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Original Article

The Impact of Energy Accessibility on Student Behaviors in Rural Tanzania*

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Abstract

Access to modern energy is pivotal in addressing energy poverty and enhancing education in sub-Saharan Africa. This study examines the impact

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of the Solar Cow project in Tanzania on students' time use. Our findings indicate that Solar Cow adoption influences student behavior, particularly in terms of time allocation. While students benefit positively from Solar Cow use, such as increased access to solar lanterns, its adoption is correlated with increased household chores and reduced study hours. This unintended outcome suggests a potential shift where a selective group of students may prioritize chores during the day and utilize solar lanterns for studying or personal time at night.

Key words: Energy Poverty, Accessibility, Solar Power, Education, Behavioral Change

Ⅰ. INTRODUCTION

Energy poverty remains a persistent and significant challenge in rural Africa, despite concerted global efforts as outlined in the United Nations Sustainable Development Goals (SDGs) to enhance energy accessibility worldwide. The International Energy Agency (IEA) reports that over 40 percent of Africa's population lacks access to electricity and 70 percent are without clean cooking fuels (IEA, 2023). The 2023 Global Sustainable Development Report underscores the urgent need for increased investment in energy infrastructure, highlighting how such deficiencies hinder essential services including education and health.

Investing in human capital, particularly through education, is crucial for development and economic growth. As Sen (1993) emphasized, enhancing individual skills and improving educational systems are pivotal for national development. This is further supported by the SDGs, especially the fourth goal, which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Despite the universal recognition of the importance of primary and secondary education, developing regions face numerous challenges in establishing equitable and high-quality education systems due to various constraints. In response, several development cooperation projects have been launched to mitigate these barriers and enhance educational opportunities.

In this context, the Solar Cow Project emerges as an innovative response, designed to tackle energy accessibility while simultaneously enhancing educational opportunities for children in underserved regions. Originally funded by KOICA, and now supported by a combination of private investments and crowdfunding efforts, the project employs a novel approach by installing solar panels at schools. These panels power devices known as Solar Milk lanterns—portable lanterns that serve multiple functions including lighting, phone charging, and as media players for educational content. Capable of charging up to 250 lanterns simultaneously, each Solar Cow installation can produce between 600–1,000 Wh of electricity per hour. This capability not only facilitates night-time study but also provides households with essential utilities, thereby enriching both home and educational environments. The project exemplifies practical implementation of SDG 7 (affordable and clean energy) and SDG 4 (quality education), demonstrating a scalable model for integrated community development.

Our research aims to investigate how the Solar Cow Project impacts student behavior in rural Tanzania, focusing particularly on time-use changes. Employing a quasi-experimental design, the study examines variations in how students use their time at home, particularly whether the availability of Solar Milk influences their educational activities. By using a school-level off-grid project as an intervention tool, this study aims to assess the impact of energy access on the education-related behavioral changes of students, which may provide more direct and reliable insights compared to household-level electrification.

A robust body of academic literature has examined the multifaceted impacts of energy access on educational outcomes, highlighting both the direct and indirect benefits of electrification. Studies by González-Eguino (2015), Riva et al. (2018), and Banerjee et al. (2021) have consistently shown that access to electricity significantly enhances health and educational opportunities by providing necessary lighting for nighttime study and reducing time spent on non-educational tasks such as gathering firewood. Furthermore, research by Oktaviani and Hartono (2022) indicates that reliable electricity improves students' access to educational media, thereby extending learning opportunities beyond the traditional classroom setting. These studies suggest that electrification contributes to a more conducive learning environment, which can lead to improved academic performance and retention rates.

Moreover, Khandker et al. (2014) and Sovacool et al. (2013) have demonstrated that rural electrification is positively correlated with increased school enrollment and reduced dropout rates, emphasizing the role of energy access in promoting consistent educational engagement. Acheampong et al. (2021) extend this discussion by illustrating how increased energy accessibility not only influences educational outcomes but also catalyzes broader human development through improved economic opportunities, gender empowerment, and urbanization. However, these studies also highlight the disparities in energy access and their consequent impact on educational inequalities, underscoring the need for targeted interventions that address both energy poverty and educational disparities in a synergistic manner. This literature forms the foundational backdrop to our study, informing our understanding of the potential impacts of the Solar Cow project on student behavior and educational attainment in Tanzania.

Our study analyzes the impact of the Solar Cow program on student in Tanzania, emphasizing behavioral changes rather than traditional metrics like attendance and test scores. The program provides cost-effective tools such as flashlights, radios, and MP3 players, along with SD cards containing recorded lessons, which enhance learning resources and allow students to review material independently. By focusing on how these tools influence daily time-use and behavioral modifications, we aim to identify key mechanisms—particularly changes in learning behaviors—through which access to energy sources can improve educational outcomes. This research seeks to clarify how these behavioral changes serve as the primary conduit for educational success, exploring the broader impact of enhanced energy access on educational opportunities.

The remainder of this paper is structured as follows: Chapter 2 provides an overview of the background and data. Chapter 3 discuss the study design and discusses the empirical results. Chapter 4 offers the conclusion.

Ⅱ. BACKGROUND AND DATA

1. Background

The Solar Cow Project is an innovative initiative that provides and installs solar panel charging systems equipped with a portable lantern that also functions as a radio and MP3 player. In schools where a Solar Cow panel is installed, students can bring a device known as Solar Milk—the lantern—to charge during class time and take home afterward. Originally funded by KOICA's CTS program, the project now also receives support from private companies and crowdfunding efforts. YOLK, the company behind Solar Cow, states that the project's aim is to provide sustainable energy to households while simultaneously enhancing children's educational opportunities.[1)]

The Solar Milk lantern offers multiple functionalities: it can recharge via solar power, serve as a phone charger, and features built-in radio and MP3 capabilities, the latter allowing users to play educational content from SD cards, typically recorded class materials. When a Solar Cow is installed at a school, it can charge up to 250 Solar Milk lanterns simultaneously, generating 600–1,000 Wh of

1) For photos and further details about the Solar Cow Program, please visit YOLK's website: http://yolkstation.com

electricity per hour. A fully charged Solar Milk can power a 2G phone three to four times, run a radio for one to two sessions, provide up to 10 hours of soft light, or four hours of intense light.

The project has seen installations across various locations in Tanzania, Kenya, and DR Congo. In Tanzania, Solar Cows were installed in Arusha, funded by KOICA's CTS program and in collaboration with the Ministry of Education in Zanzibar. The installation of the Solar Cow at Mfenesini School was a decision made by YOLK. Located in Unguja district, approximately 15 km from Stonetown—the center of Zanzibar—Mfenesini School serves 942 students and employs 37 teachers as of 2022. YOLK selected this school for the Solar Cow project because the area has a relatively low percentage of household electricity coverage and lower income levels. In Mfenesini, the Solar Cow project operates on a subscription and fee basis. Users can rent the Solar Milk monthly with the option to renew each month. The fee is set at 3,000 Tanzanian Shillings (TZS) per month, which is approximately 1.29 USD (1 TZS=0.0043 USD as of August 1, 2022). The rental program began on August 1, 2022.

2. Survey and Data

To assess the impact of the Solar Cow, we selected two control schools within the same school district that have a similar number of students and comparable results in national exams. Fujoni and Mwenge Secondary Schools were chosen due to their similarities in district location, student grade and gender composition, and national exam performance.

We conducted a baseline survey in July 2022, before the initiation of the Solar Cow program. Subsequent surveys included a midline survey between December 2022 and January 2023, and an endline survey in July–August 2023. The baseline and midline surveys encompassed all students from grades 1 through 4, as well as the parents of 3rd and 4th graders, while the final survey only includes students. These surveys collected data on basic household background, energy usage including electricity, school and daily life, and time use to observe changes resulting from the lantern use. For the parents' survey, we gathered basic information on income, household details, energy use, decision-making processes, and usage of light and radio. Additionally, for the treatment school, questions about the willingness to pay for the program subscription were included.

In this paper, we analyze data from students who participated in both the baseline and endline surveys. Due to the one-year interval between these surveys, many 4th graders from the initial sample were not present in the merged dataset. 〈Table 1〉 displays the total number of students who completed the survey at each school, categorized by their grade level at the time of the baseline survey. Only 5 of 4^{th}-grade students were followed up, highlighting the difficulty in tracking graduated students. However, many students from grade 1 to 3 responded to the endline survey, totaling 890 students in the sample. As noted in 〈Table 1〉, the retention rate for grades 1 to 3 in three schools is above 80%, except for Grade 2 at Mwenge School.

〈Table 2〉 presents the summary statistics for the analysis sample, showing minimal differences between the treated and control groups. The treated group consists of students from Mfenisini School, while the control group includes students from both Fujoni and Mwenge Schools. Both groups have a slightly higher proportion of female students than male students, with an average household size of seven members and 2–3 siblings per family. Although the t-test indicates differences between the treated and control groups for some family composition statistics, these differences are minimal. Additionally, both groups have similar characteristics regarding household assets related to energy use.

〈Table 3〉 details the daily time use patterns for the treatment and control groups, showing slight variations in how students manage their time. Students from the Mfenisini School (treatment group) report spending a bit more time studying outside of school hours, with an average of 2.99 hours, compared to 2.15 hours for

〈Table 1〉 Distribution of students by grade

Grade level	Mfenisini school		Fujoni school		Mwenge school	
	Student number	Retention rate (%)	Student number	Retention rate (%)	Student number	Retention rate (%)
Form 1	100 (119)	84.03	62 (69)	89.86	30 (36)	83.33
Form 2	240 (296)	81.08	117 (145)	80.69	73 (129)	56.59
Form 3	132 (164)	80.49	93 (112)	83.04	38 (43)	88.37
Form 4	1 (280)	0.36	4 (96)	4.17	0 (108)	0.00
Obs.	473	·	276	·	141	·

〈Table 2〉 Summary statistics

	Treat	Control	Difference	T-test
Gender (female=1)	0.61	0.6	-0.01	-0.32
	(0.49)	(0.49)		
No. of family members	7.1	6.9	-0.19**	-2.21**
	(1.30)	(1.30)		
No. of siblings	2.45	2.26	-0.19***	-2.73***
	(1.03)	(1.06)		
No. of siblings in same school	0.22	0.19	-0.03	-1.21
	(0.41)	(0.39)		
Female household head	0.08	0.13	0.04**	2.19**
	(0.28)	(0.33)		
Radio	0.69	0.68	-0.01	-0.27
	(0.46)	(0.47)		
Light	0.83	0.82	-0.01	-0.42
	(0.38)	(0.38)		
Battery Lantern	0.22	0.21	-0.01	-0.49
	(0.41)	(0.41)		
N	473	417		

Note: The treated group consists of students from Mfenisini School, while the control group includes students from both Fujoni and Mwenge Schools. Standard deviation in the brackets. T-tests for mean differences in two variables were conducted.
*p〈0.1, **p〈0.05, ***p〈0.01.

〈Table 3〉 Daily time use pattern (unit: hours)

Activity	Treatment group		Control group	
	Mean	Std. dev.	Mean	Std. Dev.
Study excluding school hours	2.99	2.17	2.15	1.75
Stay at school	6.44	2.95	4.85	3.52
Indoor chores	1.84	1.88	2.53	2.42
Outdoor chores	0.37	0.83	0.74	1.38
Paid work	0.03	0.33	0.01	0.23
Farming	0.03	0.39	0.02	0.24
Family care	0.05	0.29	0.04	0.23
Rest	10.80	2.56	12.23	3.01
Community activity	1.43	1.81	1.41	1.96
Obs.	473		417	

Note: The treated group consists of students from Mfenisini School, while the control group includes students from both Fujoni and Mwenge Schools.

students from Fujoni and Mwenge Schools (control group). Similarly, schooling hours are slightly higher in the treatment group, averaging 6.44 hours, against 4.85 hours in the control group. The control group slightly engages more in indoor chores, averaging 2.53 hours, while the treatment group averages 1.84 hours. The trend is similar for outdoor chores, with the control group reporting an average of 0.74 hours compared to 0.37 hours in the treatment group. The differences in time spent working, farming, and caring for family are relatively minimal.

III. EMPIRICAL STRATEGY & RESULT

1. Empirical Specification

In this paper, we analyze the behavioral changes of the students who benefited from the introduction of the Solar Cowprogram. Since the adoption of this additional green energy source/new learning material may be highly selective depending on students' background,[2] our main analyses in this study utilizes variation of explanatory variable in Intention-To-Treat (ITT) framework. This meanswe compare the average behavioral changes of students at the school level regardless of their individual decision on participating in the program. By observing students' behavior just before the program and a year later, we analyze the impact of the program on the school by estimating a Difference-in-Differences (DiD) regression as follows:

$$Y_{ist} = \beta_0 + \beta_1 treat_{is} + \beta_2 post_t + \beta_3 treat_{is} \times post_t + X'\beta + \varepsilon_{ist} \quad (1)$$

Subscript i denotes individual student, s for school, t for time. Y_{ist} is the students' time-use variables of our interest, which captures the behavioral change in students' daily life. $treat_{is}$ is an indicator variable that takes a value of 1 if a student i is enrolled in our treated school, and 0 if is in control schools. $post_t$ is

2) The discussion on the potential selection of this program is exhaustively discussed in other report by the authors. Please read: Kang et. al. (2023) "Research on Green Energy Cooperation with East Africa" and Woo et. al. (2023) "Energy transition and international development cooperation in response to climate chante in the Africa region".

a time indicator variable where a value of 1 denotes the end-line observation. X is a vector of control variables, including the current grade (represented as indicator variables for each grade) and the number of books at home (represented as a continuous variable). The latter serve as a potentially powerful proxy for home environment and parental attitudes towards children's education. We further look into differential impact of the program, depending on students' gender. The variable $gender_{is}$ in ⟨Eq. 2⟩ takes the value of 1 for girls, 0 for boys.

$$
\begin{aligned}
Y_{ist} = \beta_0 &+ \beta_1 treat_{is} + \beta_2 post_t + \beta_3 gender_{is} + \beta_4 treat_{is} \times post_t \\
&+ \beta_5 treat_{is} \times gender_{is} + \beta_6 post_t \times gender_{is} + \beta_7 treat_{is} \times post_t \\
&\times gender_{is} + X'\beta + \varepsilon_{ist}
\end{aligned}
\tag{2}
$$

2. Result

In this section, we present analysis results that highlight the individual level impact of the Solar Cow project, focusing specially on changes in the daily time use of students, as discussed in the previous section.

The main analysis results corresponding to ⟨Eq. 1⟩ is presented in column (1) to (3) of ⟨Table 4⟩. Given that Solar-milk functions as a new energy source and study aid, potentially allowing students to study for longer periods, one might expect to see an immediate behavior change, such as increase in total study hours. However, the results show that students with access to Solar Cow studied less, by approximately 1.6 hours, and spent more time on house chores, about 1hour indoors and 0.5 hour outdoors.

Column (4) to (6) analyzes the differential impact on daily time-use by gender, which corresponds to ⟨Eq. 2⟩. The results reconfirm the former results. On average, treated students study less and engage more in household chores. Gender differences are evident: girls perform more indoor chores and fewer outdoor chores compared to boys, who do more outdoor chores than indoor. This pattern confirms that the observed decrease in study hours and increase in household chores are not merely statistical anomalies but likely represent actual behavioral changes resulting from the Solar Cow project.

One possible explanation for this result is a change in the quality of study. Anecdotal evidence suggests that students may gather with classmates before or

〈Table 4〉 Change in time use within 24 hours

Variables	(1) Study (24 hrs)	(2) Chores indoor (24 hrs)	(3) Chores outdoor (24 hrs)	(4) Study (24 hrs)	(5) Chores indoor (24 hrs)	(6) Chores outdoor (24 hrs)
Treat	1.511***	−1.265***	−0.616***	1.511***	−0.505**	−0.955***
	(0.151)	(0.178)	(0.088)	(0.233)	(0.242)	(0.165)
Post	0.464***	−1.721***	−0.686***	0.522***	−1.045***	−0.841***
	(0.129)	(0.162)	(0.096)	(0.199)	(0.213)	(0.186)
Treat×post	−1.627***	1.016***	0.495***	−1.601***	0.449*	0.698***
	(0.181)	(0.193)	(0.106)	(0.297)	(0.271)	(0.213)
Gender				0.164	2.366***	−0.764***
				(0.184)	(0.249)	(0.166)
Treat×gender				−0.003	−1.288***	0.574***
				(0.299)	(0.309)	(0.187)
Post×gender				−0.103	−1.207***	0.285
				(0.248)	(0.280)	(0.207)
Treat×post×gender				−0.039	0.949***	−0.336
				(0.376)	(0.364)	(0.237)
Constant	1.715***	3.427***	0.960***	1.608***	1.882***	1.461***
	(0.158)	(0.223)	(0.112)	(0.200)	(0.228)	(0.173)
Sample	All	All	All	All	All	All
Observations	1,780	1,780	1,780	1,780	1,780	1,780
R-squared	0.098	0.143	0.068	0.099	0.249	0.108

Note: Current grade and number of books are controlled. Robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01.

after class to listen to and study from recorded lectures using Solar Milk. These group study sessions typically occur at school, meaning effective study hours might actually be counted as school hours. Data also show that the second most common place for students to study is at school or a friend's house. Additionally, if Solar Milk has improved the quality of self-study, the quantitative decrease in time spent studying could be offset by more efficient and effective study methods, potentially leading to an overall increase in effective learning. This is further confirmed by anecdotal evidence that students are actively using the recorded class material with Solar Milk.

A more pessimistic interpretation might be that the program discouraged studying. For instance, if parents or students view the additional energy and the lantern solely as an opportunity for students to work after sunset, such household decisions may contradict the program's initial intention. In such cases, longer chore hours for students could be seen as the optimal use of additional energy. Alternatively, this situation might result from a misallocation of time; parents or students might perceive Solar Milk as an additional opportunity to study after sunset. This perception could lead to crowding out daytime study hours in favor of spending more time on household chores, with the belief that they can compensate for lost study time during the day by studying later in the evening. However, parents and students might later realize that studying after sunset is not as effective, and consequently, students do not fully recover the lost daytime study hours. In such cases, the reduction in studying hours represents a suboptimal decision, possibly due to limitations in fully adapting to the new technology. Empirically, if the last explanation holds true, we would expect to observe changes in evening time use; students might study more after sunset, but not enough to fully compensate for reduced daytime studying. Our initial focus is on whether such behavioral changes are indeed observed.

〈Table 5〉 shows the results for students who did not study in the evening, between 7 PM and midnight, before the introduction of Solar Cow. Columns (1) to (3) analyze whether these students began studying, increased their household chores, or allocated more time to rest. The findings indicate that these students did not significantly engage more in any new activities post-introduction, though there was a slight tendency among some students to reduce their household chores.

Further analysis on a narrower subset, students who shifted from not studying to studying in the evenings, explores whether Solar Cow led to extended study hours among students at the treated school. The results, shown in Column (4), do not demonstrate a significant increase in study intensity. However, treated school students did spend significantly less time on household chores in the evening (Column (5)). However, such reduction in chores is not fully translated into increase in studying hours.

Lastly, we examine the behavioral changes focusing on the change in study hours among students who already studied in the evenings at baseline. Columns (1)

〈Table 5〉 Change in time use within 5 hours in the evening (19:00–24:00)

Variables	(1) Any study (indicator) (evening)	(2) Any chores (indicator) (evening)	(3) Any rest (indicator) (evening)	(4) Study time (continuous) (evening)	(5) Chores time (continuous) (evening)	(6) Rest time (continuous) (evening)
Treat	-0.022^{**}	0.201^{***}	−0.006	−0.031	0.337^{**}	0.081
	(0.011)	(0.074)	(0.019)	(0.021)	(0.145)	(0.187)
Post	0.826^{***}	-0.105^{**}	−0.006	2.293^{***}	-0.175^{*}	-1.550^{***}
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Treat×post	−0.081	-0.202^{**}	−0.001	−0.070	-0.410^{**}	0.096
	(0.005)	(0.010)	(0.004)	(0.013)	(0.018)	(0.027)
Constant	-0.029^{*}	0.270^{***}	0.928^{***}	-0.062^{*}	0.341^{***}	3.867^{***}
	(0.015)	(0.072)	(0.043)	(0.033)	(0.110)	(0.268)
Sample	Did not study in the evening at baseline			Did not study in the evening at baseline but studied in the evening at endline		
Observations	446	446	446	346	346	346
R-squared	0.641	0.083	0.040	0.835	0.085	0.335

Note: Outcome variables for columns 1-3 are indicator variables, while columns 4-6 are continuous variables measured in hours. Current grade and number of books are controlled. Robust standard errors are in parentheses.
$^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

to (3) of 〈Table 6〉 presents the DiD result for students who studied in the evening even before the introduction of Solar Cow. While coefficient estimates largely insignificant, the trends suggest that this selective subgroup tended to study slightly more after exposure to Solar Cow and work less. Columns (4) to (6) reconfirm this observation from previous analyses without control schools. We find that these selective group, likely characterized by high academic aspirations and a favorable background, may experience differential impacts from the introduction of the new technology.

The two sets of subsequent analyses demonstrate the multifaceted nature of Solar Cow project, revealing both differential impacts and potential unintended consequences of the intervention. Although a detailed dissection of all suggested mechanisms is beyond this paper's scope, the findings imply that Solar Cow may selectively benefit students with higher academic aspirations, while its impact may be more limited for those with lower aspirations or less advantageous circumstances.

〈Table 6〉 Change in time use within 5 hours in the evening (19:00–24:00)

Variables	(1) Study time (continuous) (evening)	(2) Chores time (continuous) (evening)	(3) Rest time (continuous) (evening)	(4) Study time (continuous) (evening)	(5) Chores time (continuous) (evening)	(6) Rest time (continuous) (evening)
Treat	−0.125*	0.089**	0.056			
	(0.074)	(0.039)	(0.083)			
Post	−0.012	−0.000	0.030	0.070	−0.068*	−0.081
	(0.084)	(0.036)	(0.094)	(0.084)	(0.041)	(0.092)
Treat×post	0.126	−0.047	−0.165			
	(0.104)	(0.049)	(0.116)			
Constant	1.884***	0.139***	2.869***	1.697***	0.242***	2.962***
	(0.079)	(0.043)	(0.091)	(0.101)	(0.066)	(0.125)
Sample	Studied in the evening at baseline			Studied in the evening at baseline (Treated school only)		
Observations	1,108	1,108	1,108	666	666	666
R-squared	0.041	0.008	0.034	0.056	0.007	0.045

Note: Outcome variables for columns 1–3 are indicator variables, while columns 4–6 are continuous variables measured in hours. Current grade and number of books are controlled. Robust standard errors are in parentheses.
*p<0.1, **p<0.05, ***p<0.01.

IV. CONCLUSION

This study finds that while the Solar Cow project in Tanzania does not dramatically change students' time allocation for studying, it does lead to an increase in household chores performed by boys and girls during the daytime. These results do not suggest adverse effects from the supplementary tools provided by the project. Instead, they hint at the possibility that students might enhance the quality of their education using MP3 and voice recording tools. Such tools may encourage students to complete their studies more efficiently, thereby allowing more personal time or enabling group study sessions to listen to recorded class materials together. Indeed, testimonies from students at Mfenesini School underscore the effectiveness of the Solar Cow project, revealing how collaborative use of these tools may improve study quality, an aspect our study did not fully capture. Considering these findings, future research should explore both the quality of study and time allocation. This underscores the importance of pedagogical interventions by organizations like YOLK in enhancing educational outcomes through innovative energy solutions.

Our results also highlight the broader implications of energy cooperation in developing countries. In 2024, the Korean government dedicated 5.9% of its total Official Development Assistance (ODA), amounting to approximately $4.59 billion USD, to the energy sector. However, this assistance largely focuses on infrastructure. Our findings suggest a need for an integrated approach that considers both energy access and interdisciplinary sectors like education to achieve SDGs. Specifically, enhancing educational pedagogy through improved energy accessibility could significantly raise the quality of education. Additionally, the effectiveness of such projects also hinges on parental education and cooperation, pointing to the need for holistic educational strategies that encompass both student and parental involvement.

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