in 2011/12; ESS2 to the second wave, carried out in 2013/14; and ESS3, the third wave, carried out in 2015/2016.

ESS uses a two-stage probability sampling procedure[5]. At the first stage, small clusters of households in geographically defined enumeration areas (EAs) or villages are selected. At the second stage, households to be surveyed in each sampled EA are selected using systematic random sampling.

The first wave, ESS1, covered only rural areas and small towns with 3,969 households in 333 EAs surveyed. ESS2 and ESS3 covered also larger urban areas, and the number of households (EAs) surveyed went up to 5,262 (433). Households interviewed in ESS1 were re-interviewed in ESS2 and ESS3, providing a panel dataset of households from rural and small-town areas (ESS Panel I). Our analysis is confined to this panel which has almost 4,000 observations. For ESS1 data was collected from January to March 2012, for ESS2 from February to April 2014, and for ESS3 from February to April 2016[6].

[5]We do not use sample weights in our regressions because those provided with the data are not suitable weights for the population of interest (households that were not electrified in ESS1). Additionally, a comparison of weighted and unweighted averages, standard deviations, and medians for several variables of interest (educational outcomes, household composition, gender, etc.) shows similar values with no significant differences (results available upon request).

[6]For documentation, see at https://microdata.worldbank.org/index.php/catalog/2053 for ESS1 (2011/2012); at https://microdata.worldbank.org/index.php/catalog/2247/get-microdata for ESS2 (2013/2014), and at https://microdata.worldbank.org/index.php/catalog/2783/get-microdata for ESS3 (2015/16). ESS was refreshed in the 2018/19 and ESS4 is the first wave of a new panel (ESS panel II) whose second wave (ESS5) was collected in 2021/22. ESS panel II is a new panel, not a follow-up of ESS panel I and therefore not used in our exercise.

We define who qualifies as a child in a household in two ways[7]. The ESS provides a list of all individuals who live in the household and share meals together, along with each member's relationship to the household head and the information on whether the child's biological mother resides in the household at the time of the survey. Based on this information, we first define children as the sons and daughters of the household head whose mothers lived in the household at the time of the survey. As a robustness check, we alternatively define children as household members who are under the age of 14, regardless of their kinship with the head of the family ("Children redefined" see figure 3 and table A1).

When analyzing women labor supply and time utilization, we refer to female household members whose relationship to the household head is categorized as 'spouse,' 'mother,' 'head,' or 'mother-in-law'. Similarly, when studying men labor supply, we refer to the male members of the family whose kinship relationship with the head of the family is categorized as 'spouse,' 'father,' 'grandparent,' or 'head'.

Treatment status: The key explanatory variable is an indicator of electrification. However, a direct measure of household electrification status is not readily available. To overcome this challenge, we follow recent studies (e.g Tenaw et al., 2026; Fried and Lagakos, 2021) and rely on responses to ESS's question on the household's "main source of light" to construct an indicator of electrification status. Households may indicate an electricity meter, solar, alternative sources such as dry cells/batteries, firewood and kerosene lamps.

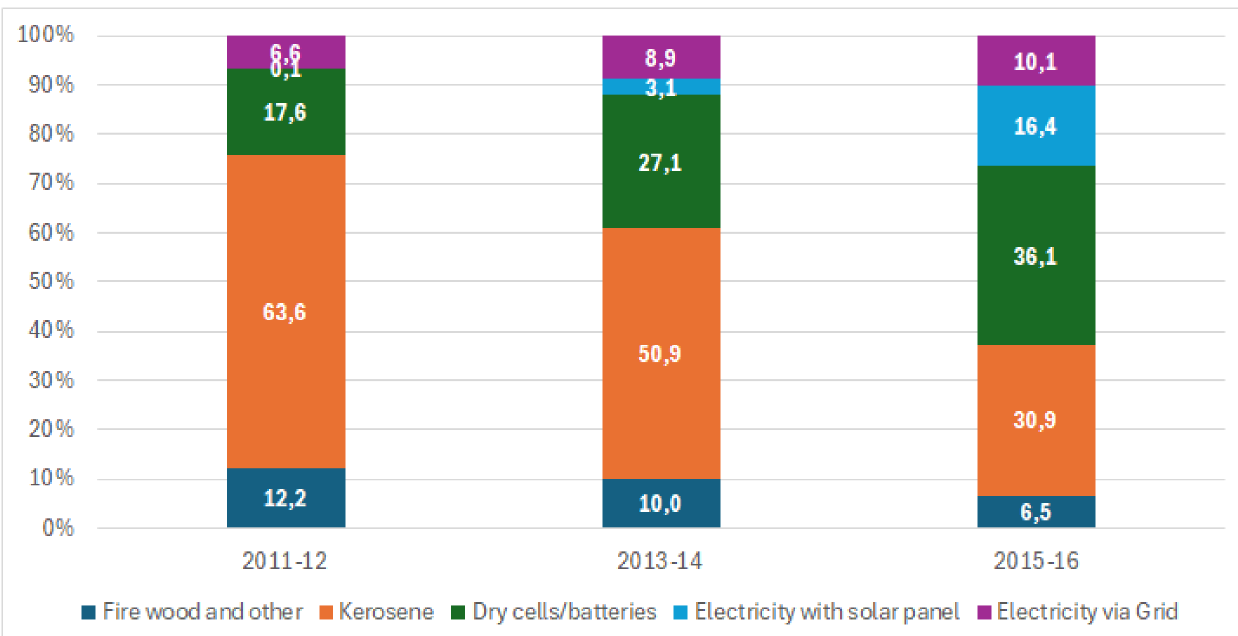
As shown in Fig.2, between 2011 and 2016 there was a rapid shift from traditional energy sources (firewood and kerosene) to modern and clean energy sources, particularly electricity, as main lightning source. However, access to electricity in rural Ethiopia still differs from that in advanced economies, so the answers to this question should be interpreted carefully. Over time, the use of dry cells/batteries has been increasing, displacing kerosene lamps, but this should not be taken as an indication of increasing electrification. Indeed, some programs aiming to promote renewables for households in rural Ethiopia specifically target those relying on "kerosene lamps or *dry cell battery-powered devices* for lighting" (emphasis added; De Martino et al. 2021). Therefore, we use this question as a proxy for electrification.

To define the treatment status of households, following Fried and Lagakos (2021), we first

[7] According to UNICEF, a child is a human being below the age of eighteen years. However, defining children as those under 18 poses challenges in a developing country context like Ethiopia. During the period under study (2011-16), Ethiopia's Labour Proclamation No. 377/2003 permitted employment from the age of 14. Although slightly raised to 15 years by Labour Proclamation No. 1156/2019, this provision remained largely unchanged. It is common to see children as young as 14 years old working. For a brief look at the 2023 report "Analysis of child labor legislation in Ethiopia" by International Cocoa Initiative.

considered whether households adopt off-grid (solar) or grid connections to access electricity, while recognizing that the increasing adoption of dry cells/batteries alone does not qualify a household as "electrified." We also consider, as robustness check, the situation without distinguishing by electricity source (i.e., grid or solar). Using these definitions, we focus only on rural households and exclude those that were already electrified in 2011/12. These two methods of electrification differ: grid connection ensures 24-hour access to electricity but can be costly for both policymakers (especially in rural communities far from existing power lines) and households; solar panels may be cheaper, especially for more remote communities, and provide electricity free of charge once installed but work only during the day (and when the sun is shining) unless costly batteries are installed. These represent different ways to access electricity, and in this work, we aim to understand their differences in terms of educational attainment.

Figure 2: Share of rural population in Ethiopia by main lighting source



The first row of Table 1 presents the number of households not electrified in 2011/12 that gained access to electricity in subsequent years through grid connection. In 2011/12, there were 2,943 rural households not connected to the power grid. By 2016, 235 households (154 by 2014 and 81 between 2014 and 2016) had gained grid connection. We classify this group as "Grid" electrified households. The remaining 2,708 households remained unconnected by 2016. Overall, 8% of households not connected to the electricity grid in 2011/12 became connected by 2016.

Similarly, the second row of Table 1 presents comparable statistics for the "Solar" treatment, i.e., households achieving electrification by installing solar panels. In total, we observe photovoltaic (PV) adoption status for 2,980 households. Among these, 2,421 households never adopted PV. By the end of 2016, 18.8% of them were solar electrified: 104 households (3.5%) acquired a PV system between 2012 and 2014, and a further 455 (15.3%) adopted one by 2015/16.

Finally, the third row reports results using the broader definition of electrification, which includes both grid and solar access. In 2011/12, there were 2,939 rural households without any access to electricity; by 2016, 761 households (25.89%) had gained access either through a solar system or grid connection. We classify this group as "Grid or Solar" electrified households. The remaining 2,178 households remained without access to electricity.

Table 1: Households in wave 1 (2011/12) by time and electricity source

Electricity sources	Never	2013/14	2015/16	Total
Grid	2,708	154	81	2,943
Solar	2,421	104	455	2,980
Grid or Solar	2,178	258	503	2,939

Educational Attainment: The main outcome variable is a measure of children's educational attainment. This paper focuses on school completion rather than enrollment. In Ethiopia, the net primary enrollment rate grew significantly, rising from 87% in 2009/10 to an impressive 104% in 2016/17 for first-cycle primary education (grades 1–4), and from 46% to 66% for second-cycle primary education (grades 5–8) over the same period. However, a notable disparity persists between the enrollment rates of the two cycles (Woldehanna et al., 2021), likely due to high repetition and dropout rates. For instance, Woldehanna et al. (2021) reports that the dropout rate increased from 9% in 1999/00 to 14.6% in 2007/09, while the primary completion rate stagnated around 44% in 2008/09 and reached 54% by 2015. Thus, Ethiopia's major challenge in achieving education-related Sustainable Development Goals (SDGs) by 2030 is not just low enrollment but also the failure to complete primary education, which hinders both girls and boys from accessing secondary education. This study aims to examine whether rural electrification policies can help Ethiopia overcome this challenge of low educational attainment.

In the analysis, we focus on children who were surveyed in 2011/12 and follow them through to 2015/16. Section 2 of the household questionnaire records whether children aged

5 years and above have ever received an education (for children aged 5 to 10, this information is provided by their caregiver). For those who have received education, the highest grade they have completed by the time of the ESS interview is recorded. The possible completed education levels are "Kindergarten," "first grade completed," "second grade completed," "third grade completed," "fourth grade completed," and so on. We code the outcome variable as 0 for children who have never received any education, 1 if the highest completed grade at the time of the survey is "Kindergarten" or first grade, and 2, 3, 4, and so on respectively if the child completed second grade, third grade, fourth grade, etc.[8]

ESS data on individuals' completed education is sometimes inconsistent over time. In Ethiopia, the school calendar runs from mid-September to early July. ESS1 collected education data from January to March 2012, while ESS3 collected data from February to April 2016. Consequently, the difference in the highest grade completed reported between ESS1 and ESS3 should range between zero and, at most, four years[9]. However, there are instances where the reported differences are either negative or exceed four years, indicating both underreporting and overreporting of grades completed. In our benchmark analysis, we exclude these inconsistent cases. However, we undertake robustness checks to see if the results remain consistent even when these cases are included.

Table 2: Average number of children's years of completed education by electrification status and time

	Grid or Solar			Grid			Solar		
Group	(1) 2011/12	(2) 2015/16	(3) Δ	(4) 2011/12	(5) 2015/16	(6) Δ	(7) 2011/12	(8) 2015/16	(9) Δ
Electrified	1.55 (0.06)	3.31 (0.09)	1.75 (0.06)	1.84 (0.13)	3.79 (0.20)	1.95 (0.13)	1.47 (0.06)	3.18 (0.10)	1.71 (0.06)
Not Electrified	1.54 (0.04)	3.28 (0.05)	1.74 (0.03)	1.52 (0.03)	3.25 (0.05)	1.73 (0.03)	1.56 (0.04)	3.31 (0.05)	1.76 (0.03)
Δ	0.01 (0.07)	0.03 (0.10)	0.01 (0.07)	0.32** (0.13)	0.54*** (0.19)	0.22** (0.13)	-0.09 (0.07)	-0.13 (0.11)	-0.04 (0.07)

Notes: Δ = difference. Standard errors in parentheses. Significance levels: ***p<0.01, **p<0.05, *p<0.1

Table 2 presents the average number of children's years of completed education, broken down by electrification status. Overall, children's educational attainment increased between

[8]ESS data also includes categories such as informal, adult, and basic education. We exclude these categories as they do not specify the number of years of education completed by the respondent. Moreover, only one child in the sample reports basic education, and only three report informal education.

[9]For instance, a child with "first grade completed" at the time of the ESS1 interview means they had already completed first grade by July 2011 and were in second grade at the time of the survey. Assuming uninterrupted schooling, by April 2016, they would be in fifth grade and report "fourth grade completed."

2012 and 2016 on average between 1.71 and 1.95 additional years, more than doubling the initial level. The situation for children in electrified households is heterogeneous and depends on the electrification source.

Households that achieved electrification via grid connection (columns 4–6) gained almost 2 additional years of education by 2016 (from 1.84 to 3.79 years), whereas households not electrified during the same period gained 1.73 additional years (from 1.52 to 3.25 years), which is 0.22 years less of additional education. In contrast, there appears to be no significant difference in additional years of education between households that gained access to electricity through solar panels and those that did not between 2012 and 2016 (columns 7–9). However, these preliminary results should be interpreted with caution, as they do not account for other concurrent factors that may influence the educational progress of both groups.

Labor and time use: Section 4 of the ESS questionnaire records information on household members' time use and labor. It asks household members aged 7 years or older about the amount of time they allocate (in hours) to various activities,[10] which informs us about the involvement of adults and children in family farm and off- farm businesses and firewood collection. For off-farm family business, we define a dichotomous variable based on the question *"How many hours in the last seven days did [member] run or help with any kind of non-agricultural or non-fishing household business, big or small, for his or herself or for the household?"*: the binary variable equals one if the individual supplies a positive number of hours of work in the off-farm family business, zero otherwise. Similarly, we define dummy variables for the involvement in farm family business and firewood collection based on the questions *"How many hours in the last seven days did you spend on household agricultural activities (including livestock and fishing-related activities) whether for sale or for household use?"* and *"How many hours did you spend yesterday collecting firewood (or other fuel material)?"*, respectively.

As Table 3 shows, the percentage of children, women, and men engaged in firewood collection decreased from 2011/12 to 2015/16. We also observe a general decline in the percentage of individuals engaged in non-agricultural activities between 2011/12 and 2015/16. In the households connected to the grid the share of children, women, and men working in non-farm enterprises dropped from 13%, 40%, and 28% in 2011/12 to 3%, 17%, and 8% in 2015/16, respectively. Similarly, in non-electrified households, these percentages declined

[10] For children aged 7–10 years, their caregiver is asked questions about time use.

Table 3: Descriptive statistics on labor and time use by electrification status

Source of electrification: Grid or Solar						
	Children		Women		Men	
Group	2011/12	2015/16	2011/12	2015/16	2011/12	2015/16
	Firewood collecting yesterday (0/1)					
Not electrified	0.26	0.12	0.37	0.16	0.12	0.04
Electrified	0.19	0.12	0.43	0.18	0.05	0.07
	Employed in off-farm family business (0/1)					
Not electrified	0.10	0.02	0.28	0.08	0.20	0.06
Electrified	0.09	0.02	0.29	0.11	0.22	0.09
	Employed in farm family business (0/1)					
Not electrified	0.53	0.50	0.59	0.50	0.79	0.69
Electrified	0.50	0.49	0.52	0.46	0.73	0.55
Source of electrification: Grid						
	Children		Women		Men	
Group	2011/12	2015/16	2011/12	2015/16	2011/12	2015/16
	Firewood collecting yesterday (0/1)					
Not electrified	0.24	0.12	0.39	0.17	0.10	0.05
Electrified	0.20	0.10	0.35	0.17	0.10	0.05
	Employed in off-farm family business (0/1)					
Not electrified	0.10	0.02	0.28	0.08	0.20	0.07
Electrified	0.13	0.03	0.40	0.17	0.28	0.08
	Employed in farm family business (0/1)					
Not electrified	0.52	0.50	0.59	0.50	0.77	0.66
Electrified	0.44	0.40	0.41	0.42	0.74	0.58
Source of electrification: Solar						
	Children		Women		Men	
Group	2011/12	2015/16	2011/12	2015/16	2011/12	2015/16
	Firewood collecting yesterday (0/1)					
Not electrified	0.25	0.11	0.37	0.17	0.11	0.04
Electrified	0.18	0.12	0.45	0.17	0.04	0.08
	Employed in off-farm family business (0/1)					
Not electrified	0.10	0.02	0.28	0.09	0.21	0.07
Electrified	0.08	0.02	0.26	0.09	0.21	0.09
	Employed in farm family business (0/1)					
Not electrified	0.51	0.48	0.57	0.50	0.78	0.69
Electrified	0.52	0.51	0.54	0.48	0.71	0.55

from 10%, 28%, and 20% in 2011/12 to 2%, 8%, and 7% by 2015/16. In a context of general reduction of adults and children participation in farm and non-farm family businesses, as well as in firewood collection, regardless of the definition of the treatment, Table 3 does not show trends clearly different between electrified and non-electrified households.

4 Empirical Strategy

The aim of the study is to identify the causal impact of electrification in rural Ethiopia on children educational attainment. A simple way to achieve this is by taking the mean difference between children in electrified and non-electrified households. However, such a strategy assumes that the two groups are comparable, which is unlikely in our setup. For instance, electric infrastructure projects are unlikely to be randomly placed; villages closer to existing power grids are more likely to be connected than those farther away (Akpandjar and Kitchens, 2017). Similarly, although the government provides the electric grid, the decision to connect to it (the "last mile") lies with individual households. This decision is not random; factors such as income and education significantly influence a household's choice to adopt energy (Bonan et al., 2017). These issues pose an identification challenge due to unobserved factors correlated with both the decision to connect to the electric grid or adopt a solar system and the decision to keep children in school.

To overcome these challenges, we first employ a differences-in-differences (DiD) strategy that mirrors the one used by Fried and Lagakos (2021). We consider the following specification:

$$\Delta y_{ihv} = \beta E_{hv} + \boldsymbol{x}'_{ihv}\boldsymbol{\delta} + \theta_v + \epsilon_{ihv} \quad (1)$$

where Δy_{ihv} is the change in the outcome of interest (years of educational attainment) between 2011/12 and 2015/16 of the individual i, a member of household h living in village v; E_{hv} is a dummy for the change of the electrification status that takes value 1 in households that gained access to the electricity by 2015/16 (the treatment group), and 0 for the others (the control group); $\boldsymbol{x}_{ihv}$ is a vector of individual and household characteristics observed in 2011/12, θ_v is the village fixed effects. We cluster standard errors at the household level to account for the correlation of error terms ϵ_{ihv} among members within the same household.[11]

Fried and Lagakos (2021) show that the changes in electricity access in Ethiopia facilitated

[11] As the treatment is at household level, using household clustered standard error is our benchmark. We also experimented clustering at village level, obtaining very similar results. Details are available upon request.

the structural transformation of electrified villages. Thus, changes in village- or location-level factors could potentially influence changes in the outcome of interest. For instance, electrification may lead to the establishment of a school, which in turn increases the number of years of education completed. This creates a broader village-wide effect rather than a direct impact of household electrification itself. To account for such village-level changes, we include village (called "enumeration area" in the survey) fixed effects (θ_v). This helps minimize the risk that our estimates are confounded by differential trends in electrification across locations or other unobserved location-specific factors.

Similarly, household characteristics may also influence educational attainment. To control for these factors, we include household size in 2012, a dummy variable indicating whether the floor of household's home was made of mud in 2012 (as a proxy for household wealth), and the main source of light of the household in 2012. We use the 2012 values rather than those from 2011/12 to reduce the risk of endogeneity, ensuring that electrification in the 2011/12 - 2015/16 period cannot itself influence these pre-determined variables. For instance, research by Akpandjar and Kitchens (2017) in Ghana suggests that household electrification led to lower fertility rates, highlighting the potential for electrification to alter key household characteristics over time.

The estimate for β from equation 1 represents the DiD estimator of the impact of electrification [12]. The (parallel trend) assumption necessary to ensure the validity of this identification strategy is that, in the absence of electrification, the average difference between outcome variables for households with and without electrification would have remained the same as before the electrification. In other words, outcome variables can differ in levels between households with and without electricity, but their changes over time should be similar.

The parallel trends assumption (i.e., that in the absence of treatment, the control and treated groups would have followed similar outcome trajectories) cannot be directly tested when focusing only on the first and last waves of the survey. However, we investigate its validity by implementing an event-study design which takes advantage of all three waves of surveys, ESS1-ESS3, and the different moments at which households gain access to electricity. Reassuringly, as demonstrated later, there is no evidence of differential trends in child education prior to electrification.

[12] For a brief description of the Difference-in-Differences setup, see Donald and Lang (2007).

5 Results

5.1 Benchmark results

Table 4 presents our benchmark results, based on a DiD estimator, of the impact of access to electricity on children's educational attainment. As discussed earlier, the results are broken down according to three different definitions of access to electricity: a broader definition (either via grid or solar; columns 1 and 2); via grid only (columns 3 and 4); and via solar only (columns 5 and 6). All regressions include village fixed effects. The regressions in columns 2, 4, and 6 also include the following individual and household controls: child's sex; child's age; household size; and a dummy variable indicating whether the house floor is made of mud–used as a proxy for household socioeconomic status and dummies for the household's main source of light. Standard errors (in parentheses) are clustered at the household level. The number of households included in the regressions is smaller than the total household sample described earlier, because not all households have information on the outcomes of interest.

Table 4: Access to electricity and changes in children's education: benchmark results

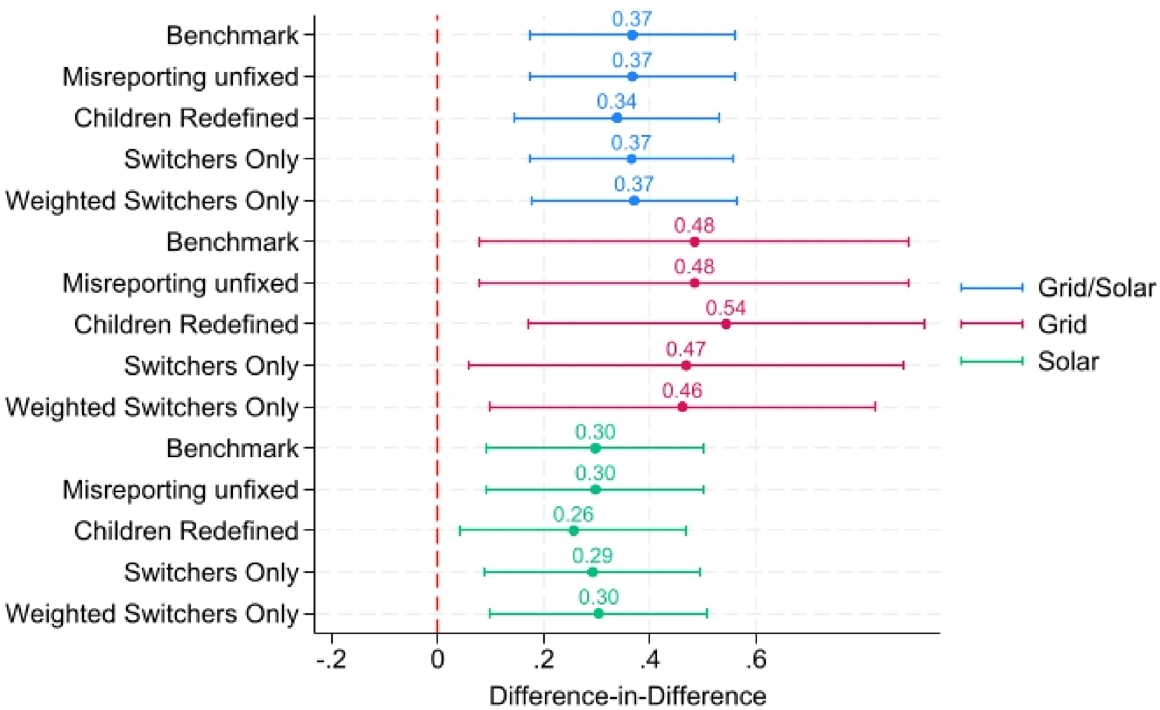
	Type of Electrification					
	Grid or solar		Grid		Solar	
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect	0.36***	0.37***	0.46***	0.48***	0.29***	0.30***
	(0.10)	(0.10)	(0.20)	(0.21)	(0.11)	0.10
Observations	3,921	3,920	3,922	3,921	3,965	3,964
R-squared	0.23	0.23	0.22	0.23	0.22	0.23
Controls	No	Yes	No	Yes	No	Yes
Households	1,663	1,662	1,664	1,663	1,684	1,683
Villages	278	278	278	278	278	278

Notes: The table reports the difference-in-differences estimates using ESS1 and ESS3. Controls include child's sex, child's age, household size, a dummy for whether the house floor is made of mud, and dummies for the household's main source of light. All regressions include village fixed effects. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

The results suggest that children from households that gained access to electricity between 2011/12 and 2015/16 exhibit a significant difference in educational outcomes compared to children from households that did not gain access during this period (on average, between

3 and 6 months of additional educations). As reported in Table 4, children in households that gained access to either solar or grid electricity in 2015/16 completed, on average, 0.36 more years of education than those without access. When specifically focusing on grid connection, the educational gains are even larger, with children from grid-connected households showing an increase of 0.46 years of completed education compared to those in non-electrified households, while the effect seems lower when electricity is gained through PV (on average, 0.29 more years). An intuition behind these results is that photovoltaics generate electricity only during sunny days, unless the house has a storage system, which is rare. Consequently, electricity is not always available, particularly in the evening and at night, which limits opportunities for studying or using appliances such as electric stoves or heaters. This creates a need to find alternative fuels for cooking and heating during those hours.

Figure 3: Electrification and child education: robustness



Notes: Estimated effect with 95 % confidence intervals using ESS1 and ESS3. All regressions include child sex, child age, household size, a dummy for the house floor being mud, dummies for the type of main source of light for the household, and village fixed effects. Standard errors are clustered at the household level.

5.2 Robustness checks

Our benchmark results pass several robustness tests. Figure 3 or alternatively, Table A1 presents the results of these robustness tests. Below we discuss each estimation in turn.[13]

As mentioned in the data section, we encountered both underreporting and overreporting of grades completed. In the benchmark, we presented estimates after excluding from the sample those children with inconsistencies in their reported completed grades of education. However, such an exercise may bias the estimates if the misreporting is systematic. For instance, individuals who are less likely to complete their education may be more prone to misreporting, while those who complete their education report accurately. To address this concern, we present estimates without excluding from the sample those children with inconsistencies in their reported completed grades of education. The results are reported in Figure 3 under the "Misreporting unfixed" label, and the difference-in-differences estimates are similar to the benchmark results.

In the benchmark analysis, children are defined as individuals aged 5 or more, related to the household head as daughters or sons, regardless of their age. We adopt an alternative definition of children ("Children redefined"): specifically, we define children as all household members who were under 14 years old in 2011/12. The results are robust to using this alternative definition.

Areas not served by the grid may differ systematically from those connected to it, potentially introducing bias from factors unrelated to electrification (e.g., remoteness, underdevelopment, or policy neglect). We do not have direct information on the infrastructural changes that occurred in the villages. Nonetheless, we focus on the households living in what we call "Switcher" villages, i.e., villages where at least one household changed from being not electrified in 2011/12 to being electrified in 2015/16. By restricting the analysis to villages where at least some households experienced electrification, we focus on those contexts in which grid electrification was a real option for the household. The results are reported in column 5 (for grid or solar) and column 6 (for grid) in Table A1. The sample size decreases to 2,565 children, 1099 households, and 190 villages for grid or solar electrification, and to 950 children, 422 households, and 81 villages for grid electrification. Importantly, our findings remain robust under this restrictive specification as well.

Furthermore, we apply inverse probability weighting (IPW) to the "Switchers" sample,

[13] In the benchmark case, the sample of children falling under different definitions of electrification is slightly different (see Table 4). To ensure comparability, we estimated the models in columns (3) and (4) on the same sample used for columns (1) and (2) and the main results were unaffected. Detailed results are available upon request.

with results reported in Table A1 under the label "Weighted Switchers." The propensity score is estimated using child age in 2011/12, household size in 2011/12, a dummy for a mud floor in 2011/12, and dummies for the type of house lighting in 2011/12. We use the Hotelling test to assess whether the means of these covariates are equal across treatment and control groups after weighting and fail to reject the null hypothesis.[14] This indicates good overlap in covariate distributions, making IPW a reliable method (Busso et al., 2014) to adjust for potential selection bias.

As shown in columns 7 and 8 of Table A1, applying inverse probability weighting (IPW) to the "Switchers" sample substantially reduces the number of children, households, and villages in the analysis. For example, column 8 shows that only 950 children, 422 households, and 81 villages remain in the grid electrification sample. Nonetheless, even under this conservative approach, the difference-in-differences estimate for grid electrification is 0.46 years of completed education—very close to our earlier estimates. Likewise, the estimate for grid or solar electrification remains nearly unchanged compared to the benchmark results.

5.3 The dynamics of the effects of electrification on children educational attainment

For the benchmark analysis, we used the first wave (ESS1) as the baseline and the third wave (ESS3) as the endline survey. However, this approach may overlook that different households gain access to electricity at different periods. We first presents the estimates of the average treatment effect on the treated (ATT) using a two-way fixed effects (TWFE) difference-in-differences model which exploits all three waves of the ESS. The estimated equation is

$$y_{ihvt} = \alpha_{ihv} + \beta E_{hvt} + \boldsymbol{x}'_{ihv}\boldsymbol{\delta} + \theta_v + \gamma_t + \epsilon_{ihvt} \tag{2}$$

where α_{ihv} and γ_t are individual and time fixed effects, respectively, and E_{hvt} is the electrification status of household h in village v at time t. The results are presented in Table 5: they follow a pattern similar to the benchmark case, with grid electrification that has the largest effect, followed by combined grid or solar access, with solar-only electrification having the smallest effect. Also, the estimates are generally larger than those obtained in the benchmark analysis using only ESS 1 and 3 (see Table 4). This may suggest that the dynamics occurring between survey waves play an important role and may lead to underestimation

[14] As an alternative to the Hotelling test, plots of the propensity score distributions before and after weighting, available upon request, visually confirm improved balance between treatment and control groups.

when intermediate periods are not accounted for.

Table 5: Access to energy and child education: TWFE and Event Study estimates

	Type of Electrification		
	Grid or solar	Grid	Solar
	(1)	(2)	(3)
Treatment effect (TWFE ATT)	0.44***	0.64***	0.35***
	(0.09)	(0.17)	(0.09)
Event Study (Dynamic) ATT	0.48***	0.65***	0.39***
	(0.09)	(0.17)	(0.09)
Observations	11,561	11,568	11,707
R-squared	0.46	0.46	0.46
Controls	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Group dummies	Yes	Yes	Yes
Controls × Treatment group dummies	No	No	No
Controls × Year dummies	No	No	No
Parallel trends Assumption (PTA) holds	Yes	Yes	Yes
Households	1,666	1,668	1,693
Villages	282	282	282
Mean of Dep Var	2.4	2.4	2.4

Notes: The estimates are obtained using the 'JWDID' Stata command by Rios-Avila et al. (2024). All regressions include village and year fixed effects and the following controls: child sex, child age, household size, and a dummy housing condition. Treatment group dummies are defined according to the year at which households become electrified. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

As shown in Table 1, not all households gained electricity access at the same time. There is staggered treatment adoption, with some households electrified between 2012 and 2014, and others between 2014 and 2016. In such staggered designs—where interventions are adopted across units at different times, standard difference-in-differences estimators, such as the two-way fixed effects (TWFE) model, may yield biased estimates (De Chaisemartin and d'Haultfoeuille, 2020; Borusyak et al., 2024). As an alternative, we thus employ the staggered Difference-in-Differences (DiD) method (Callaway and Sant'Anna, 2021; Nagengast et al., 2024; Nagengast and Yotov, 2025) [15].

The staggered DiD approach is suitable for settings with more than two time periods, where units receive treatment at different points in time (like our setting). Specifically, it allows us to: (i) examine the effects of treatment dynamics, as households exposed for longer periods may experience different gains compared to those with shorter exposure; (ii) provide evidence in support of the parallel trends assumption; and (iii) estimate cohort-specific treatment effects.

In our data, we define electrification as an absorbing state, that is, once electrified the households keep being electrified for the remaining periods. Moreover, a large fraction of households never gain access to electricity, which makes them the most appropriate control group. The effects of electrification on school outcomes may not be immediately apparent and may depend on how long children have had access to electricity. This suggest an 'event study' approach to the analysis of the effects using the following Extended TWFE (ETWFE) model:

$$y_{ihvt} = \alpha_{ihv} + \beta_{-4}^{pre} E_{-4,ihv} + \sum_{e=0,2} \beta_e^{post} E_{e,ihv} + x'_{ihv}\delta + \theta_v + \gamma_t + \epsilon_{ihvt} \quad (3)$$

where $E_{e,ihv}$ is a binary variable that equals one for all the individuals in the treated group who are e periods from the year they became electrified, and zero otherwise. The immediate ATT effect, that is the ATT at the time electrification has been recorded for the first time, is $ATT_e(0) = \beta_0^{post}$; the ATT at the successive wave, after two years, which is identifiable only for those who become electrified by ESS2 and are observed also in ESS3, is $ATT_e(2) = \beta_2^{post}$. Comparing $ATT_e(0)$ and $ATT_e(2)$ allows us to appreciate how ATT varies as the time the child has been able to enjoy the connection to electricity increases. The aggregate ATT is the weighted average

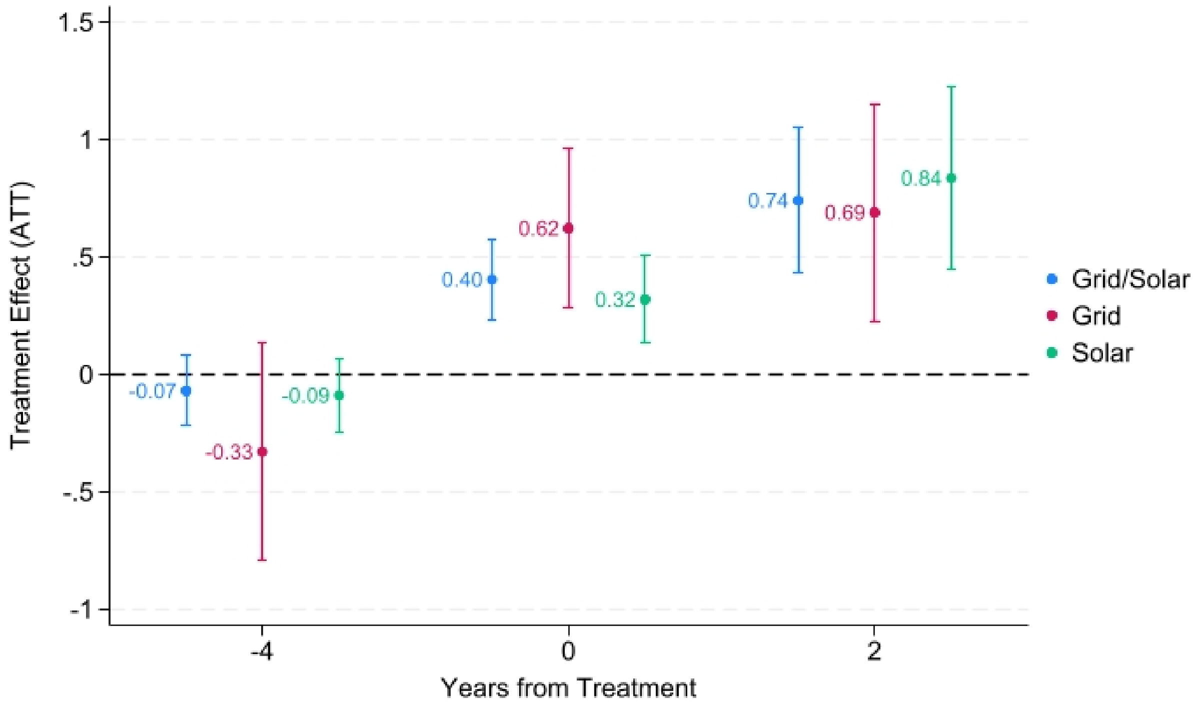
$$ATT = \frac{\sum_{e=0,2} \beta_e^{post} \sum_i E_{e,ivh}}{\sum_{e=0,2} \sum_i E_{e,ivh}} \quad (4)$$

Finally, $ATT_e(-4) = \beta_{-4}^{pre}$ captures pre-treatment differences in the trends between those who never acquired access to electricity and the households electrified in 2016. The latter are the only ones for which is possible to test if the the parallel trend assumption holds, that is $ATT_e(-4) = 0$.

The estimates of the ETWFE model confirm that, as in the benchmark case, the ATT effects of grid electrification are larger than those of solar electrification or the combination

[15] We rely on the JWDID estimation routines provided by (Rios-Avila et al., 2024). As Rios-Avila et al. (2024) notes, these routines offer greater transparency and user control compared to other implementations—such as those by Callaway and Sant'Anna (2021)—where much of the model estimation is handled internally, making it more difficult to trace what is being estimated.

Figure 4: Electrification and Child Education: Event Study Estimates



Notes: The figure reports event study estimates of electrification on child education, estimated using the JWDID Stata command. All regressions include village and time fixed effects and the following controls: child sex, child age, household size, and a dummy for the house floor being mud, and dummies for the household's main source of light. 95% confidence intervals are shown using standard errors clustered at the household level. ATT =0.48 (std. err. 0.09) for Grid/Solar; 0.66 (0.17) for Grid, and 0.30 (0.09) for Solar.

of both. More specifically, the point estimate of the ATT effect for grid electrification is 0.66 (std. err. 0.17); compared to 0.30 (0.09) for solar, and 0.48 (0.09) for the case where electrification is achieved either *via* grid or photovoltaic. All three estimated ATTs are in line with those obtained from the TWFE model (see Table 5).

Figure 4 presents the estimated $ATT_e(-4)$, $ATT_e(0)$ and $ATT_e(2)$ for the tree alternative definitions of electrification. Reassuringly, the results show that, for all of them, there is no evidence to reject the null hypothesis of parallel trends (all the $ATT_e(-4)$ are not statistically different from zero). The ATT effects vary considerably with the time elapsed since electrification. The point estimate of the immediate effect of grid electrification is considerably higher than that of solar electrification ($ATT_e(0) = 0.62$ *vs* $ATT_e(0) = 0.32$ additional years of completed schooling, with the grid or solar treatment in the between, 0.40). As time goes by, the ranking between the ATT effects of grid and Solar electrification reverse and the difference becomes smaller: $ATT_e(2) = 0.69$ *vs* $ATT_e(2) = 0.75$ additional years of schooling. Notice that the confidence intervals of $ATT_e(0)$ and $ATT_e(2)$ for Grid electrification fully overlap, whereas the overlapping is very limited for the Solar treatment. Overall, this suggests that while connecting to the grid provides immediate, round-the-clock benefits of electrification, it takes time for households to fully understand and utilize the advantages of solar electrification.

5.4 Complementarity in infrastructure

Sofar, our analysis focuses on the effect of electrification. However, recent studies suggest that the effects of electrification may interact with complementary infrastructure, such as roads (Foster et al., 2025; Vagliasindi and Gorgulu, 2025). If multiple forms of infrastructure—such as roads and electricity—expand simultaneously, it becomes difficult to disentangle their individual contributions to observed outcomes. In our context, this would imply that part of the effect we attribute to electrification might, in fact, be driven by concurrent improvements in transport infrastructure.

To investigate this possibility, we focus on the dimension for which data are available in the ESS—proximity to major roads. We first examine whether road expansion coincided with the electrification rollout. The mean distance to the nearest major road remained virtually unchanged over the study period, suggesting that the two types of infrastructure did not evolve together. This evidence indicates that we are unlikely to be attributing to electrification an effect that is, in fact, due to improved road access.

Nevertheless, because our data do not include information on all roads or other types of infrastructure, we cannot completely rule out the possibility that broader infrastructure developments may have amplified the estimated effects.

Finally, we explore whether the effects of electrification vary with proximity to major roads. Specifically, we compare households located near major roads with those farther away to assess whether the benefits of electrification differ by accessibility. As shown in Table A2, the estimated effects are more pronounced in remote areas, suggesting that electricity access may yield especially strong gains where other infrastructure remains limited.

5.5 Potential Mechanisms

In this section, we explore the mechanisms through which electrification may influence children's education. Specifically, we examine three dimensions: (i) whether the individuals change the habit to collect firewood, (ii) whether they change their engagement in family non-farm activities, and (iii) whether they change their participation in family farm activities[16]. We present the estimates of the TWFE estimator of eq. 2 and the event study - ETWFE estimator of eq. 3, separately for children, women, and men.

When testing for the mechanisms, we run into cases where the parallel trends assumption (PTA) do not hold. To address this, we enriched our TWFE and event study specifications by introducing interactions between the vector of controls $\boldsymbol{x}_{ivt}$, two treatment group dummies, which identify the households electrified by ESS2 or ESS3, and two time dummies. More specifically, we adopted the most parsimonious specification such that the PTA holds.

The sample of children analyzed corresponds to those included in the benchmark education regression sample (see table 5). Likewise, the analysis for women and men is restricted to households with at least one child in the benchmark education regression sample.

As for firewood collection, the estimated ATT effects (see Table A3) show that electrification reduces the probability that a child collects firewood. The magnitude of the effects is remarkable (5/7 percentage points, out of 15 percent of children involved in firewood collection), with the impact of grid electrification slightly larger than that of solar in the event study case. There is also evidence of a reduction of firewood collection for women in case of solar electrification, whereas for men the results are not clear cut: there are no effects for grid electrification and apparently positive effects for solar, but in this case the PTA does not hold and the results are not reliable.

Grid electrification also leads to a reduction in child labor in non-farm family businesses. As shown in Table A4, access to electricity decreases the likelihood of a child engaging in non-farm family business, but this effect is significant only when the household is connected to the power grid. In contrast, the results in Table A5 show no statistically significant impact on children agricultural activities. Therefore, electrification appears to affect children primarily by reducing the time they spend collecting firewood and, specifically for households connected to the grid, the time spent on non-farm family activities.

Focusing on the effect of electrification on women's participation to family businesses, electrification has no significant effect on their involvement in non-farm family businesses, see Table A4. As for agricultural labor (Table A5) there is no systematic evidence of a relevant impact, with only the ATT effect based on the TWFE model being marginally significantly positive. Finally, the evidence regarding men's labor supply in family businesses shows that, in the case of solar electrification, they increase their support for non-farm family businesses

[16] We also attempted to investigate whether electrification modifies participation in non-family businesses for paid jobs; however, the low participation in these activities in our sample does not allow us to study the phenomenon in a reliable way.

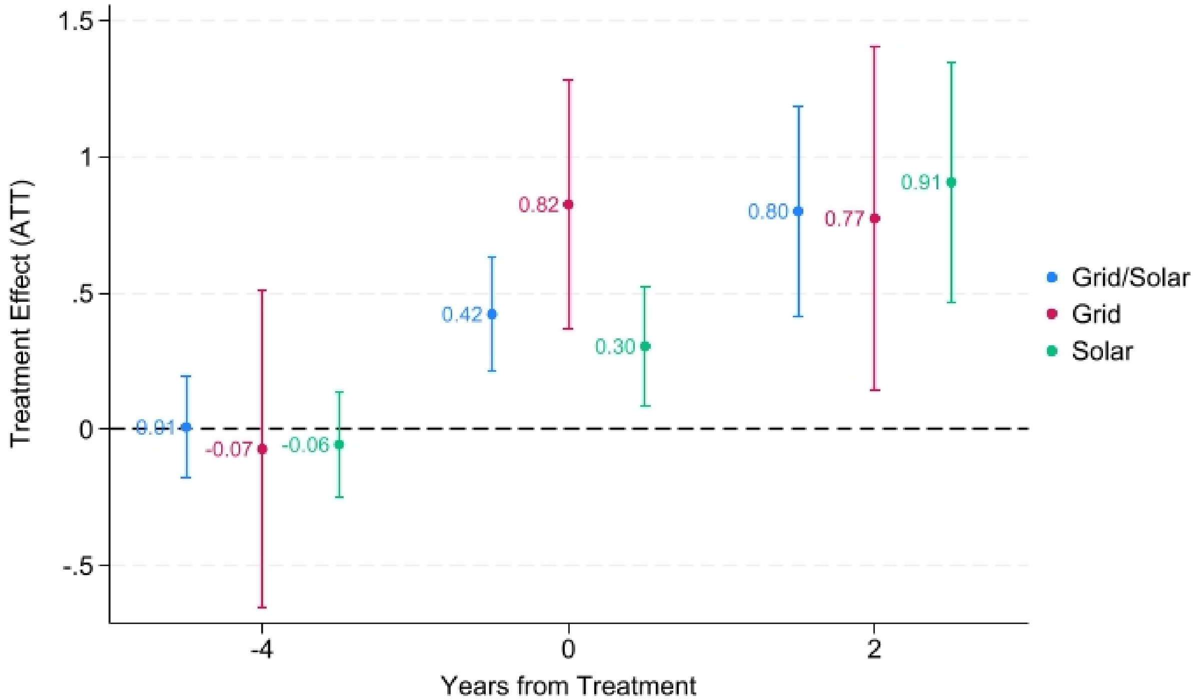
(Table A4) and reduce their involvement in farming (Table A5).

Overall, the evidence suggests that in rural Ethiopia, electrification impacts children by reducing firewood collection and non-farm activities. For their parents, solar panels appear to reduce women's firewood collection and decrease men's labor supply in farming activities.

Our findings on the mechanisms in Ethiopia are broadly consistent with evidence from other settings. Akpandjar and Kitchens (2017) find that in Ghana, electrification leads to a shift away from agriculture for both men (and women) and is associated with greater household investment in children's education. Dasso and Fernandez (2015) in Peru finds that rural electrification increases the probability that women work outside the agricultural sector. Similar to Khandker et al. (2014)'s results for India, we find that rural electrification reduces the time household members devote to collecting firewood. We are also aligned with the findings of Rathi and Vermaak (2018) for South Africa, who report that electrification does not significantly affect the labor force participation of either men or women. Indeed, we do not find evidence that rural electrification increases the labor supply of either men or women.

We have shown that electrification reshapes child labor patterns and reduces the collection of firewood by the adults. To investigate if this reshaping is a mechanism through which electrification has an impact on children educational attainment, we reconsider equation (2) by including in $\boldsymbol{x}_{ivt}$ the labor and firewood collection variables of the children. We conjecture that firewood collection negatively affects children's educational attainment, and we have seen that electrification reduces children's firewood collection. Thus, should the reduction of firewood collection being a mechanism through which electrification affects educational attainment, we expect the estimates of the ATT effects based on the original equation (2) to be an overestimate of the effect. Table A6, columns (1)-(3) shows that firewood collection indeed negatively affects children education, but the estimates of the ATT effects based on the TWFE models do not change significantly with respect to the estimates in Table 5. When we also consider parents' firewood collection and involvement in family businesses, columns (4)-(6) of Table A6 show that if parents spend time for firewood collection the educational outcome of their children is lower, whereas parents' involvement in family businesses does not affect their children education. The estimated ATT effects remain almost the same as those in columns (1)-(3). We complement the analysis with Figure 5, which reports the event study counterpart of the TWFE estimates in columns 4-6 of Table A6. This Figure is similar to Figure 4, but here we control for child and adult labor as well as firewood collection indicators. In the short run, grid electrification appears to benefit more children, resulting

Figure 5: Electrification and child education: event study estimates



Notes: The figure reports event study estimates of electrification on child education, estimated using the JWDID Stata command. All regressions include village and time fixed effects and the following controls: child sex, child age, household size, and a dummy for the house floor being mud, dummies for the household's main source of light, child and adult labor as well as firewood collection indicators. 95% confidence intervals are shown using standard errors clustered at the household level. ATT =0.49 (std. err. 0.11) for Grid/Solar; 0.81(0.23) for Grid, and 0.38 (0.11) for Solar.

in an additional 0.82 years of completed education. However, after 2 years, children in households with off-grid electrification catch up, with an additional 0.91 years of education.

These results show that firewood collection is significantly associated with lower schooling. For children, time and energy dedicated to domestic chores are taken away from attending school and studying; for the adults they are taken away from mentoring and supporting them. For both children and adults, the need of collecting wood fuel also signals that the family has limited resources, which is known to be negatively correlated with the educational outcomes. The fact that, once controlled for firewood collection, the estimated effect of electrification on completed schooling does not decrease suggests that the increase in schooling is mostly due to a direct effect of the access to electricity, rather than to a reshuffling of children's (and parents) time use. That is, it is likely due to the fact of having electricity *per se*, rather than having more time for studying or looking after the children.

6 Conclusion

Can rural electrification help address the challenges of low educational attainment? Evidence on the impact of rural electrification on children's education—and the mechanisms through which it operates—remains limited. Against this backdrop, this paper addresses that question by focusing on Ethiopia, a country that has made significant progress in expanding electrification.

This analysis uses data from the Ethiopian Socioeconomic Survey (ESS), collected between 2011 and 2016 to investigate whether children in households who gained access to electricity during this period had better schooling outcome than those who did not. As a benchmark analysis, we employ a differences-in-differences identification strategy, comparing households that remained not electrified during the period with those that gained access to electricity by 2016. We complement this evidence also using alternative estimators leveraging the natural experiment created by the staggered rollout of electrification across households.

Our empirical findings indicate that rural children from electrified households experience significant improvements in educational attainment: after 2 years from electrification, children in newly electrified households gained up to 10-11 months, depending on the electrification source, of additional schooling than children without access to electricity. In the short run, grid electrification exhibit a larger effect, then there is a catch-up for households with solar panels.

We show that electrification alters children's and adults' time use and labor supply, two channels through which electrification may improve child education. Electrification reduces child labor (in firewood collection and non-farm family businesses); increases women's participation in non-farm family business and reduces firewood collection, and shift men's labor supply from non-farm to farm family business. Electrification, and in particular grid electrification, likely creates the conditions for an increase in household income and reduces the need for child labor (a channel that we could explore in further research). Also, electricity from the power grid might allow children to study in the evening, giving them more time to carry out their duties without having to forgo studying. Together, these changes support greater school attendance and attainment.

The findings underscore the transformative role of rural electrification in promoting intra-household structural changes; advancing gender equality and child well-being. Given the availability of a large amount of electricity in the future because of the GERD project, connection to rural areas, either with grid or off-grids solutions, might lead to a significant increase in educational attainment. In the future, we might try to assess the impact of this increase in electricity production and further explore the channels through which electrification affects education. Another avenue to explore concerns the relationship between electrification and climate change; as collecting wood in drier areas results in additional deforestation, electrification might contribute to climate change mitigation. Also, as desertification due to climate change advances, electrification (and connected services, such as cooling) provides a way to adapt to the effects of climate change. Unfortunately, there are no questions in the ESS that help us address these issues at the moment.

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A Appendix

Table A1: Electrification and child education: robustness checks

	Misreport fixed			Children redefined			Switchers			Weighted switchers		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	
	Grid or Solar	Grid	Solar	Grid or Solar	Grid	Solar	Grid or Solar	Grid	Solar	Grid or Solar	Grid	Solar
Treatment Effect	0.37***	0.48**	0.30***	0.34***	0.54**	0.26**	0.37***	0.47**	0.29**	0.37***	0.46**	0.30***
	(0.10)	(0.21)	0.10	(0.10)	(0.19)	(0.11)	0.11	(0.21)	(0.10)	0.10	(0.18)	0.10
Observations	3,920	3,921	3,964	3,206	3,206	3,246	2,565	950	2,218	2,565	950	2,218
R-squared	0.23	0.23	0.23	0.28	0.28	0.28	0.25	0.23	0.25	0.25	0.27	0.26
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Households	1662	1663	1683	1562	1562	1582	1099	422	935	1099	422	935
Villages	278	278	278	277	277	277	190	81	155	190	81	155

Notes: All models include the following control variables: child sex, child age, household size, a dummy for the house floor being mud, dummies for type of main source of light for the household and village fixed effects. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table A2: Electrification and Education: Heterogeneity by distance to Major Road

	Type of Electrification											
	Grid						Solar					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Distance cut-off	≤10	>10	≤15	>15	≤20	>20	≤10	>10	≤15	>15	≤20	>20
Treatment Effect (TWFE)	0.35**	0.98***	0.35**	1.35***	0.35**	1.61***	0.33**	0.34***	0.23**	0.61***	0.19*	0.91***
	(0.17)	(0.28)	(0.14)	(0.41)	(0.17)	(0.36)	(0.13)	(0.13)	(0.12)	(0.16)	(0.10)	(0.20)
Observations	5,436	6,096	7,200	4,328	8,619	2,915	5,507	6,146	7,278	4,378	8,741	2,929
R-squared	0.49	0.43	0.47	0.44	0.48	0.41	0.49	0.43	0.47	0.44	0.48	0.42
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Group dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Treatment group dummies	No	No	No	No	No	No	No	No	No	No	No	No
Controls × Year dummies	No	No	No	No	No	No	No	No	No	No	No	No
Households	800	893	1041	655	1230	451	811	902	1052	663	1251	454
Villages	146	157	184	117	210	86	145	157	184	117	210	86

Notes: The estimates are obtained using the 'JWDID' Stata command by Rios-Avila et al. (2024). All regressions include village and year fixed effects and the following controls: child sex, child age, household size, and a dummy for housing condition. Treatment group dummies are defined according to the year at which households become electrified. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table A3: Potential mechanisms: firewood collection

	Children			Women			Men		
	Type of Electrification								
	(1) (Grid/Solar)	(2) (Grid)	(3) (Solar)	(4) (Grid/Solar)	(5) (Grid)	(6) (Solar)	(7) (Grid/Solar)	(8) (Grid)	(9) (Solar)
ATT (TWFE)	-0.05***	-0.05	-0.05***	-0.02	0.06	-0.05*	0.04**	-0.00	0.05**
	(0.02)	(0.04)	(0.02)	(0.03)	(0.05)	(0.03)	(0.02)	(0.03)	(0.02)
ATT (Event)	-0.06***	-0.07*	-0.05**	-0.03	0.05	-0.06*	0.04**	-0.00	0.05**
	(0.02)	(0.04)	(0.02)	(0.03)	(0.05)	(0.03)	(0.02)	(0.03)	(0.02)
Observations	11,079	11,298	11,315	5,016	5,022	5,086	4,065	4,074	4,124
R-squared	0.11	0.11	0.11	0.27	0.27	0.27	0.19	0.19	0.19
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Group dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Treatment group dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Controls × Group	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Year	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
PTA holds	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Households	1,648	1,658	1,684	1,653	1,656	1,681	1,355	1,359	1,378
Villages	282	282	282	281	281	282	279	279	280
Mean of Dep Var	0.151	0.149	0.151	0.147	0.243	0.243	0.111	0.0630	0.0630

Notes: The dependent variable is a dummy of firewood collection. The estimates are computed using the 'JWDID' Stata command by Rios-Avila et al. (2024). Controls include sex, age, household size, a dummy for whether the house floor is made of mud, and dummies for the household's main source of light, and village fixed effects. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table A4: Potential mechanisms: labor in non-farm family activities

	Children			Women			Men		
	Type of Electrification								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	(Grid/Solar)	(Grid)	(Solar)	(Grid/Solar)	(Grid)	(Solar)	(Grid/Solar)	(Grid)	(Solar)
ATT (TWFE)	-0.01	-0.07**	0.01	-0.00	-0.07	0.02	0.03	-0.07	0.05**
	(0.01)	(0.03)	(0.01)	(0.02)	(0.05)	(0.02)	(0.02)	(0.05)	(0.02)
ATT (Event)	-0.01	-0.07**	0.02	-0.00	-0.07	0.02	0.02	-0.07	0.05**
	(0.012)	(0.03)	(0.01)	(0.02)	(0.05)	(0.02)	(0.02)	(0.05)	(0.02)
Observations	11,110	11,327	11,341	5,008	5,015	5,081	4,090	4,095	4,151
R-squared	0.15	0.15	0.15	0.26	0.26	0.26	0.24	0.24	0.24
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Group dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Group	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PTA holds	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Households	1,650	1,659	1,685	1,651	1,655	1,680	1,356	1,358	1,380
Villages	281	281	282	282	282	282	279	279	280
Mean of Dep Var	0.0430	0.0430	0.0430	0.149	0.149	0.150	0.112	0.112	0.112

Notes: The dependent variable is a dummy if a household member spent any hours running or helping with any kind of non-agricultural or non-fishing household business, big or small, for his or herself or for the household. The estimates are computed using the 'JWDID' Stata command by Rios-Avila et al. (2024). Controls include sex, age, household size, a dummy for whether the house floor is made of mud, and dummies for the household's main source of light, and village fixed effects. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table A5: Potential mechanisms: labor in farm family activities

	Children			Women			Men		
	Type of Electrification								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	(Grid/Solar)	(Grid)	(Solar)	(Grid/Solar)	(Grid)	(Solar)	(Grid/Solar)	(Grid)	(Solar)
ATT (TWFE)	0.03	-0.01	0.04	0.03	0.10*	0.01	-0.09***	-0.06	-0.10**
	(0.03)	(0.05)	(0.03)	(0.03)	(0.06)	(0.04)	(0.03)	(0.07)	(0.04)
ATT (Event)	0.03	-0.01	0.04	0.03	-0.10	0.00	-0.10**	-0.06	-0.10**
	(0.03)	(0.06)	(0.03)	(0.03)	(0.06)	(0.04)	(0.04)	(0.07)	(0.04)
Observations	11,102	11,320	11,335	5,017	5,024	5,089	4,112	4,117	4,167
R-squared	0.19	0.19	0.19	0.23	0.23	0.23	0.22	0.22	0.22
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Group dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Group	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PTA holds	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Households	1,649	1,658	1,685	1,651	1,655	1,680	1,359	1,361	1,380
Villages	281	281	282	281	281	282	280	280	280
Mean of Dep Var	0.497	0.495	0.495	0.512	0.512	0.511	0.717	0.717	0.718

Notes: The dependent variable is a dummy if a household member spent any hours in agricultural activity (including livestock and fishing) for sale or household use, and 0 otherwise. The estimates are computed using the 'JWDID' Stata command by Rios-Avila et al. (2024). Controls include sex, age, household size, a dummy for whether the house floor is made of mud, and dummies for the household's main source of light, and village fixed effects. Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table A6: Electrification, child labor, Adult labor and child education

	Type of Electrification					
	Grid or Solar	Grid	Solar	Grid or Solar	Grid	Solar
	(1)	(2)	(3)	(4)	(5)	(6)
ATT (TWFE)	0.48***	0.85***	0.35***	0.46***	0.81***	0.34***
	(0.11)	(0.23)	(0.11)	(0.11)	(0.23)	(0.11)
Child Firewood collection (1/0)	-0.11*	-0.11*	-0.13**	-0.09	-0.09	-0.12*
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)
Child Farm labor (1/0)	-0.07	-0.07	-0.08*	-0.09*	-0.09*	-0.10**
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Child Non-farm labor(1/0)	-0.05	-0.05	-0.07	0.03	0.03	0.01
	(0.11)	(0.11)	(0.11)	(0.13)	(0.13)	(0.13)
Women Firewood collection (1/0)				-0.17***	-0.20***	-0.17***
				(0.06)	(0.06)	(0.06)
Women Farm labor (1/0)				0.07	0.07	0.07
				(0.05)	(0.05)	(0.05)
Women Non-farm labor(1/0)				-0.09	-0.09	-0.09
				(0.08)	(0.08)	(0.08)
Men Firewood collection (1/0)				-0.40***	-0.38***	-0.40***
				(0.11)	(0.11)	(0.11)
Men Farm labor (1/0)				0.07	0.05	0.05
				(0.06)	(0.06)	(0.06)
Men Non-farm labor(1/0)				-0.13	-0.14	-0.14
				(0.09)	(0.09)	(0.09)
Observations	8,452	8,530	8,620	8,452	8,530	8,620
R-squared	0.46	0.45	0.45	0.46	0.46	0.46
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Group dummies	Yes	Yes	Yes	Yes	Yes	Yes
Controls × Group	No	No	No	No	No	No
Controls × Year	No	No	No	No	No	No
Parallel trends Assumption (PTA) holds	Yes	Yes	Yes	Yes	Yes	Yes
Households	1,332	1,342	1,360	1,332	1,342	1,360
Villages	279	279	280	279	279	280

Notes: Standard errors (in parentheses) are clustered at the household level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.