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Electricity Access Linkages to Sustainable Development Goals in Rural Sudan

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Abstract: This paper investigates the impact of a lack of electricity services on social and economic development in the context of patriarchal, rural Sudan. Quantitative data were gathered from key informant interviews in four rural villages across three different states (n = 240). Not having access to electricity adversely affects four main variables: (i) health, (ii) education, (iii) gender equality, and (iv) income generation. A multiple logistic regression model assessed school attendance of all boys or girls in a household as a function of declared household income, survey respondent education level, number of children, number of hours per day of household chores, and hours per day of biomass collection (a task that girls usually undertake). Boys are observed to be more likely to attend school than girls regardless of household income; their attendance likelihood increases with the number of children in the household (which we attribute to the greater likelihood of girls being in a household to undertake tasks). Increased biomass collection time is seen to increase the likelihood of boys' attendance to school as this is typically seen as a female task. Girls are primarily required to undertake chores which reduces school attendance. Girls' attendance also appears dependent on a higher household income (Odds Ratio 1.24, *p* value 0.052). The likelihood of attendance at school for each additional hour of required household chores was reduced by 22% for boys and 10% for girls. In relation to accessing health services, (traditional vs. modern), we observed no influence of household income suggesting social norms play a strong role here.

Keywords: electricity access; Sudan; household energy surveys; sustainable development goals; gender equality; multivariate regression analysis

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1. Introduction

According to the 2021 UN Human Development Report, Sudan ranks 171st amongst the 191 countries in terms of the Human Development Index (HDI) [1]. This poor performance across the socio-economic development parameters is partly attributed to electricity access levels in the Sudan [2]. Sudan's electrification rate in 2022 was 63.2% of the population, in terms of having access to electricity services, with access in urban centers at 84% compared with 49% in rural areas [3]. The latter is a small share, given that the rural population of Sudan represents 64% of the total population of 48.1 million [4].

1.1. Electricity System in Sudan

The 2019 World Bank report into Sudan's electricity sector stated that the country's electrical system was operating efficiently from a technical standpoint compared to other countries in the region. System losses were viewed as relatively low and bill collection was

almost universal. The cost of providing this service was estimated to be USD 0.20 per kWh, close to the regional average. The major challenge for electricity provision in Sudan was viewed as a financial sustainability one where, in 2017, the average electricity end-user tariff was USD 0.015 per kWh (see page 45 [2]). This low tariff has exacerbated demand growth and required the Government of Sudan to spend ~13.5% of its budget on fuel subsidies, a value which is likely to rise dramatically in the future [2]. The main reason for not extending the national grid to Sudanese rural communities is attributed to infrastructural challenges of connecting the sparsely populated rural areas, where the population density for the entire country is only 24 people per km^2. In comparison, Ethiopia has a population density of 102, Kenya 94, and Uganda 228 people per km^2. In addition to low population density, the low price of electricity and a below-cost connection charge of SDG 4500 (Sudanese Pound) for households (USD ~7) further weakens the economics of Sudan's electricity system [2]. Nationally, household expenditure is SDG 7000 per month (see page 44 [2]). Since April 2023, Sudan has been subject to a civil war which has clearly stalled development and investment.

1.2. Energy Access and Development in a sub-Saharan Africa Context

Tiba and Omri reviewed the relationships between energy, environment, and economic growth between 1978 and 2014 in numerous contexts. Causal linkages amongst energy use variables, environment, and economics were presented. The study highlighted the importance of dealing with this dynamic relationship when setting strategies across this three-way linkage [5]. Stern et al. assessed the impact of electricity on economic development, specifically in a sub-Saharan Africa context. They showed that electricity use and access are strongly correlated with economic development and recommended that future studies should assess the impact of the reliability of energy access on development [6]. In a South African context, Ateba et al. assessed the significance of electricity supply sustainability to industrial growth. The study highlighted the importance of prioritizing electricity supply sustainability to industries to ensure industrial growth [7]. Trotter et al. undertook a systematic review of electricity planning and implementation in a sub-Saharan Africa context. They found that frequently mentioned success factors for electrification in sub-Saharan Africa included adequate policy design, sufficient finance, and favorable political conditions [8]. The 2023 UN report "Commodities at a Glance" focused on access to energy in a sub-Saharan Africa context. It highlighted the vast resources of solar, wind, hydro, geothermal, and biomass available alongside the challenges of exploiting these [9]. Rao and Pachauri showed, in their 2017 paper, that in a sub-Saharan Africa context, countries would have to undergo unprecedented rates to improvement to achieve their SDGs (Sustainable Development Goals) in relation to energy [10].

1.3. Energy Access and Its Linkage to Sustainable Development Goals (SDGs) in Rural Sudan

Rural communities in Sudan live under challenging conditions and are constrained by a lack of quality public services and modern economic activities, perhaps most notably access to electricity. Provision of energy access directly maps to UN Sustainable Development Goal 7, namely, affordable, reliable, sustainable, and modern energy for all. In addition, in the context of the deeply embedded patriarchal society of rural Sudan, energy access can potentially play a significant role in addressing Sustainable Development Goal 5, Gender Equality. Muneer and Mohammed assessed the adoption of biomass-improved cookstoves in Khartoum State, Sudan. They showed that the educational level of the housewife has a significant positive effect on a households' innovativeness regarding the use of an improved cookstove. However, a wife's age and the educational level of the husband has significant negative effects, reflecting the division of labor, gender relations, and decision making

processes in Sudanese households [11]. This paper states "unexpectedly, the household's monthly income has significant negative effect on its innovativeness regarding adoption of the improved cookstove". It is suggested that the negative effect of the husband's education level and the family's monthly income may be associated with a household's socioeconomic status and ability to use sources of energy even when prices are high and biomass is scarce.

There have been several studies focusing solely on the context of Sudan and energy for development. Ghandour's 2016 paper explored the challenges faced by Sudan in relation to electrical power. Of note is the decision to increase the country's electricity tariffs by 100% (from a very low base), with the then government minister highlighting that current tariffs covered only 20% of costs, which was clearly not sustainable [12].

The interlinkages between SDGs were assessed by McCollum et al.; they found that the positive interactions between the SDGs outweighed the negatives in terms of both number and magnitude. In addition, the authors viewed energy as the logical place in which to start on a development path, given how "deeply woven it is into the fabric of the Sustainable Development Goals" [13]. Cabraal et al. assessed productive use of energy in the context of providing modern energy services. They highlighted that narrow, traditional definitions of productive use (notably GDP per capita) need to be updated to encompass education, health, and gender equality [14], which we explore in this paper. Bahaj and James discuss the intricacies and interdependences of energy access in the context of mini-grids in Kenya and Uganda, highlighting the fine line that exists between energy affordability and economic growth in particular [15]. Similarly, Hartvigsson et al. linked household and productive use of electricity in mini-grid sizing and operation in a Tanzania context. They found that while productive use customers only represent 25% of the customer base, they account for 44% of the operator's income and so are therefore key to the economic sustainability of a mini-grid [16].

The Food and Agriculture Organization of the United Nations provide a detailed analysis of the Republic of Sudan in terms of gender and agriculture and the rural sector [17]. This report highlights that 'inconsistency of available sex-disaggregated data and poor understanding of gender analysis pose a serious challenge to addressing gender issues in agriculture' (Page 20). Women's excessive workload is summarized as being a result of being a double, and sometimes, triple-level role of production, reproduction, and community. This makes their workload such that they are unable to participate in activities that promote their development as individuals and as farmers.

The UNDP 2020 report "Empowering Sudan: Renewable Energy Addressing Poverty & Development" highlights the strong linkage between energy, poverty, and gender in a Sudanese context [18]. It notes that "the lack of modern energy provision exerts economic impacts on societies which are different for rural women than those experienced by men. The opportunity cost of firewood collection and water gathering activities frequently prevents women from effectively undertaking income-generating activities, which reduces the potential to provide poor rural households with much needed income". The incidence of poverty in Sudan is seen to correlate strongly with education levels. Poverty rates are highest for those living in households whose head has no formal education. Individuals who attain a higher level of education are significantly less likely to be living in acute poverty, suggesting that education is an essential dimension to reduce poverty. Women in Sudan are also seen to face restrictions in terms of their mobility, which limits their access to markets and services including education, training, and health as well as opportunities for social interaction within their neighborhoods [19]. Omer highlights the use of renewable energy sources for electricity generation in Sudan in their 2007 paper [20]. Of note is the observation that use of 'free' firewood for cooking is seen as a preferred approach, which will continue the gender imbalance which is ingrained in these societies.

The study reported here provides insight in a rural Sudanese context providing detailed, gender-based survey data for the activities undertaken in rural villages. Here, we quantify the far-reaching impacts of poor energy provision in these villages. The stated gender imbalances that are highlighted in the numerous reports are formally assessed here, providing a quantified assessment of how gender, education, health, and energy are interlinked in these rural Sudanese communities. This study addresses this gap by exploring how community members perceive the daily challenges that result from the lack of electricity across four study sites: Taebeen, Al Hashieb 2, Wiheishat, and Helbeh extension; the locations of these are shown in Figure 1. Here, we try to assess how energy access provision could help unlock the barriers to delivering SDGs 5 and 7 in a rural Sudanese context.

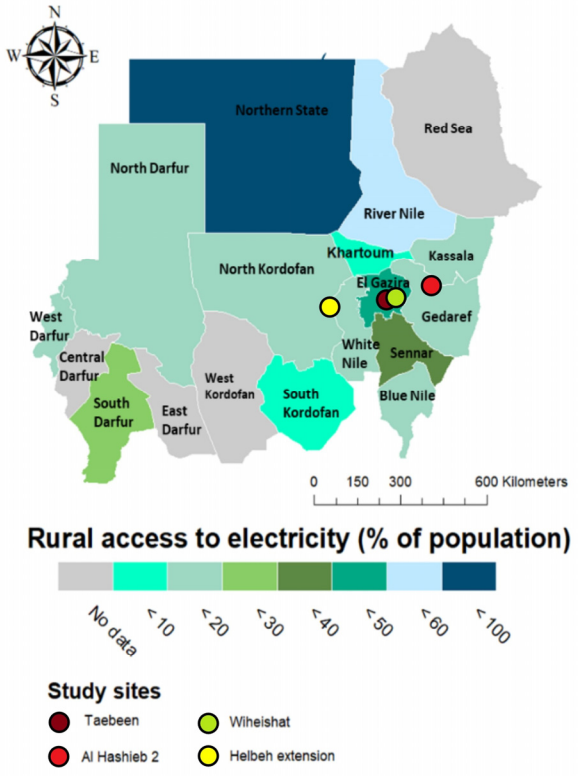

Figure 1. Sudanese states showing rural electrification rates and data collection sites. Taebeen, Al Hashieb 2, Wiheishat, and Helbeh extension are highlighted.

Electricity is fundamental in providing services that support human development as it allows for better health services in medical facilities and well-equipped classrooms, thus achieving higher literacy rates. It also participates in women empowerment and reduces the gender gap since women will have more opportunities to participate in unremunerated activities. It also has a substantial role in economic development, since it improves productivity, economic growth, employment, and reduces rural–urban migration.

In the health field, energy access facilitates the work of rural medical staff and improves ambulance services and nursing care [21,22]. According to a case study in the southern Philippines, electricity access enhanced emergency services and night deliveries [23]. In a Kenyan context, the provision of a rural mini-grid was seen to enhance health provision. A health care worker in the Kitonyoni dispensary in Kenya stated "Nowadays I am able to work at night if any patient comes to the dispensary, it is easy. Before this, if I am carrying out a delivery at night, there would be no-one to help me hold the torch or lantern" [24].

In terms of education, electricity access has been associated with higher youth literacy rates [25]. A case study in Assam state, India, recorded a higher literacy rate and a further

possible increase from 63.3% to 74.4% was assumed due to improved electricity access. Moreover, light via solar technology improved the performance of 12,500 secondary school students in north Tanzania between 2014 and 2016 [26,27]. The percentage of students who passed the academic years between the age of 13+–16+ increased from 5.9% to 10% due to the provision of light in schools and at home. Kelly et al. assessed access to electricity and its impact on primary education outcomes across nine countries in Central Africa. They showed that between 1997 and 2019, electricity contributed both positively and significantly to primary educational attainment in the region [28].

Moreover, energy access positively contributed to gender equality and women empowerment in rural Tanzania by supplying them with solar lanterns and appliances, which created over 700 new job opportunities for women [29]. With regard to employment, a study in South Africa concluded a positive correlation between electricity provision and rates of employment [30]. Concerning income generation, the impact was highlighted by a study in rural Kenya, where a rural electrification project increased income levels by 20–70% depending on the product made [31].

The rationale, therefore, is that energy access has a multi-faceted impact on rural communities, across gender, health, poverty, etc., mapping 12 of the 17 UN Sustainable Development Goals (SDGs) [32]. Figure 2 shows the multi-faceted pathways of energy provision and the anticipated impact on rural communities in a sub-Saharan Africa context. This paper seeks to provide additional insight into these pathways and impacts through an assessment of four case study settlements in rural Sudan.

Figure 2. Multi-faceted pathways of energy provision and their anticipated impact on rural communities in a sub-Saharan Africa context and linkage to Sustainable Development Goals (SDGs) [32].

2. Materials and Methods

In choosing the sites for data collection, the consensus-based Nominal Group Technique was applied through the participation of five experienced energy specialists in Sudan. It is a decision making process that produces fast results and has a low-cost advantage [33]. The sites were chosen from a suitability map that was designed using ArcGIS (ArcGIS 10.8.1) and considered eight specific criteria, which were equally weighted including the following: distance to the national grid, population, accessibility, political stability, natural hazards, service sector, willingness to pay, and security. The authors aimed to select villages based on similar criteria, such as proximity to the national grid and a population size of 500, amongst other criteria. However, they also prioritized diversity to ensure the sample was representative of the country as a whole. Experts selected villages with varying economic activities—those relying on different sources of income and located in different states—to capture a broader and more diverse population.

The sample selection was carried out randomly but with guidance from the village Diwan members (group of village masters). In each village, a local guide assisted in identifying households that would be open to participating in the survey. This approach was necessary due to cultural and social factors that influenced community responses. In rural Sudan, there is a general distrust of outsiders, especially those conducting surveys. People are often wary of questions related to family size, fearing that sharing such details could bring misfortune or the "evil eye". Additionally, questions about energy consumption and solar products were met with skepticism. This was largely due to past experiences where organizations had visited, conducted surveys, and made promises about providing solar panels, but never returned. As a result, many community members believed that such surveys were misleading or had no real benefit to them.

Whilst the approach taken helped improve response rates, it also introduced a selection bias, as the sample was influenced by the village master's recommendations and the willingness of households to participate. The argument for this approach is that the Diwan members are those who know their villages and their people well and their advice could be considered as reliable. In each village, the author first consulted the Diwan members, who then appointed someone to accompany the author to visit households. The selection of households was based on their knowledge of individuals who would be willing to participate in the survey.

For the data collection process, the quantitative research method was used to enable statistical analysis. The interview questions were derived from the following three surveys: (1) Living Standard Measurement Survey (LSMS), a survey that involves aspects focusing on the socio-economic information of household members [34]; (2) Time Use Survey, which helps in the analysis of roles performed by men and women and gender gaps, if there are any when it comes to domestic chores, and the unremunerated activities performed by household members [35]; and (3) Specialized Household Energy Survey (SHES), which involves aspects that focus on quality and reliability of energy sources, and external factors affecting them [36].

The sample size was 60 participants from different households in each village, and an age group of 18–79. The data were collected using the Fulcrum app (Fulcrum 2.40.0), which is an application that allows field data to be entered and stored with precise geographic coordinates in a cloud-based platform [37,38]. The average household across the four villages had six members; therefore, each village has around 84 households. For a confidence level of 95% and a margin of error of 7%, we would therefore need a sample size of 59 households. We collected n = 60 surveys from each village [39] between 30 July 2021 and 22 August 2021.

Statistical significance of differences in responses was assessed using a chi-squared test statistic. For 2 × 2 contingency tests, the Fisher Exact Test was used as this was specifically developed for small sample sizes [40]. Further information regarding these statistical tests can be found here [41]. We conducted a multiple logistic regression analysis [42] to evaluate the influence of five factors from the survey on the likelihood of children attending school using Sigmaplot (Sigmaplot 16.0.0.28) [43]. These five factors were first tested as independent variables of a linear regression against the dependent variable of either (i) all the boys or (ii) all the girls attending school in a household. The five selected survey questions were converted into independent variables with categorical values. These were (1) number of hours of chores per day that the children in a household are required to undertake, (2) education level of the survey respondent (adult), (3) the declared household income, (4) number of children in a household, and (5) the number of hours of biomass collection per day per household.

2.1. Four Case Study Sites

There are four case study sites for this study: Taebeen, Al Hashieb 2, Wiheishat, and Helbeh Extension. Each settlement has its own distinct economic circumstances but common themes of gender inequality in relation to energy in particular.

2.1.1. Taebeen

Located in Al Jazirah state, south of the capital Khartoum, the settlement covers an area of 2.87 km^2 and has a population of ~500. Land cover is poor-savannah, and the primary source of livelihood is livestock, mainly sheep and goats. Dairy products are sold to neighboring villages; however, excess dairy product production often has to be disposed of because transport is not available to sell it in other villages or due to high temperatures. This provision of electricity in the settlement would represent a clear opportunity here to reduce dairy product wastage. Taebeen also trades the leather of their livestock in the capital Khartoum, where the men also travel to in the post-harvest season to work as casual laborers and market porters to generate income. The village is 50 km away from the nearest electricity grid, 12.4 km from the nearest hospital, 13 km away from the nearest school, and 3 km from the water pond.

2.1.2. Al Hashieb 2

Located in Gadarif state, south-east of the capital Khartoum, the settlement covers an area of 0.85 km^2 and has a population of ~500. Land cover is rich-savannah, and the primary source of livelihood is artisanal gold mining. The people of Al Hashieb 2 use mercury to extract gold and sell it in the Butana locality in Gadarif State. Mercury use causes serious health and ecological impacts in the village because villagers clean their tools in the village water pond. Villagers claim that using electrical tools for gold mining instead of the primitive ones they currently use would minimize the health impacts in the village. The village is 160 km away from the nearest electricity grid, 98 km away from the nearest hospital, 23 km away from the nearest school, and 2.2 km from the water pond.

2.1.3. Wiheishat

Located in Al Jazirah State, south of the capital Khartoum, the settlement covers an area of 0.45 km^2 and has a population of ~500. Land cover is poor-savannah, and the primary source of livelihood is agriculture. Wiheishat villagers produce mainly sorghum and groundnuts and sell to buyers in the capital Khartoum. After the harvest season, they also travel to other cities to find temporary work opportunities. The main challenge that they face as a result of not having access to electricity is the highly fluctuating fuel prices, which they need to operate their water pumps. The village is 51 km away from the nearest

electricity grid, 4.7 km from the nearest hospital, 5.4 km away from the nearest school, and 2 km from the water pond.

2.1.4. Helbeh Extension

Located in the White Nile State, south-west of the capital Khartoum, the Helbeh extension has an area of 3 km^2 and has a population of ~500. Land cover is semi-arid, and the primary source of livelihood is small-scale fishing and agriculture. The people of Helbeh extension travel at least three times a week, a distance ~65 km, to the White Nile river to fish. In addition to the high price of these trips to the river, they have to bear the high cost of ice, which they need to keep the fish fresh until they sell them in their surrounding cities. Ice production would be an ideal base load demand for a solar powered mini-grid with a likelihood of strong willingness to pay for ice amongst fishermen which would enhance the sustainability of such a system. The community also produce millet and sells this in the North Kordufan State. The village is 51 km away from the nearest electricity grid, 47 km away from the nearest hospital, 11.8 km away from the nearest school, and 2 km away from the water pond.

3. Results

This section presents the four village survey results to assess the impact of electricity absence in rural Sudan.

3.1. Health

This section assesses the impacts of having no access to electricity on rural health in the contexts of cooking, the use of contaminated water, receiving important health information, respondent's behavior in case of medical emergencies, and the medical staff retention rate in rural medical clinics. Interviews highlighted that participants rely on different types of biomass: charcoal, agricultural waste, and firewood, also known as Soraib.

Figure 3 reflects the perceived impact of using biomass indoors. The highest share of the participants declared that using biomass for cooking caused them shortness of breath, coughs, and eye infections; however, 18% of all the respondents deemed the use of biomass indoors as clean; this rises to 21% if no responses to the question are also considered as evidence of no health impact. There was no statistical difference between the prevalence of eye infections, shortness of breath, or cough responses observed between the four villages (chi-squared test, statistic 5.95, *p*-value 0.428, n = 189).

Figure 3. Respondents' perceived health impact from using biomass for cooking by village. n = 189.

We wished to understand households' views on the importance of heating water before using it for cooking and drinking and whether or not they practice this to avoid

water-borne diseases. The results show that almost 100% of the participants do not heat the water before using it. However, more than 50% of the respondents in the four villages do perceive it necessary to purify contaminants. Across the four villages, 113 male respondents stated 'Yes' (86%) and 19 'No', compared to 40 females stating 'Yes' (37%) and 68 'No'. A Fisher exact statistic was used to test if there is a gender difference in the perception that heating water is necessary prior to drinking. The Fisher exact test statistic value is <0.00001, the result is significant at $p < 0.05$, n = 240.

Respondents state that the reason for not heat-treating water is the amount of additional biomass quantity required, which will put an extra burden on them when they collect it or buy it. Moreover, the results highlighted interlinkages between health and the gender gap in accessing information. This was observed from participants' answers on how they learned about the importance of heating water. The results show the main source of information was media (TV and radio) in Taebeen and Al Hashieb 2 for men, whereas for women in these settlements, it was predominantly from the school. No respondents of either gender mentioned media as an information source in the Helbeh Extension settlement. If we compare gender with the three sources of information (media, school, and word of mouth), as shown in Figure 4, we see a statistically significant difference. A chi-squared test statistic is 16.8584 and the p-value is 0.000219, which is significant at $p < 0.05$, n = 151.

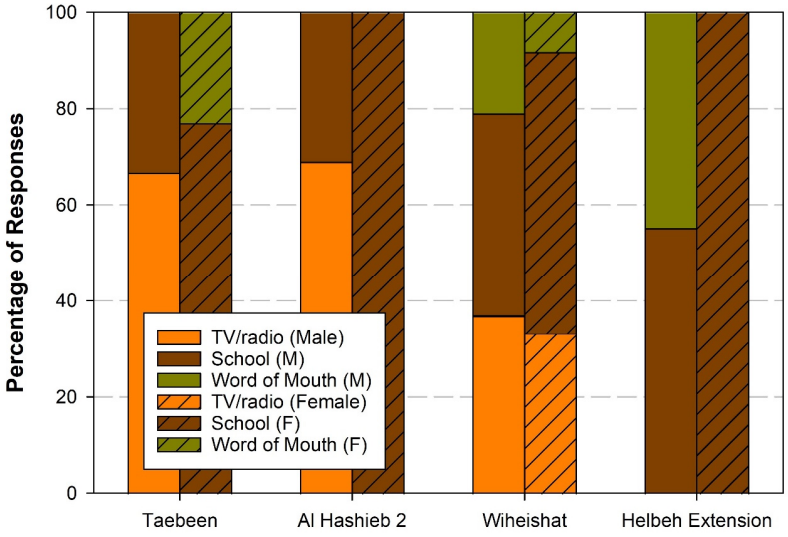

Figure 4. Percentage of respondents by village and gender to the stated sources of information they have access to in relation to water-borne diseases and the need to treat drinking water. n = 151. LEFT stacked bar is male responses (M); RIGHT stacked bar is female responses (F).

In relation to the absence of medical clinics in the villages, the rural medical staff in Tibaib Al-Nafa'ab Rural Hospital refer to the lack of electricity. Hence, people who are sick are not left with many options. We have clustered these actions into three options when they need to seek medical assistance: (1) walk to the nearest clinic, (2) wait for a vehicle to be driven to the nearest clinic, and (3) make use of traditional medicine. Figure 5 reflects their behavior in response to needing medical treatment. It is not surprising that for Al Hashieb 2 and Helbeh Extension, no one walks to the nearest clinic when it is 98 km and 47 km away, respectively.

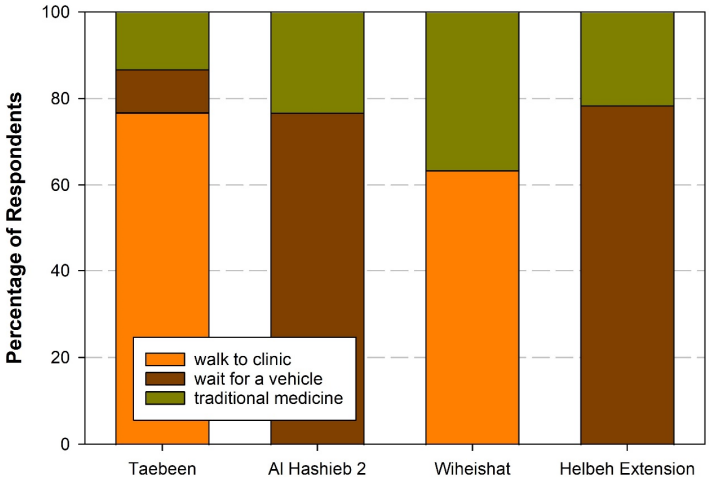

Figure 5. Respondents' stated method of obtaining medical assistance by village. The distance to the nearest formal medical clinic: Taebeen 12 km, Al Hashieb 2 98 km, Wiheishat 5 km, and Helbeh Extension 47 km. n = 240.

Three of the medical staff in Tibaib rural hospital were asked about their perception of the working conditions in rural areas, and they all answered with the term "unsatisfactory" with the reason being, amongst others, not having access to electricity.

Figure 6 shows a boxplot (25th–75th percentile) of declared household income of respondents in each village with their stated method of obtaining medical assistance (walk, wait for a vehicle, and traditional medicine). Whisker bars are shown at 10th and 90th percentile and all outliers are shown. The median income is the solid line and the dashed line is the average income. It is interesting to note that we see no influence of household stated income on the choice of medical assistance. This perhaps indicates the influence of social norms on decision making in this respect, rather than simply the 'ability to pay'.

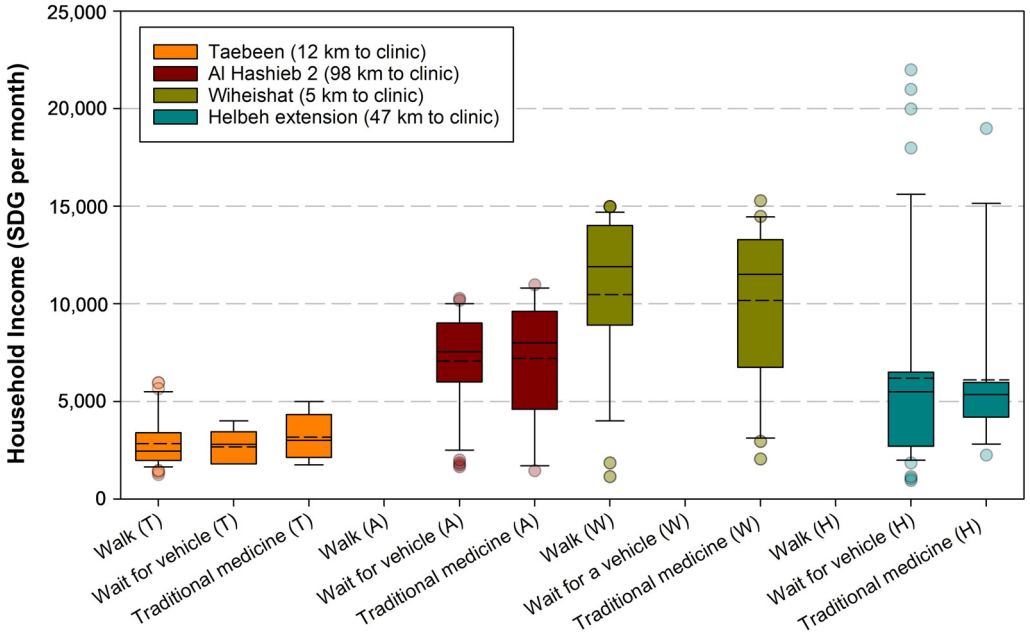

Figure 6. Boxplot (25th–75th percentile) of respondents' stated method of obtaining medical assistance by village as a function of household income (Sudanese Pound, SDG per month). Whisker bars are shown at 10th and 90th percentile and all outliers are shown. Distance to nearest medical clinic: Taebeen 12 km, Al Hashieb 2 98 km, Wiheishat 5 km, and Helbeh Extension 47 km. n = 60 for each settlement.

The responses 'Walk' and 'Wait for a vehicle' are both decisions based on choosing to use a formal medical clinic. In the case of Al Hashieb 2 and Helbeh Extension, no one walks due to the long distance to the clinic (Figure 6). We have combined 'Walk' and 'Wait for a vehicle', termed here as 'Modern medicine', to compare against the 'Traditional medicine' alternative. We compare the number of 'Modern medicine' and 'Traditional medicine' responses with a declared household income either below, or greater than or equal to the median of their village. A Fisher 2 × 2 exact test for each village is not significant for any of the villages at $p < 0.05$: Taebeen (0.7095), Al Hashieb 2 (0.5398), Wiheishat (1), and Helbeh Extension (1). n = 60 for each settlement.

3.2. Education

This section presents the participants' level of education, the impact on educational attainment when assigning children to household chores, and the relation between the parents' level of education and their behavior regarding sending their children to school. Additionally, it investigates the possibility of increasing the number of educated people if electricity is provided. The level of survey respondents' education in the villages is shown in Figure 7.

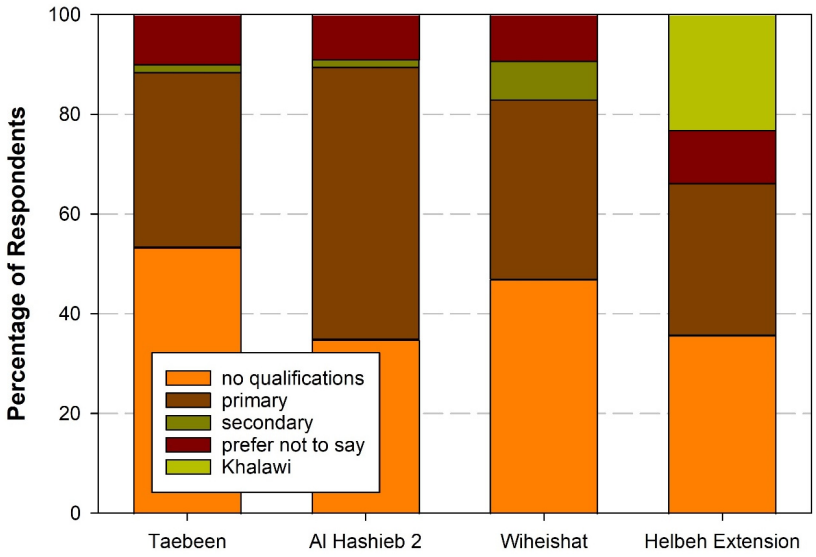

Figure 7. Respondents' stated level of education by village. n = 60 for each settlement.

Those who received education mainly stopped at the primary level, and only a few respondents pursued secondary or higher education. However, across the four villages, 44% to 63% had no academic education or refrained from answering (prefer not to say). Some of the participants attended what is known as Khalawi, classes offered by Sheikhs to educate children on how to read and write in Arabic to learn the Quran. There is a clear gender imbalance in terms of school attendance between girls and boys as highlighted in Figure 8. Education inequality is not only associated with income and parental education but also gender. The Helbeh Extension does not offer girls schooling and so this settlement has been excluded from a statistical comparison of gender and school attendance. Across the three other settlements, 60 of 264 girls attend school, compared to 181 of 240 boys. A Fisher exact test statistic has a value of <0.00001 showing significance at $p < 0.05$, n = 504. Education literature in a Sudanese context highlights the gender equality issue due to the requirement on girls to undertake chores and collect firewood in particular [17,18]. Here, we provide a quantitative assessment which supports the findings of other predominantly qualitative research.

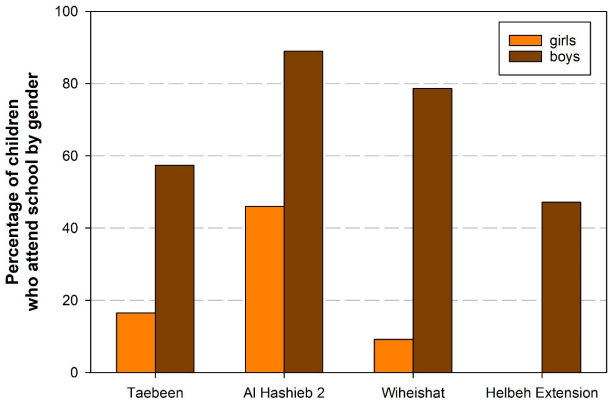

Figure 8. Percentage of children who attend school by gender and settlement. n = 504.

The respondents attributed their low level of education to spending considerable time on household chores, or the absence of lighting services in schools or at home. This was emphasized by their responses regarding their possible uses of electricity at home if it were available, and 48% in Taebeen, 70% in both Al Hashieb 2 and Wiheishat, and 38% in Helbeh extension stated that they would use it to provide their children with light for education and reading purposes.

Additionally, it was found that collecting biomass and performing other household chores are often performed by women and children. The results indicate that households spend more than four hours each day on the former and thirteen hours on the latter. See Table 1. This shows that the number of children not attending school to collect biomass could be reduced if they had access to electricity and/or other clean energy sources for cooking.

Table 1. Average number of individuals per household and hours per day spent on unremunerated activities.

Description	Taebeen	Al Hashieb 2	Wiheishat	Helbeh Extension
Women	1	1	1	1
Girls	1.5	1.3	1.6	1.0
Boys	1.2	1.2	1.6	1.0
Time spent on household chores (h/day)	14	15	13.8	13.5
Time spent collecting biomass (h/day)	5.4	5.8	7.25	4.2

Moreover, the increase in the school attendance rate and educational attainment has been shown in other studies to result in higher literacy rates and improved economic opportunities in the future [35]. It also ensures an increase in the number of educated children in the next generation [44]. In the questionnaire, this was assessed by comparing the number of educated and uneducated parents who send their children to schools. See Figure 9. Across the four villages, 25% of respondents stated that they sent all their children to school. A respondent was deemed to be 'not educated' if they stated to have either 'no qualifications' or that they 'preferred not to say'. The percentage of educated parents who send all their children to school was twice that of uneducated parents who send all their children to school. A Fisher exact test compared the education level of respondents who sent all of their children to school with those who did not. This comparison is statistically significant with a Fisher exact statistic value 0.0311; the result is significant at $p < 0.05$, n = 225.

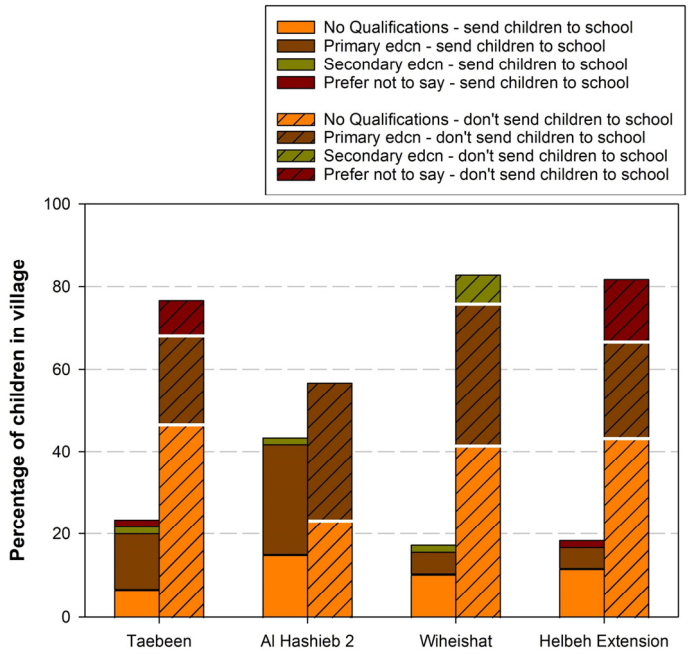

Figure 9. Percentage of respondents who send ALL their children to school (LEFT), compared to those who send SOME/NONE to school (RIGHT) by village. n = 225.

3.3. Gender Equality

As highlighted above, there is clear gender inequality in terms of education between girls and boys. In rural Sudan, as in some other African societies, women and girls are culturally accustomed to performing labour intensive and time-consuming household chores, thus exposing them to health risks and time poverty. See Figure 10 and Table 1. This sub-section reveals the impacts on the gender gap due to a lack of electricity by quantifying the time spent, and distance traveled by women and girls to perform domestic and other unremunerated activities.

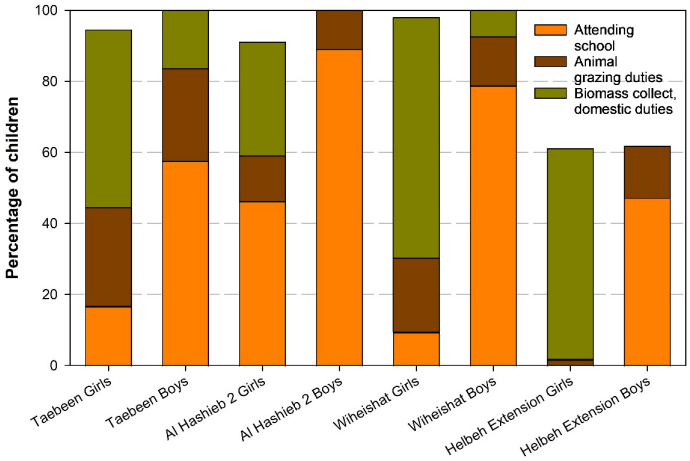

Figure 10. Percentage of children by gender who either (i) attend school, (ii) undertake animal grazing duties, or (iii) collect biomass or undertake biomass duties. n = 618.

The results show that animal grazing and domestic activities are the most time consuming, followed by collecting biomass, fetching water, and acquiring sources of lighting. As for the daily distance traveled to perform these activities, people walk further distances to collect biomass, which is followed by animal grazing, fetching water, and acquiring sources of lighting. Both animal grazing and collecting biomass requires the covering of a large radius around the villages. In contrast, the fetching of water from the nearby

pond, and the buying of torches and candles for light from the village shop is a far shorter distance for households.

3.4. Linear Regression of Independent Variables Influencing School Attendance by Gender

We assessed a range of independent variables in terms of their individual influence on school attendance of all the boys or girls in a household to school. A linear correlation of attendance by gender was correlated against the following independent variables from the interview survey: (i) household income, (ii) head household education level, (iii) number of children in the household, (iv) household time spent on chores per day, (v) distance to school, and (vi) time spent collecting biomass per day as shown in Table 2.

Table 2. Linear correlation regression coefficient and *p* value for household survey variables and their correlation with attendance or all boys/girls in a household to school.

Dependent Variable	Independent Variable	Regression Coefficient	*p*-Value
All boys in a household attend school	(1) Declared household income	0.016	0.381
	(2) Respondent household education level	**0.173**	**0.008**
	(3) Number of children in household	**0.053**	**0.007**
	(4) Time completing chores	**−0.031**	**<0.001**
	(5) Time collecting biomass	**0.069**	**<0.001**
	(6) Distance to school	0.004	0.178
All girls in a household attend school	(1) Declared household income	0.032	0.170
	(2) Household head education level	0.081	0.289
	(3) Number of children in household	−0.026	0.267
	(4) Time completing chores	**−0.025**	**<0.001**
	(5) Time collecting biomass	**−0.052**	**0.014**
	(6) Distance to school	**−0.011**	**<0.001**

In terms of the attendance of all the boys in a household at school, we observe that the education level of the head of household has the strongest positive regression coefficient which is statistically significant. It is interesting to note that household income is not seen as being statistically significant in influencing attendance or either girls or boys but the coefficient is more positive for girls. The number of children in a household is seen to increase the likelihood of all boys attending school—we interpret this as that there will be a greater likelihood of girls being present in larger households who will bear the majority of the household chores. Time on chores is seen to be negative for school attendance for both boys and girls. Regarding distance to school, we have only four distinct distance values for boys and three for girls (there is no girls school in the Helbeh extension); therefore, these correlations should be treated with caution. We do observe a negative coefficient for girls' attendance with distance to school as one might expect. Time collecting biomass (which is stated as a female activity in these villages) is seen to increase the likelihood of boys attending school in a household. Conversely, an increase in biomass collection time reduces the likelihood of all girls attending school. We interpret this as a reflection of the gender bias of biomass collection.

3.5. Multiple Logistic Regression of School Attendance by Gender

We have shown that the educational level of a parent is statistically correlated to the likelihood of boys in that household attending school. We observe a strong gender bias towards boys in terms of attending school and towards girls undertaking domestic activities rather than attending school. A multiple logistic regression model has been used to model attendance to school (YES/NO) for boys or girls using five of the six independent variables shown in Table 2: (1) declared household income, (2) respondent education level, (3) number of children in household, (4) time required for household chores per day, and (5) the time required for biomass collection per household per day. We have not used distance to school as this has little variability in the sample. We have analyzed boys and girls separately for the settlements of Taebeen, Al Hashieb 2, and Wiheishat combined. We have not used responses from the Helbeh Extension settlement in the analysis due to the lack of a girls' school which would distort the results. In terms of education level in the logistic regression, we have chosen to group 'no qualifications' and 'prefer not to say' together.

3.5.1. Multiple Logistic Regression of Boys Attendance to School

Table 3 shows the multiple logistic regression coefficients and statistics for boys' attendance to school. n = 160 complete responses for analysis.

$$\text{Logit P} = -2.679 - (0.249 \times \textit{chores}) + (0.801 \times \textit{education level}) + (0.030 \times \textit{income}) + (0.347 \times \textit{number children}) + (0.760 \times \textit{biomass collection})$$

chores = time required for household chores per day (hours)
education level = adult respondent level of education
income = stated household income, SDG per month
number children = number children in household
biomass collection = time required for biomass collection per day (hours)

The Pearson Chi-square Statistic, 144.046 (p = 0.686), indicates a good agreement between the logistic regression equation and the survey data. The p value of the Wald statistic is the probability of being wrong in concluding that there is a true association between the independent variable and the dependent variable. We observe that $p < 0.05$ for 'Chores', 'Number of children', and 'Biomass collection' which means we conclude that these variables show statistical significance in contributing to predicting the dependent variable of a boy attending school. The VIF (Variance Inflation Factor) values are less than 2.5, so we can consider that multi-collinearity is not an issue with this regression model [45]. The Odds Ratio is the estimate of the increase (or decrease) in the odds if an independent categorical variable value is increased by 1. For example, if the time required for a boy to undertake chores was to increase by one hour, the Odds Ratio is 0.780. So, a boy would, in this case, be 22% less likely to attend school. In terms of the 'Education level' of the adult respondent, a single categorical education level increase (such as no education to primary) would predict a 2.2 times increase in the likelihood of a boy attending school, although it is not statistically significant (Odds Ratio 2.23, p value 0.086). Income is not seen to correlate with boys' attendance at school (Odds Ratio 1.03, p value 0.790).

Table 3. Multiple logistic regression of boys' attendance to school (n = 160 complete responses).

Independent Variable (Categorical)	Coefficient	Standard Error	Wald Statistic	*p* Value	VIF	Odds Ratio	5% Conf. Lower	5% Conf. Upper
Constant	−2.679	1.061	6.373	0.012		0.069	0.009	0.549
Chores Number of hours per day per household	−0.249	0.048	27.436	**<0.001**	1.281	0.780	0.710	0.856
Education level No education, prefer not to say (1) Primary (2) Secondary (3)	0.801	0.466	2.949	0.086	1.108	2.227	0.893	5.556
Income Self-reported by household, 9 bands SDG/month 0. . .2000 (1) ≥2000. . .<4000 (2) ≥16,000 (9)	0.030	0.114	0.071	0.790	1.026	1.031	0.824	1.289
Number of children Integer value	0.347	0.167	4.308	**0.038**	1.124	1.415	1.020	1.963
Biomass collection Number of hours per day per household	0.760	0.173	19.421	**<0.001**	1.333	2.139	1.525	3.000

3.5.2. Multiple Logistic Regression of Girls Attendance to School

Table 4 shows the multiple logistic regression coefficients and statistics for girls' attendance to school. n = 126 complete responses for analysis.

$$\text{Logit P} = 0.542 - (0.108 \times \textit{chores}) + (0.336 \times \textit{education level}) + (0.218 \times \textit{income}) - (0.122 \times \textit{number children}) - (0.182 \times \textit{biomass collection})$$

chores = time required for household chores per day (hours)
education level = adult respondent level of education
income = stated household income, SDG per month
number children = number of children in household
biomass collection = time required for biomass collection per day (hours)

The Pearson Chi-square Statistic, 123.809 (p = 0.363), indicates a good agreement between the logistic regression equation and the survey data. We observe that $p < 0.05$ for 'Chores', which means we conclude that this variable shows a statistical significance in contributing to predicting the dependent variable. The VIF (Variance Inflation Factor) values are less than 2.5. So, we can consider that multi-collinearity is not an issue with this regression model [45]. If the time required for a girl to undertake chores were to increase by one hour, the Odds Ratio of 0.897 indicates that, in this case, a girl would be 10% less likely to attend school. In terms of the household income, a single categorical income level increase (+2000 SDG) would predict a 24% increase in the likelihood of a girl attending school; this approaches statistical significance in the model (Odds Ratio 1.24, p value 0.052). The education level of the respondent is seen to increase the likelihood of a girl attending school but this is not at a statistically significant level (Odds Ratio 1.4, p value 0.382).

Table 4. Multiple logistic regression of girls' attendance to school (n = 126 complete responses).

Independent Variable (Categorical)	Coefficient	Standard Error	Wald Statistic	*p* Value	VIF	Odds Ratio	5% Conf. Lower	5% Conf. Upper
Constant	0.542	0.988	0.301	0.583		1.720	0.248	11.934
Chores Number of hours per day per household	−0.108	0.051	4.455	**0.035**	1.443	0.897	0.812	0.992
Education level No education, prefer not to say (1) Primary (2) Secondary (3)	0.336	0.384	0.765	0.382	1.140	1.400	0.659	2.973
Income Self-reported by household, 9 bands SDG/month 0. . .2000 (1) ≥2000. . .<4000 (2) ≥16,000 (9)	0.218	0.112	3.784	0.052	1.052	1.244	0.998	1.551
Number of children Integer value	−0.122	0.130	0.879	0.349	1.133	0.885	0.686	1.142
Biomass collection Number of hours per day per household	−0.182	0.126	2.104	0.147	1.425	0.833	0.652	1.066

3.6. Income Generation and Alleviating Poverty

Here, the impact of not having access to electricity on productivity was analyzed. Accordingly, the participants were classified into three groups depending on their electricity needs: (1) using light to increase the number of their productive hours, (2) using electrical equipment for work purposes, and (3) using electrical appliances at home to perform household chores, thus finishing earlier and spending their time on income-generating activities.

The provision of village street lighting was reported by respondents as a way to increase productive hours. Their income-generating activities were either porting, weaving wicker baskets in front of their huts/houses, sewing, preparing food to sell in the market, selling coffee and tea, and opening kiosks and shops for longer hours. In terms of those who would benefit from electricity to increase their work productivity, this would include water pumping for irrigation and livestock use, freezers and refrigeration, sewing machines, grain processing machines, small-scale gold mining electrical equipment (only in Al Hashieb 2), and miscellaneous uses (ironing, telephones and laptops, and cooking stoves).

Finally, having electricity in their villages would enable households to use electrical equipment that would save time. This would particularly help women and girls to benefit from the time 'wasted' on fetching water and collecting biomass on a daily basis. It is also important because it helps overcome the challenges related to the availability and fluctuating prices of biomass during the rainy season.

More than 75% of the respondents in the villages viewed using biomass as unreliable, becoming less available and having a higher price if they needed to buy it during the rainy season. Therefore, accessing electricity would not only achieve SDG7 and improve the previously mentioned development parameters, but also other SDGs from 1 to 11 and 16, as highlighted in Figure 2.

Here, we now group electricity usage responses across four sectors for comparison: (1) lighting (street lighting and lighting for shops), (2) agriculture (pumping of water and grain processing), (3) cooling, and (4) others (sewing machines, small gold mining, miscellaneous, and no need) as shown in Figure 11. We observe a statistical difference in the stated desired productive use of electricity across the four settlements. The Chi-squared

statistic is significant at $p < 0.05$. X2 (12, N = 240) = 59.8745, p-value is <0.00001. This reflects the differences in the ways in which each settlement earns money (Figure 11). Al Hashieb 2's activities, for example, are dominated by artisanal gold mining. Here, respondents stated that electricity would enable the processing of gold ore at night (street lighting) and the use of electrical machines for enhanced processing. In contrast, in the Helbeh Extension, the agricultural activities would benefit from the availability of cooling in particular, which is seen as the dominant future application of electricity. This highlights the importance of understanding local context in energy provision to achieve success.

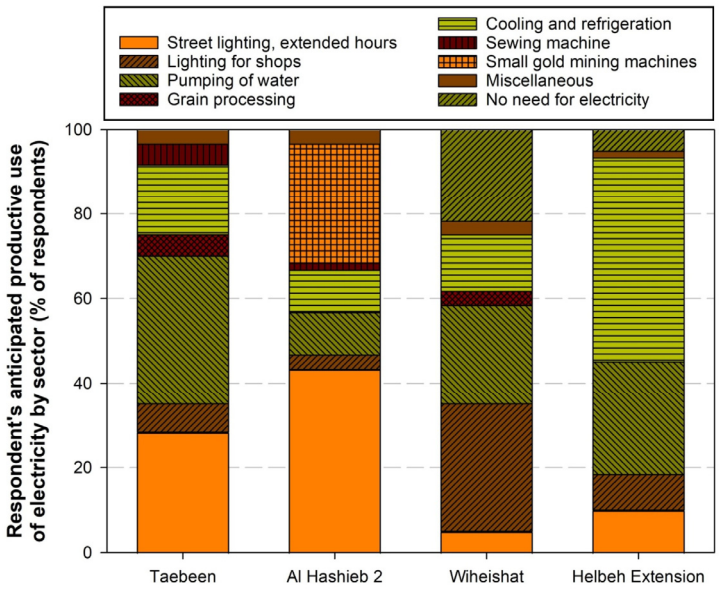

Figure 11. Respondents' anticipated use of electricity to enhance economic activity by settlement, n = 240.

4. Discussion

Having access to electricity is vital to improve the standard of living and quality of life for Sudan's rural communities. The results generated in this study highlight the importance of electricity services for rural health by providing efficient and clean cooking options, using clean water and avoiding water-borne diseases, receiving important health information via media access, and creating a satisfactory work environment that could increase the retention rate of medical staff to rural areas.

Having access to light, whether in schools or at home, would improve the rural level of education; therefore, even if children participated in household chores, they would have time in the evening to read and do their homework. This could ultimately increase the number of educated children in the future.

The considerable amount of time spent mostly by women and girls on household and unremunerated activities could be reduced if they had access to electricity. This is true in particular for the collection of biomass and the fetching of water, because they are the most time-consuming activities that are performed on a daily basis. This would potentially allow women to invest their time and energy in educational attainment, job creation, or other social activities, all of which would improve their quality of life and reduce the gender gap. Moreover, having light to extend working hours in the evening, or being able to use electricity services either for work via various electrical devices, or at home to save time spent on time-consuming activities will increase the rural residents' daily productivity.

However, addressing the above issues would not be possible without electricity. Thus, there is an urgent need to accelerate the access rate in rural Sudan to allow for a desirable social and economic development and to achieve the UN SDG7 "universal electricity access by 2030". Considering that Sudan's rural population is sparsely distributed, economies

of scale in the electricity sector would not be cost advantageous, because both production and consumption are assumed to be low. This indicates that, currently, the most suitable approach would be to provide access via small mini-grids.

At present, these rural societies in Sudan exhibit a high level of gender inequality which is exacerbated by the lack of access to energy and the services it can provide. Boys are observed to be more likely to attend school than girls regardless of household income. Boys' attendance likelihood increases with the number of children in the household (which we attribute to the greater likelihood of the presence of girls in the household). Increased biomass collection time is seen to increase the likelihood of boys' attendance at school as this is typically seen as a female task. Girls are primarily required to undertake chores which reduces school attendance and also appears dependent on a higher household income (Odds Ratio 1.24, p value 0.052). The likelihood of attendance at school was reduced by 22% for each additional hour of required household chores for boys and 10% for girls. In relation to accessing health services (traditional vs. modern), we observed no influence of household income suggesting social norms play a strong role here. It appears, therefore, that households prioritize the education of boys over girls in a rural Sudanese context, which will reinforce the gender inequality that exists in these societies.

As for the rural electrification business model to deliver such interventions, a Government-Run Model was applied in a rural electrification project via Solar Home Systems (SHS) in West Sudan [46]. The project was managed by governmental bodies and funded by an international institution for the preliminary phase. However, this project stopped because the funding for the other phases was not secured. Therefore, the participation of the private sector in funding these projects would reduce the risks of failure to obtain long-term funding from international donors.

In terms of a government-run model, management, allocation of resources, implementation, and the billing process are all determined by the government. However, funds are obtained from international donors, and it is for this reason that the literature sometimes refers to this as a donor-approach model [47,48]. Although this model targets people at the Base of the Pyramid (BOP), its sustainability and sufficiency have been questioned due to the significant level of capital needed, in addition to the continuously rising demand for energy due to the growing world population.

The Partnership Model is currently the most widely used model because the roles are divided between the partners according to their specialty [49]. In this model, the government sets the electrification policies, while the international organizations and private sector provide funds, expertise, and improve capacities needed during the planning and implementation phases of the projects. Many African countries have adopted this model, such as Burkina Faso, Mauritania, Senegal, Madagascar, Kenya, Uganda, and Tanzania [50].

The Private Sector Model enables investors to manage and implement electrification programs independently. In principle, it is considered to be the preferred route since it enables investors to choose the billing system that mitigates investment risks and provides the highest returns. Nevertheless, the development cooperation of the African, Caribbean, and Pacific–European Union (AFC-EU) regards it as an unattractive option for private investors [51]. This is rational since the initial capital, power plants, and transmission line costs could be prohibitive and only the generation and distribution of renewable electricity, which comes as a later step, is considered profitable. In the context or rural Sudan, the Private-Sector Model is unlikely to be attractive to investors; due to the low return on investment, which stems from the low demand for electricity.

Therefore, a Partnership-Run Model, where rural electrification projects are managed by governmental bodies, the private sector and international organizations and funded by

the private sector and international organizations would possibly be a suitable business model for rural electrification [52]. It would allow for the participation of (1) national stakeholders in setting policies and strategies that facilitate the projects' implementation and operation, whilst (2) benefiting from the international donors' experience in funding similar projects, and (3) creating a competitive market for the private sector, which would ultimately help in disseminating electrification projects in the country. All projects should be community-focused to enhance their acceptability. The current political instability of Sudan clearly exacerbates these issues and makes them far more challenging, however.

5. Conclusions

This study has shown that there are currently multiple weaknesses in the context of rural Sudan in terms of ambitions to achieve SDGs 5 and 7. The provision of electricity access offers a route to numerous pathways to address these limitations, but significant and persistent cultural and financial barriers exist. If we view education as a key pillar to achieving SDGs 5 and 7, we observe quite different circumstances in terms of school attendance of boys and girls in the studied villages. Both education level of household survey respondent and household income are seen to increase the likelihood of girls attending school. In addition, household chores and biomass collection (both associated with females) are seen to reduce the likelihood of girls' attendance of school. All four of these variables are directly linked to energy, which makes the case for electrification strong in this context. In contrast, for boys we do not see an influence of household income on school attendance. Higher education of household survey respondents is seen to influence boys' attendance to school far more strongly than for girls, highlighting the patriarchal nature of these communities.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The survey datasets which were collected and analyzed in this paper will be available via the University of Southampton data repository (pure.soton.ac.uk, available from 4 March 2025).

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Abbreviations

The following abbreviations are used in this manuscript:

BOP	Base of Pyramid
HDI	Human Development Index
SDG	Sudanese Pound
SDGs	Sustainable Development Goals
GDP	Gross Domestic Product
LSMS	Living Standard Measurement Survey
SHES	Specialized Household Energy Survey
SHS	Solar Home Systems

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