SUDAN

IFPRI

SUDAN STRATEGY SUPPORT PROGRAM WORKING PAPER 22 DECEMBER 2024

Determinants of Household Water and Energy Access and Their Impacts on Food Security and Health Outcomes in Sudan

Oliver Kiptoo Kirui, Mosab Ahmed, Mariam Raouf, Hala Abushama, Khalid Siddig

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ABSTRACT

This study investigates the determinants of access to safe water and reliable energy for households in Sudan using nationally representative data from a recent labor market survey. The results show that urbanization, education, and wealth significantly enhance the access households have to these essential services, while rural areas and less developed regions, particularly in the Darfur and Kordofan regions, face substantial challenges. Access to reliable energy correlates with better food security and health outcomes within households, and improved access to safe water significantly enhances the health of household members. Policy recommendations supported by these research results include targeted rural infrastructure investments, educational improvements, and regional interventions to address disparities in household access to safe water and reliable energy across Sudan.

Keywords: water-energy access, Sudan, socioeconomic disparities, rural-urban divide, food security, health

1) INTRODUCTION

Water, energy, and food are all interrelated, with numerous connections between them. The water-energy-food nexus is the term used to describe this idea (Ringler et al. 2013; Hlahla 2022). Natural resources are becoming scarce. This could impede efforts to achieve goals related to human well-being and economic progress. Nexus thinking has emerged from these considerations. Shortages of water, energy, and food could result from strains on available resources, particularly for weaker members of society. This may negatively affect economic development, social cohesion, and the environment (Ringler et al. 2013).

The water-food linkage is particularly important, given that irrigated agriculture remains a significant global user of freshwater, making up over 70 percent of global withdrawals, 90 percent of consumptive usage, and 40 percent of total grain output (Ringler et al. 2013). Water is essential to produce food and energy, particularly hydroelectricity, which is a significant energy source, as well as for maintaining the ecosystems that have an impact on agriculture and other economic sectors vital for ensuring food security. Food production and the provision of water, including its extraction, purification, and delivery, depend on energy (Hlahla 2022). Electricity is a key driver of economic growth and poverty reduction in developing countries. Electricity can drive economic and social development by increasing productivity, enabling new types of job-creating enterprises, and reducing household workloads, thereby freeing up time for paid work (Pueyo and Maestre 2019).

The energy-water nexus is increasingly being studied, as both resources are becoming scarcer in many contexts. Changes in the availability of one are influencing the availability of the other. Looking at a developing country context, this study investigates household access to water and energy in Sudan and the impact of differing levels of access on household food security and health status.

In section 2, we provide a review of relevant literature related to access to water and energy, the determinants of such access, the impact of restricted access to water and energy on household food security and health, any gender dimensions to these associations, and the methods used to assess them. Section 3 provides an overview of access to clean water and reliable energy in Sudan. Section 4 covers the data and methods used in this research. Section 5 presents the results of the research, while Section 6 concludes and draws some policy recommendations.

2) LITERATURE REVIEW

While the water-energy-food nexus is increasingly recognized as vital for sustainable development, research findings that incorporate the concept still needs to be expanded, particularly in the context of monitoring progress towards the SDGs (Nkiaka et al. 2022). The water-energy-food nexus is complex, involving multiple scales across several dimensions—spatial (local, national, regional, or global), temporal (present or future), and institutional (transboundary river basin, sub-regional, or other). This complexity makes it challenging to assess and address the interdependencies between water, energy, and food comprehensively.

Nkiaka et al. (2022) developed a multidimensional index to investigate the determinants of access to water, energy, and food, incorporating indicators of water security, energy security, and food security. Their analysis identified seven key socioeconomic variables as potential drivers of water, energy, and food security—GDP per capita, government effectiveness as proxied by the Government Effectiveness Index (World Bank 2024), human development as proxied by the Human Development Index (UNDP 2024), the urban population as a share of the total population, infrastructural development, foreign direct investment levels, and official development assistance directed to water supply and sanitation, agriculture, and energy.

2.1 Determinants of clean water and reliable energy access

Access to water is universally recognized as a human right, as emphasized in the global Sustainable Development Goals (SDG)—SDG-6 focuses on the provision of universal and equitable access to safe and affordable drinking water. This goal is particularly pertinent in low- and middle-income countries where marginalized groups, such as women and those living in remote rural communities, often face additional challenges in accessing water. Poor water, sanitation, and hygiene services and practices disproportionately affect these populations (UNICEF and WHO 2023).

Several studies have explored the determinants of access to clean and safe water at household level, particularly in developing and least-developed countries. Adil et al. (2021) identified key factors influencing access to safe drinking water and improved sanitation in Punjab. Their analysis revealed that media exposure, education level of the household head, household wealth, and ethnic background significantly impact the degree of access households have to safe drinking water. Notably, the study found that household wealth plays a critical role, with wealthier households enjoying better access to safe drinking water.

In Nepal, Behera, Rahut, and Sethi (2020) observed a significant decline in the proportion of households using piped water in urban areas. Their study concluded that education level, economic status, and location are key determinants of household access to improved drinking water, sanitation, and waste disposal services.

Antunes and Martins (2020) focused on countries with national water supply service coverage below 95 percent. The study found that investments in infrastructure, particularly in urban areas, education, and encouraging paid female employment positively impact water access. They also noted that countries with a large agricultural share in their GDP tend to have lower water access, highlighting the need for targeted efforts to achieve universal water access.

Energy access, defined as the ability to reliably use energy, is crucial for socioeconomic development. Saputri, Setyonugroho, and Hartono (2024) investigated household-level energy poverty in Indonesia. They found that energy prices and household economic conditions and demographic characteristics are closely linked to energy poverty. Specifically, household wealth and higher income significantly reduce the likelihood of energy poverty. Larger household sizes and higher education levels also play important roles in improving household access to energy. The study also noted that households with male heads are more likely to experience energy poverty, while women's involvement in energy-related decisions decreases this likelihood.

In a study of energy poverty in Ethiopia, Alema and Demekeb (2020) emphasized the impact of rising kerosene prices, a primary cooking fuel in urban areas, on energy poverty. A 10 percent increase in kerosene prices was found to have resulted in a 1.8 percent increase in energy poverty, underscoring the vulnerability of low-income Ethiopian households to energy price fluctuations.

2.2 Effects of poor access to clean water and reliable energy on household well-being

Inadequate access to clean water and reliable energy, as well as to several other basic services, can lead to significant health and economic costs, particularly for low-income households. Lack of access to safe drinking water can result in waterborne diseases, increasing medical expenses for the households and reducing members' ability to work, thereby reducing household well-being. Poor sanitation further compounds these challenges, posing serious threats to public health and environmental sustainability (Behera, Rahut, and Sethi 2020).

Similarly, energy poverty—characterized by the inability to reliably obtain affordable energy—has substantial implications for human development, affecting the economic productivity, health, and education of household members. Improved access to cleaner burning fuels can reduce indoor air pollution, a leading cause of premature death in developing countries. In 2012, household air pollution from biomass-based fuels accounted for 4.3 million deaths, mostly among women and children, representing 7.7 percent of global mortality (Smith et al. 2005). In sub-Saharan Africa, the death toll from indoor air pollution surpasses that of tuberculosis and is comparable to malaria.

2.3 Gender dimensions to household water and energy access

Women in many countries are responsible for providing food for their households, gathering fuelwood for cooking, and fetching potable water, all of which are unpaid productive activities (Villamor et al. 2018). Therefore, there are significant gender dimensions to exploring the interlinkages between water and energy access and household food security and health. Disparities are seen not only across regions but also between the sexes. The challenges that women face in obtaining reliable access to clean water align with two of the SDGs—SDG-5 on gender equality and SDG-6 on clean water and sanitation. The water and sanitation sector has the potential to contribute to redressing inequality and can greatly improve the social, political, and economic position of women (WSP 2010).

Despite their primary responsibility for managing the water supply and sanitation for the household and for safeguarding the health of household members, women face significant inequities in access to water resources. In Malawi and Ethiopia, for example, schoolgirls often lack access to adequate sanitation and hygiene facilities, such as clean water supplies and sufficient latrines (Hlahla 2022). Additionally, women and girls in rural areas are frequently compelled to walk long distances to fetch water, a task that consumes time and energy—the average distance for a water collection trip in sub-Saharan Africa is estimated at between 4 and 5 kilometers, taking approximately 33 minutes each way (Connell 2017). For women, inadequate access to water is particularly detrimental, as it increases their vulnerability to waterborne illnesses and reduces their time for other productive activities. Proximity to water sources can enhance household and personal cleanliness and improve health outcomes, particularly in resource-limited regions like eastern Zimbabwe, where gathering water can take over 10 hours per week (Connell 2017). The connections between gender, water, and health are well-documented. Poor access to water and sanitation for women generally results in increased health costs (Kayser et al. 2019).

In addition, rural women bear the primary responsibility within the household for energy-related tasks (Hlahla 2022). The time spent by women in Benin in collecting fuelwood was shown to be four times greater than it was for men (Köhlin et al. 2011). In rural Gujarat, India, women spend up to 40 percent of their day engaged either in fuel collection or cooking (WLPGA 2014). Studies have also highlighted the benefits for women of investing in clean fuels and improved cookstoves, which can enhance efficiency, reduce pollution, and yield significant health and economic benefits (World Bank 2017).

These daily burdens significantly limit the opportunities of women and girls to engage in other activities, such as education. These gendered challenges to household well-being highlight the need for targeted interventions to improve water and energy access, particularly for women and girls.

2.4 Methods of analysis of water and energy access and their effects on household well-being

The determinants of water and energy access, and their combined effects on household well-being, have been widely studied using diverse methodological approaches. These methods focus on understanding access disparities and their implications for food security and health, particularly among vulnerable populations.

Several studies have employed regression-based methods to explore access patterns. For instance, Adil et al. (2021) used binomial logistic regression to examine access to safe drinking water and improved sanitation in Punjab, emphasizing the role of socio-economic and regional disparities. Similarly, Behera, Rahut, and Sethi (2020) applied multinomial logistic regression to analyze factors influencing access to water, sanitation, and waste management in Nepal over three decades, providing insights into how access evolves over time and across socio-economic groups.

Other studies have incorporated techniques to address causality and initial conditions. Antunes and Martins (2020) used a linear multivariate regression model with lagged independent variables to study global water access, highlighting the impact of historical conditions and policy interventions on current access levels. Saputri, Setyonugroho, and Hartono (2024) analyzed energy poverty in Indonesia using logistic regression with district-level fixed effects, accounting for regional heterogeneity and emphasizing the role of energy pricing and socio-economic factors.

Innovative thresholds for defining energy poverty have also been explored. For instance, Alema and Demekeb (2020) employed the Minimum Energy Consumption Threshold Approach, defining energy poverty as consumption below 50 kilograms of oil equivalent annually for cooking and lighting. This method, although debated, offers a benchmark for identifying households lacking basic energy needs.

This study builds on existing literature by applying a doubly robust estimation method to examine the effects of access to clean water and reliable energy on household well-being, specifically food security and health outcomes. The doubly robust approach combines propensity score weighting and regression adjustment, ensuring unbiased estimates even if one of the two models is mis-specified. This method addresses potential endogeneity and selection bias, which are common challenges in analyzing access to essential services. By using this advanced technique, our study extends prior work by providing more accurate and policy-relevant insights into how water and energy access influences key well-being indicators. Furthermore, the focus on combined access to both resources offers a holistic perspective on their synergistic effects, an area often overlooked in earlier research.

3) ACCESS TO CLEAN WATER AND RELIABLE ENERGY IN SUDAN

This study focuses on Sudan. Millions of Sudanese do not have access to reliable energy, safe drinking water, or sanitation facilities. In part as a result, one-fourth of Sudan's population is malnourished. Sudan has huge discrepancies within its population in access to water, energy, and food nexus. The country's population is projected to continue to expand rapidly, further increasing demand for water, energy, and food.

In Sudan, 71.4 percent of the population has access to basic improved water (Table 3.1). However, rural households face much greater challenges in obtaining safe water—only 64 percent of rural households have access to basic improved water, compared to 78 percent of urban households. There also are sharp disparities between states—only about one-third of households have access to safe water in Red Sea, White Nile, and Gedaref, compared to 90 percent in Khartoum and Northern. Insufficient funding and inadequate management underlie the poor supply of safe drinking water to Sudanese households.

Table 3.1 Access to water in Sudan, Egypt, Ethiopia, and South Africa, in 2015 and 2022

Indicators	Sudan		Egypt		Ethiopia		South Africa	
	2015	2022	2015	2022	2015	2022	2015	2022
Access to drinking water, at least basic, %	91.8	94.5	98.7	98.8	41.5	51.5	57.1	64.9
Access to drinking water, limited (more than 30 mins), %	2.8	2.7	<1.0	<1.0	21.4	28.0	25.3	28.9
Access to drinking water, unimproved, %	2.0	1.1	1.0	<1.0	24.3	16.0	12.1	3.9
Access to drinking water, surface water, %	3.4	1.6	<1.0	<1.0	12.8	4.5	5.5	2.3
Access to drinking water, annual rate of change in at least basic, %/year	nd	0.5	nd	0.0	nd	1.5	nd	0.9
Drinking water, share of population using improved water supplies, accessible on premises, %	74.5	79.3	96.8	97.7	14.8	21.7	36.3	41.2
Drinking water, share of the population using improved water supplies, available when needed, %	73.6	71.4	79.7	82.4	51.7	66.9	45.8	55.1
Drinking water, share of population using improved water supplies, piped, %	nd	90.5	97.0	98.7	34.9	44.1	46.5	nd
Drinking water, share of population using improved water supplies, non-piped, %	nd	6.8	2.0	<1.0	28.0	35.4	35.9	nd
Basic drinking water services, share of population using at least, %	nd	64.9	98.7	98.8	41.5	51.5	91.8	nd

Source: UNICEF and WHO (2023).
Note: nd = "no data".

Thirteen million Sudanese are estimated to still use unimproved and unsafe sources of drinking water (UNICEF 2017). These sources include surface water and groundwater from open or damaged groundwater wells. Chemical or bacterial contamination often reduces the quality of the water sources. These contaminants are mostly derived from industrial, commercial, and domestic waste, including excreta, urine, and grey water, which is washed into surface water bodies or injected into groundwater aquifers. National and state-level acts to prevent harmful pollutants have been legislated in Sudan, but they are rarely activated and enforced. Access to improved water sources has increased over the last 30 years in Sudan. However, this access is gradually being eroded due to the country's high population growth, limited investment in housing, water, and sanitation infrastructure, and climate change compromising existing water supplies. The ongoing conflict which started in April 2023 has also reduced access to safe water supplies for many Sudanese households (IFPRI and UNDP 2024)

Only 53 percent of rural households have improved drinking water sources within a 30-minute walk, while 28 percent have even less access and must travel farther to safe water sources. The rest of the rural population uses dirty water from shallow waterholes (O'Brien 2023). This lack of access to safe water, combined with poor sanitation and inadequate hygiene practices, poses serious risks to children and has a considerable impact on rising malnutrition rates, illness outbreaks, and needless deaths. In 2022, over 3 million children under five years of age in Sudan suffered from acute malnutrition, half of which was associated with recurring diarrhea or worm infections caused by poor water, sanitation, and hygiene conditions (UNICEF 2023).

In parallel, Sudan's energy sector is underdeveloped, making household access to energy one of the country's greatest obstacles to social and economic development. Many people in Sudan rely largely on traditional biomass fuels, like wood, charcoal, dung, and agricultural waste, for cooking and heating. Only around 60 percent of the population has access to electricity or other clean cooking fuels (Table 3.2). Moreover, there are significant variations across Sudan in per capita energy consumption, particularly between urban and rural households.

Table 3.2 Access to energy in Sudan, Egypt, Ethiopia, and South Africa in 2015 and 2022

Indicators	Sudan		Egypt		Ethiopia		South Africa	
	2015	2022	2015	2022	2015	2022	2015	2022
Modern renewable sources, share in total final energy consumption, %	23.3	22.9 *(2020)*	2.2	3.3 *(2020)*	2.5	3.0 *(2020)*	2.4	3.9 *(2020)*
Access to clean cooking fuel, share of population, %	47.2	61.9	99.8	99.7	4.2	7.6	83.8	89.1
Access to clean fuels and technologies for cooking, share of population, %	48.0	65.6	99.9	99.9	4.3	8.8	83.8	89.4
Total electricity access rate, share of population %	48.0	63.2	99.3	100.0	29.0	55.0	85.3	86.5

Source: IEA, IRENA, UNSD, World Bank, and WHO (2023).

4) METHODOLOGY

The objectives of this study are twofold. First, we investigate the status and determinants of clean water and reliable energy access for Sudanese households. Second, the analysis is then extended to estimate the effect of access to clean water and reliable energy sources on selected household welfare outcomes, particularly food security and general health and well-being.

4.1 Data sources and sample characteristics

The data used for this study is the 2022 Sudan Labor Market Panel Survey (SLMPS), which was implemented by the Economic Research Forum in collaboration with Sudan's Central Bureau of Statistics. SLMPS is a comprehensive, national household survey designed to capture a wide range of socio-economic variables pertinent to the Sudanese labor market (Krafft, Assaad, and Cheung 2023). It is the first wave of a planned longitudinal study aimed at understanding human resource development and deployment in Sudan. The survey is modeled after similar labor market surveys conducted in Egypt, Jordan, and Tunisia. The survey questionnaire includes modules from the Living Standards Measurement Study Plus household survey program to collect gender-disaggregated information on asset ownership, employment, and entrepreneurship activities, including household enterprises. The survey is designed to be nationally representative, providing estimates at the national level, for urban and rural areas, and across all states of Sudan. The SLMPS sample is made up of approximately 5,000 households. Information is collected on all household members aged five years and above.

The SLMPS 2022 survey instruments encompass a broad range of topics essential for understanding the socio-economic landscape of Sudan. These include information on parental background, education attainment of household members, housing and access to services for the household, residential mobility and migration, and the time use of household members of working age. Questions are asked in the survey on the food security of the household and the health status of its members. The survey also explores marriage patterns, fertility, and women's empowerment, and provides detailed data on employment, unemployment, and earnings of household members of working age. Additionally, it examines the operation of household enterprises and farms, community infrastructure, and the use of social safety nets. The survey also captures household vulnerability and the strategies members use to cope with shocks to the household. Notably, it includes a significant number of retrospective questions about major life events, including residential moves, employment changes, marriage, and fertility. This allows for a comprehensive understanding of the timing and context of these events. Overall, the survey aims to provide a detailed and nationally representative picture of Sudan's labor market and related socio-economic processes, covering a diverse range of issues that affect the Sudanese population.

A random stratified cluster sampling technique was used to create the sample for SLMPS 2022. The survey is representative across several strata, including refugee camps, internally displaced persons (IDP) camps, and urban and rural areas. Two hundred fifty primary sampling units (PSU) were initially selected, with backup PSUs also selected for use if logistical challenges in surveying any of the initially selected PSUs arose during fieldwork. Data collection was conducted through face-to-face interviews from June to November 2022. Multiple visits were made to each household to ensure that information was collected directly from all members aged five years and older. The survey instruments included a household questionnaire and an individual questionnaire, both of which contained multiple modules to capture detailed socio-economic data.

Sample weights were generated to ensure national representativeness. The weights accounted for the probability of PSU selection and household inclusion within the selected PSUs. Detailed efforts were made to address potential biases due to non-response or logistical challenges during fieldwork.

Table 4.1 presents descriptive statistics on the sample households. Most of the households are headed by middle-aged males with very limited formal education. Table 4.1 also shows that most household heads in Sudan are either not employed or are self-employed.

Table 4.1 Analytical variables used, descriptive statistics

Variable	Mean
Dependent variables	
Access to clean water and reliable energy (1= yes, 0 =otherwise)	0.386
Access to improved energy sources (1= yes, 0 =otherwise)	0.322
Access to both improved water and improved energy sources (1= yes, 0 =otherwise)	0.250
Independent variables	
Urban household (0/1)	0.50
Female head of household (0/1)	0.23
Age of household head (years)	47.07
Household members (adult equivalent units)	5.22
Dependents in household (number)	2.49
Females in household (number)	2.65
Education level of household head (share of all household heads)	
Did not complete primary school, cannot read or write	0.43
Did not complete primary school, but can read and write	0.19
Completed primary school	0.19
Completed secondary school	0.11
Completed post-secondary schooling (not university)	0.01
Completed university	0.06
Completed postgraduate education	0.01
Employment of household head	
Wage worker	0.61
Employer	0.07
Self-employed	0.26
Unpaid family worker	0.05
Has no employment	0.02
Sector of employment of household head	
Agricultural sector	0.19
Manufacturing sector	0.04
Services sector	0.44
Not employed	0.32
Wealth index (5 = wealthiest; based on principal component analysis)[1]	3.22
Travel time to work (minutes)	32.53

Source: Authors' weighted analysis of the 2022 Sudan Labor Market Panel Survey.
Note: In the analysis, state-level dummy variables were included for all 18 states of Sudan.

4.2 Determinants of access to clean water and reliable energy

To assess the determinants of access to clean water sources and reliable energy sources in Sudan, we estimated a binary logistic regression model using cross-sectional data from the SLMPS for 2022. The binary logistic model is appropriate for our analysis as it is designed to

[1] The wealth index used to rank households was constructed using Principal Component Analysis (PCA), a common method for creating composite indices based on household asset ownership, housing characteristics, and access to services. PCA assigns weights to various indicators, creating a standardized index to rank households into wealth quintiles. For details on this methodology, see Filmer and Pritchett (2001) and Vyas and Kumaranayake (2006).

predict the probability of a binary outcome, i.e., access to clean water, access to reliable energy, or both, based on one or more predictor variables.

The model estimates the probability that a given observation falls into one of these categories. The reduced form of the binary logistic model applied in our study is given by:

$$logit(P(Y=1)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon_i \quad (1)$$

where Y is the dependent variable (access to clean water; access to reliable energy; or both); β_0 is the intercept; β_1, β_2, $\cdots$ β_n are the coefficients for the independent variables; and ϵ_i is the error term. The independent variables for the analyses include the range of demographic, socio-economic, and regional factors described in Table 4.1.

4.3 Effect of access to clean water and reliable energy on selected household outcomes

The second objective of this study is to estimate the effects of access to clean water and reliable energy on household food security and the overall health status of the household. The model used to estimate these effects can be expressed as:

$$Y_i = \beta_0 + \beta_1 T_i + \beta 2 X_i + \epsilon_i \quad (2)$$

Y_i represents the outcome variable for household *i*. We use two different outcome variables. The food security status of the household is based on the Food Insecurity Experience Scale (FIES) (Cafiero, Viviani, and Nord 2018, FAO 2021). The second outcome, the overall health status of the household, is based on a multinomial variable measured across five levels in ascending order from “very poor” to “excellent.” It is expected that households with access to clean water and reliable energy sources will have better health outcomes because of reduced incidences of waterborne diseases and respiratory-related illnesses.

The main explanatory variable of interest is T_i, which is measured as a binary treatment variable taking the value of one if a household accessed clean water or reliable energy sources, or both, and zero otherwise. X_i denotes a vector of covariates, including a range of demographic, socio-economic, and regional factors as described in Table 4.1. ϵ_i is a random error term, and the βs are the parameters to be estimated.

We recognize that there is a potential selection bias problem when estimating the effects of access to clean water, reliable energy, or both (equation (2)), given that access to water or energy is not based on random assignment. To reduce this potential bias, we apply the inverse-probability regression adjustment method, which is also known as the doubly robust estimation technique (Wooldridge 2010). While this method can correct for selection bias due to observable characteristics, it cannot control unobserved heterogeneity. Unfortunately, the access to clean water and reliable energy being assessed here is not based on experimental design, which can properly address unobserved heterogeneity bias. Furthermore, we are unable to rely on an instrumental variable (IV) approach to correct for selection bias problems because of the difficulty in identifying valid instruments based on the secondary nature of our data. Thus, we refer to the estimated relationships between T_i and Y_i in equation (2) as correlations rather than causal impacts.

The doubly robust method follows three steps.

- First, logit regression models are used to estimate the probability of a household accessing clean water, reliable energy, or both, i.e., the treatment model.
- Second, using inverse-probability weights obtained from the first step, weighted outcome models are fitted to obtain the predicted outcomes for the households with access and those without access (outcome models). Note that the outcome models are fitted using linear, probit, and Poisson regression models for continuous, binary, and count outcome variables, respectively.
- Finally, the means of the predicted outcomes are then used to estimate the average treatment effect on the treated (ATET), which quantifies the effects on household food security or general health status of access to clean water or reliable energy sources.

These three steps of the doubly robust method are jointly estimated using the *teffects ipwra* command in the Stata statistical software package.

In this instance, the doubly robust method is superior to other commonly used selection-on-observable estimators, such as propensity score matching (PSM). This is because the doubly robust property ensures that if either one of the treatment or outcome models is misspecified, the ATET estimates will still be consistent (Imbens and Wooldridge 2009).

5) RESULTS AND DISCUSSIONS

5.1 Summary statistics and t-tests

We constructed three different binary outcome variables for this study—access to clean water sources, access to reliable energy sources, and access to both clean water and reliable energy sources. We conducted t-tests to compare the means of the explanatory variables across the access and no-access groups for the three different outcome variables.

For access to clean water, the t-tests show significant differences between households with and without clean water access for several explanatory variables (Table 5.1). Households with clean water access are more likely to be urban and to have heads that are male and relatively older. Additionally, households with lower ratios of dependents in the household lower are more likely to be able to access clean water. Higher educational attainment of the household head is significantly associated with clean water access across all education levels—households with heads that have not completed primary education are more likely not to have access to clean water. Households with wage workers and employers are significantly likely to have access to clean water, as are households with workers employed in the services sector. Wealthier households are more likely to have access to clean water.

Table 5.1 Clean water access—explanatory variables t-tests

Variable	Overall mean	Clean water access		Difference	p-value
		Clean water	Unclean water		
Urban household	0.503	0.707	0.378	-0.328	0.000
Female head of household	0.226	0.167	0.262	0.095	0.000
Age of household head	47.070	49.750	45.830	-3.920	0.000
Household members	5.224	5.195	5.241	0.046	0.260
Dependents in household	2.487	2.184	2.674	0.489	0.000
Females in household	2.653	2.597	2.687	0.090	0.021
Cannot read write	0.425	0.224	0.549	0.324	0.000
No ed–can read write	0.194	0.176	0.205	0.030	0.005
Completed primary	0.191	0.275	0.139	-0.136	0.000
Completed secondary	0.106	0.172	0.066	-0.106	0.000
Completed post-sec	0.011	0.023	0.004	-0.020	0.000
Completed university	0.055	0.101	0.027	-0.074	0.000
Completed postgrad	0.008	0.020	0.000	-0.020	0.000
Wage worker	0.186	0.280	0.128	-0.152	0.000
Employer	0.045	0.064	0.033	-0.031	0.000
Self-employed	0.283	0.302	0.271	-0.032	0.010
Unpaid family worker	0.047	0.022	0.062	0.040	1.000
Has no employment	0.286	0.223	0.325	0.102	1.000
Agricultural sector employ	0.188	0.102	0.242	0.140	1.000
Manufacturing sector employ	0.035	0.047	0.028	-0.019	0.001
Services sector employ	0.432	0.579	0.342	-0.237	0.000
Wealth quintile	3.216	4.204	2.607	-1.597	0.000
Travel time to work	32.529	26.613	36.170	9.558	1.000

Source: Authors' analysis.

The t-tests for access to reliable energy similarly reveal significant differences for the explanatory variables for households with and without such access (Table 5.2). Households with access to reliable energy are significantly more likely to be urban, with older or more educated household heads. Wealthier households are more likely to have access to reliable energy.

Table 5.2 Reliable energy access—explanatory variables t-tests

Variable	Overall mean	Energy access		Difference	p-value
		Reliable sources	Unreliable sources		
Urban household	0.503	0.706	0.409	-0.296	0.000
Female head of household	0.226	0.154	0.259	0.105	1.000
Age of household head	47.019	49.737	45.758	-3.979	0.000
Household members	5.224	5.190	5.239	0.050	0.749
Dependents in household	2.487	2.136	2.650	0.514	1.000
Females in household	2.653	2.599	2.678	0.079	0.959
Cannot read write	0.425	0.160	0.548	0.387	1.000
No ed–can read write	0.194	0.171	0.205	0.034	0.997
Completed primary	0.106	0.194	0.066	-0.128	0.000
Completed secondary	0.011	0.024	0.005	-0.019	0.000
Completed post-sec	0.055	0.123	0.024	-0.098	0.000
Completed university	0.008	0.023	0.001	-0.022	0.000
Completed postgrad	0.186	0.278	0.144	-0.134	0.000
Wage worker	0.045	0.075	0.031	-0.044	0.000
Employer	0.000	0.312	0.269	-0.042	0.002
Self-employed	0.047	0.022	0.059	0.037	1.000
Unpaid family worker	0.286	0.218	0.318	0.100	1.000
Has no employment	0.188	0.098	0.230	0.132	1.000
Agricultural sector employ	0.035	0.051	0.028	-0.023	0.000
Manufacturing sector employ	0.432	0.605	0.352	-0.252	0.000
Services sector employ	0.432	0.605	0.352	-0.252	1.000
Wealth quintile	3.216	4.487	2.626	-1.860	0.000
Rooms per adult	0.636	0.787	0.566	-0.221	0.000
Travel time to work	32.529	29.196	34.075	4.880	1.000

Source: Authors' analysis.

For access to both clean water and reliable energy (Table 5.3), significant differences are observed for multiple variables. Urban households are significantly more likely to have combined access. Households with older household heads and with lower dependents ratios are both associated with combined access. Households with heads with relatively higher educational attainment are significantly more likely to have access to both clean water and reliable energy. Wealthier households are significantly more likely to have combined access.

Table 5.3 Both clean water and reliable energy access—explanatory variables t-tests

Variable	Overall mean	Both clean water and reliable energy access		Difference	p-value
		Does not have access to both	Unreliable sources		
Urban household	0.503	0.726	0.431	-0.295	0.000
Female head of household	0.226	0.148	0.251	0.104	0.000
Age of household head	47.019	50.559	45.866	-4.693	0.000
Household members	5.146	5.146	5.249	0.103	0.096
Dependents in household	2.487	2.069	2.623	0.555	0.000
Females in household	2.653	2.568	2.680	0.112	0.011
Cannot read write	0.425	0.126	0.522	0.396	0.000
No ed–can read write	0.194	0.153	0.207	0.055	0.000
Completed primary	0.191	0.311	0.152	-0.159	1.000
Completed secondary	0.106	0.207	0.074	-0.134	1.000
Completed post-sec	0.011	0.029	0.005	-0.024	1.000
Completed university	0.055	0.137	0.029	-0.108	1.000
Completed postgrad	0.008	0.029	0.001	-0.028	1.000
Wage worker	0.186	0.296	0.150	-0.146	1.000
Employer	0.045	0.075	0.036	-0.039	1.000
Self-employed	0.283	0.326	0.269	-0.057	1.000
Unpaid family worker	0.047	0.021	0.055	0.034	0.000
Has no employment	0.286	0.193	0.316	0.123	0.000
Agricultural sector employ	0.188	0.097	0.218	0.121	0.000
Manufacturing sector employ	0.035	0.050	0.030	-0.019	0.997
Services sector employ	0.432	0.614	0.373	-0.241	1.000
Wealth quintile	3.216	4.573	2.774	-1.799	1.000
Travel time to work	32.529	26.145	34.607	8.462	0.000
Travel time to work	32.529	29.196	34.075	4.880	1.000

Source: Authors' analysis.

5.2 Regression analysis on determinants of household access to clean water and reliable energy

We estimated three logistic regression models to examine the determinants of the access that Sudanese households have to clean water, to reliable energy, and to both clean water and reliable energy. The results (odd-ratios) are presented in Table 5.4.

Table 5.4 Determinants of improved water and improved energy access

Variable	(a) Clean water access		(b) Reliable energy access		(c) Access to both clean water and reliable energy	
	Coefficient	Stnd. error	Coefficient	Stnd. error	Coefficient	Stnd. error
Urban household	1.633***	0.121	0.483***	0.135	1.067***	0.142
Female head of household	0.160	0.137	-0.266	0.167	-0.223	0.182
Age of household head	0.016***	0.004	0.000	0.004	0.007	0.005
Household members	-0.057	0.042	0.020	0.048	-0.027	0.050
Dependents in household	-0.056	0.042	-0.026	0.049	-0.050	0.051
Females in household	-0.008	0.051	-0.062	0.060	-0.033	0.063
No ed–can read write	0.381***	0.144	0.450***	0.170	0.420**	0.190
Completed primary	0.697***	0.142	0.893***	0.158	1.152***	0.173
Completed secondary	0.777***	0.177	0.967***	0.192	1.238***	0.204
Completed post-sec	1.559***	0.534	1.653***	0.560	1.734***	0.541
Completed university	0.574**	0.232	1.430***	0.262	1.315***	0.255
Completed postgrad	3.333***	1.098	4.218***	1.211	4.506***	1.174
Employer	-0.189	0.232	-0.004	0.247	-0.295	0.255
Self-employed	0.005	0.126	0.036	0.144	-0.103	0.148
Unpaid family worker	-0.212	0.303	-0.115	0.384	-0.280	0.428
Employer	0.075	0.141	0.351**	0.164	0.297	0.182
Manufacturing sector employ	-0.173	0.255	-0.123	0.296	-0.562*	0.296
Services sector employ	0.225**	0.110	-0.045	0.129	0.068	0.140
Wealth quintile	0.870***	0.054	1.634***	0.088	1.786***	0.105
Rooms per adult	-0.138	0.124	0.414**	0.163	-0.004	0.147
Travel time to work	-0.012***	0.002	-0.004*	0.002	-0.013***	0.003
Central Darfur	-0.780***	0.299	0.000 [a]	0.000	0.000 [a]	0.000
East Darfur	-2.363***	0.235	-3.900***	0.324	-3.379***	0.362
North Darfur	-2.410***	0.246	-3.703***	0.344	-2.904***	0.372
South Darfur	-2.377***	0.229	-3.821***	0.320	-3.294***	0.360
West Darfur	-3.494***	0.378	-3.819***	0.490	-3.559***	0.637
North Kordofan	-1.097***	0.227	-3.430***	0.290	-3.066***	0.314
South Kordofan	-5.318***	1.021	0.000[b]	0.000	0.000 [b]	0.000
West Kordofan	-3.668***	0.406	-5.510***	0.661	-4.386***	0.676
Sennar	1.309***	0.261	-1.511***	0.237	-0.415*	0.241
Gedaref	-1.923***	0.256	-2.242***	0.286	-2.564***	0.334
Blue Nile	-0.769***	0.231	-3.638***	0.332	-2.942***	0.356
White Nile	-2.905***	0.279	-2.818***	0.292	-4.421***	0.621
Northern	0.957***	0.290	0.783**	0.377	0.742***	0.281
River Nile	1.650***	0.304	2.306***	0.429	2.867***	0.385
Aj Jazirah	1.508***	0.226	-1.878***	0.208	-0.924***	0.205
Kassala	-0.017	0.229	-1.837***	0.252	-1.057***	0.260
Red Sea	-5.390***	0.398	-1.017***	0.256	-5.291***	0.418
Constant	-3.758***	0.340	-5.937***	0.445	-7.797***	0.530
Observations	4,741		4,365		4,365	
Chi-squared	3547.8		3573.1		3234.8	
Adjusted R-squared	0.563		0.636		0.639	
p-value	0.000		0.000		0.000	

Source: Authors' analysis.

Note: The analytical variables ‘Cannot read write’, ‘Wage worker’, ‘Agricultural sector employ’, and ‘Khartoum’ were dropped from the regression analyses to avoid overspecification.
[a, b:] Central Darfur and South Kordofan have zeros in the reliable energy and combined access models due to insufficient data or lack of variation in access levels in these regions.

5.2.1 Access to clean water

The logistic regression results for household access to clean water identify several significant predictors (Table 5.4, panel (a)). Urban households are notably more likely to have access to sources of clean water compared to rural households, highlighting the disparity in infrastructure and resource allocation between urban and rural areas. Urban centers typically benefit from higher investments and better governance, which improve access to essential services and infrastructure for urban households. This is consistent with findings by Antunes and Martins (2020), who emphasize the importance of infrastructure investments and governance in urban areas for improving water access.

Examining specific determinants of household access to clean water, the age of the head of the household shows a positive and significant effect on access to clean water—households with older heads are more likely to have such access, possibly due to their generally greater financial stability. The educational attainment of the head emerges as another crucial determinant of water access, aligning with findings by Bamou Tankoua (2021) and Adams et al. (2016). It is particularly households with heads that cannot read and write that are likely not to have access to clean water. All of the variables on educational attainment used in the regression show positive coefficients relative to the base case of households with heads that cannot read and write. These results underscore the role of education in enhancing household welfare and access to essential services, as educated individuals are more likely to understand the benefits of clean water sources and navigate the systems to obtain them. Furthermore, there is a noticeable trend that higher education levels correlate with better access to water.

Wealth, as indicated by the household's wealth quintile, is another significant positive predictor of clean water access. Households with greater wealth have the financial capacity to invest in better water sources, either through direct infrastructure investments or by residing in areas with superior public services.

The “Travel time to work" variable is used as a proxy for the quality of local infrastructure. This variable has a significant negative effect on access to clean water access. Longer travel times suggest poor local infrastructure, which hinders the access of households to clean water sources.

Spatially across the states of Sudan, several exhibit significantly lower odds of households having access to clean water compared to the reference category of Khartoum—East Darfur, North Darfur, South Darfur, West Darfur, South Kordofan, and West Kordofan states are particularly disadvantaged in their access to clean water. These regional disparities highlight the need for targeted interventions to improve access to clean water in order to resolve underlying spatial inequalities. Conversely, certain regions show significantly higher odds of households having access to clean water relative to Khartoum—households in Sennar, Aj Jazirah, River Nile, and Northern states all have relatively good access to clean water sources. A common factor among these states is their location within the Nile Basin, with the river providing a reliable water source. Additionally, these states generally have smaller populations compared to the densely populated capital, Khartoum, which may reduce the strain in each on the provision and continuing maintenance of clean water infrastructure.

5.2.2 Access to reliable energy

The findings for access to reliable energy are detailed in Table 5.4, panel (b). The results indicate that urban households are significantly more likely to have access to improved energy sources than their rural counterparts. This mirrors the pattern observed in access to clean water, further emphasizing the urban–rural divide in the availability of essential services. Unlike other factors, the sex of the household head does not significantly impact energy access, suggesting it is not a determining factor for households in securing access to reliable energy sources. This pattern was also seen in the analysis of the determinants of household access to clean water.

As with access to clean water, education is also a key predictor of household access to reliable energy, with a pattern similar to that seen for clean water—households that are headed by individuals who can read or write or have completed some education are significantly more likely to have access to reliable energy. These findings highlight the pivotal role of education in household welfare and the accessibility of modern energy services, as educated individuals tend to be more knowledgeable about the benefits and methods of obtaining improved and reliable energy.

Wealth is another significant positive determinant of access by households to reliable energy. Households with greater financial resources are better able to afford the higher costs associated with accessing reliable energy sources. Additionally, the number of rooms in a household serves as an indicator of better living conditions, so the variable is positively correlated with a household having access to reliable energy. As with access to clean water, poor local infrastructure quality, as measured by the "Travel time to work" variable, negatively affects the access of local households to reliable energy. Longer travel times to work suggest poorer infrastructure, which, in turn, hampers the ability of households to access sources of reliable energy.

As with access to clean water, households in most of the states in the Darfur and Kordofan regions face challenges in accessing reliable energy sources. However, households in several other states also are found to face significant difficulties in accessing reliable energy, even though their access to clean water is relatively good—notably, Gedaref, Blue Nile, and White Nile. This pattern should motivate efforts to enhance energy infrastructure across Sudan and address the inequalities in access to reliable energy. However, several states stand out for households in them having relatively good access to reliable energy—River Nile, particularly, but also Northern state exhibit significantly higher odds of securing better energy sources compared to Khartoum. Even after accounting for other factors, these states appear to have better access to reliable energy.

5.2.3 Combined access to clean water and energy

The results for combined access to clean water and energy are presented in Table 5.4, panel (c). Urban households exhibit higher odds of having combined access to clean water and reliable energy compared to rural households. This result, consistent with the previous models, highlights the substantial advantages urban households have over rural ones in accessing essential services.

Education remains a consistent and significant predictor across all levels. Households where the head can read and write or has received any education are more likely to have combined access to clean water and energy than households in which the head cannot read or write. This underscores the overarching importance of education in securing better living conditions and access to services.

Wealth significantly increases the likelihood of a Sudanese household having combined access to clean water and reliable energy—wealthier households are better able than poorer ones to afford both clean water and reliable energy. Infrastructure development, as indicated by the time spent commuting to work, shows a significant negative effect on combined access, suggesting that household's resident in areas with poorer local infrastructure face greater barriers in obtaining both clean water and reliable energy.

The regional disparities seen with access to clean water and reliable energy, respectively, persist when considering combined access to both. Again, households in most of the states in the Darfur and Kordofan regions have poor access. However, households in many of the other states also face challenges in accessing both clean water and reliable energy. Only households in Northern and River Nile states are more likely than households in Khartoum to have access to both clean water and reliable energy. These results highlight the compounded disadvantage faced by households in most states in Sudan, necessitating comprehensive regional development strategies to address the multifaceted nature of deprivation in access to essential services, including clean water and reliable energy.

5.2.4 Summary of the analyses of the determinants of household access to clean water and reliable energy in Sudan

The logistic regression analyses provide critical insights into the determinants of access to clean water and reliable energy for the population of Sudan. Urbanization, education, and wealth emerge as significant positive predictors, highlighting the disparities between urban and rural areas and the importance of socioeconomic status in securing basic services. Urban households consistently show higher access to both clean water and reliable energy. This underscores the need for rural development programs to bridge the gap in service provision between urban and rural areas. Investment in rural infrastructure and services is essential to ensure equitable access to essential services across different geographic locations.

Education is a powerful determinant of access to clean water and energy. Higher levels of education achieved by household heads are associated with significantly better access for their households to both. This indicates that educational attainment enhances the ability of individuals and their households to navigate and benefit from available resources and services, including clean water and reliable energy. These findings suggest that policies aimed at improving educational outcomes could have far-reaching effects on access to essential services and overall household welfare.

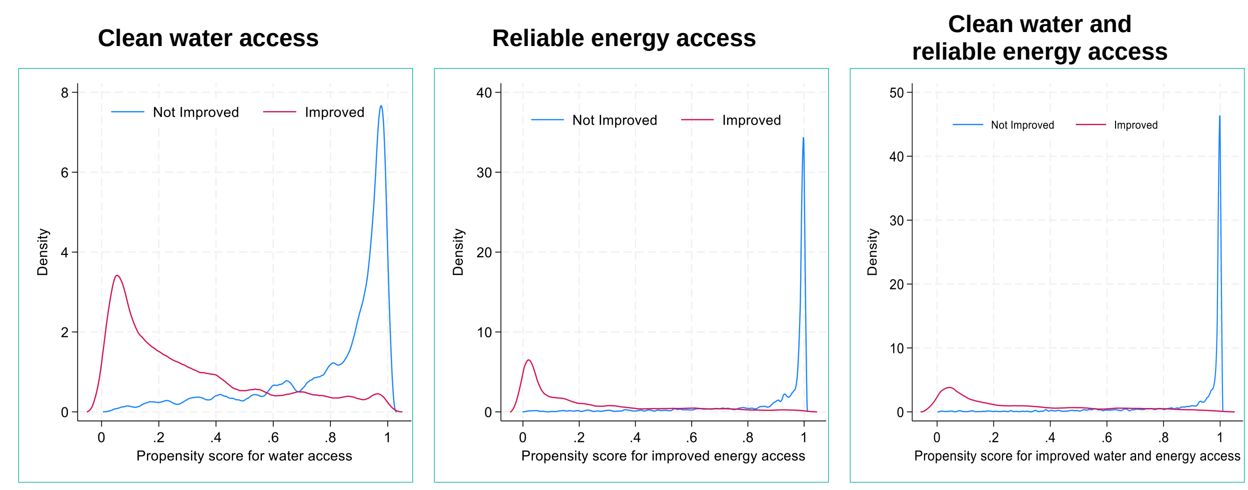
Wealth also plays a crucial role in determining access to clean water and reliable energy. Wealthier households can better afford the costs associated with accessing and maintaining these services. This finding highlights the need for economic policies that promote income growth and reduce poverty to enhance access to such essential services.

The significant regional disparities in access to clean water and reliable energy, particularly in the Darfur and Kordofan regions, point to the need for targeted regional interventions. The states in these regions face compounded disadvantages that require comprehensive development strategies addressing infrastructure and public services.

5.3 Effects on household welfare of access to clean water and reliable energy

Before examining the doubly robust estimation results on the effects of access to clean water and energy on household food security and health, we first ensure that the estimated models pass essential diagnostic tests. Figure 5.1 shows sufficient overlap in the covariate distributions of households with access and those without access to clean water and reliable energy sources. This suggests a non-violation of the overlap or common support condition (Imbens 2004). Furthermore, following Imai and Ratkovic (2014), we present corroborating balance diagnostic test results in Table 5.5. Those results show insignificant Chi-squared statistics, which confirm that the first step of the doubly robust model successfully balanced the covariates by weighting.

Figure 5.1 Overlap plots for covariate distributions of households with access and those without access to clean water and energy sources



Source: Authors' analysis.

Table 5.5 Covariate balancing test results

Treatment variable	Chi-squared	p-value
Food security		
Access to clean water sources	68.74	0.7865
Access to reliable energy sources	46.48	0.1130
Access to clean water and reliable energy sources	8.66	0.9997
Household health status		
Access to clean water sources	71.09	0.7848
Access to reliable energy sources	46.52	0.1127
Access to clean water and reliable energy sources	8.65	0.9997

Source: Authors' analysis.

The results in Table 5.6 show that access to clean water is positively correlated with food security and health. However, the treatment effect estimate is only significant for the health status of the households with access to clean water have a 54 percent higher likelihood of having better health status than households without access. On the other hand, access to reliable energy is positively and significantly correlated with both food security and health status of households. Specifically, the analysis shows that households using reliable energy sources have a 19 percent and 72 percent higher likelihood of having better food security and health status, respectively, than households without access to reliable energy. Furthermore, households with access to both clean water and reliable energy sources show positive correlations with both food security and health status, though only the effect on health status is marginally statistically significant, with a 46 percent higher likelihood of having better health status than households with access to neither clean water nor reliable energy.

Table 5.6 Effects of improved water and improved energy on household food security and health

Variable	Clean water access			Reliable energy access			Both clean water and reliable energy access		
	ATET	Robust SE	ATET in %	ATET	Robust SE	ATET in %	ATET	Robust SE	ATET in %
Food security (1/0)	0.082	0.024	118.5	0.446***	0.052	19.0	0.054	0.050	23.5
Health status (1/0)	0.025*	0.018	54.4	0.047***	0.021	72.4	0. 060*	0.032	46.2

Source: Authors' analysis.
Notes: ***p < 0.01, **p < 0.05, *p < 0.1.
ATET = "average treatment effect on the treated", SE = "standard error".

These findings align with the research literature indicating that access to clean water and reliable energy sources is crucial for enhancing household well-being. For instance, Hutton and Haller (2004) found that access to clean water and sanitation reduces the incidence of waterborne diseases, thereby improving overall health. Similarly, the World Health Organization (WHO 2006) reported that improved and more reliable energy sources, such as electricity and clean cooking fuels, reduce indoor air pollution and related health risks, contributing to better health outcomes. Additionally, studies by Guarcello, Lyon, and Rosati (2008) show that clean water and reliable energy infrastructure can enhance food security by increasing agricultural productivity and reducing the time burden on household members, particularly women, allowing them more time for food production and other income-generating activities.

6) CONCLUSIONS AND POLICY RECOMMENDATIONS

This study explored the determinants of household access to clean water and reliable energy in Sudan, drawing on data from the 2022 Sudan Labor Market Panel Survey. By employing binary logistic regression models and the doubly robust estimation technique, the analysis revealed critical insights into the disparities in household access to these essential resources and their impact on food security and health outcomes.

The analysis identified several key determinants of the access of households to clean water and reliable energy in Sudan. Urban households are significantly more likely to have access to these resources than rural ones, highlighting the urban-rural divide. Education also emerged as a crucial determinant, with higher educational attainment by the head of the household being strongly associated with better access by the household to both water and energy. Wealthier households were found to have a greater ability to secure clean water and reliable energy services, underscoring the importance of economic resources in obtaining these essential services. Additionally, regional disparities were evident, particularly in the Darfur and Kordofan states, where access to clean water and reliable energy is notably lower compared to other states. These findings underscore the urgent need for targeted interventions to ensure equitable access to essential services across Sudan.

The impact of access to clean water and reliable energy on food security and health outcomes was also a key focus of this study. The results indicated that households with access to improved energy were more likely to experience better food security and health outcomes. In contrast, access to improved water was strongly associated with better health outcomes, but a less important driver of improved household food security. These findings align with the broader literature, emphasizing the importance of clean water and reliable energy access in enhancing household well-being and reducing vulnerability to health risks.

Given the disparities and the critical role of water and energy access in improving livelihoods, several policy recommendations emerge from these findings. There is a pressing need for investments in rural infrastructure, particularly in the water and energy sectors. Expanding access to these services in rural areas can significantly enhance living standards and economic opportunities, helping to bridge the urban-rural divide. Strengthening educational systems, particularly in rural areas, should be a priority. Education is a powerful tool in improving access to essential services, as higher educational attainment is closely linked to better access to water and energy. Policies aimed at improving educational outcomes could have a multiplier effect on household welfare and access to resources.

Enhancing household incomes through economic growth and poverty reduction strategies is vital. Wealth is a significant determinant of access to clean water and reliable energy. Policies that promote economic development and reduce poverty can help more households secure these essential services. Significant regional disparities in the access households have to clean water and reliable energy require targeted interventions to eliminate. These should include investments in infrastructure, improved governance, and tailored public services that address the unique challenges faced by disadvantaged regions. Such comprehensive development strategies are necessary to mitigate the compounded deprivations experienced by households in these areas.

In conclusion, addressing the multifaceted challenges of water and energy access by households in Sudan is critical for improving the quality of life for all its citizens. By implementing the recommended policy measures, Sudan can make significant strides toward achieving equitable access to essential services, thereby fostering greater social and economic development across the country.

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ABOUT THE AUTHORS

Oliver K. Kirui is a Research Fellow in the DSG Unit of IFPRI, based in temporarily Nairobi, Kenya. **Mosab Ahmed** is a Senior Research Assistant in the Development Strategy and Governance (DSG) Unit of the International Food Policy Research Institute (IFPRI), based in Cairo, Egypt. **Mariam Raouf** is a Senior Research Associate in IFPRI's DSG Unit, based in Cairo. **Hala Abushama** is a Research Assistant in IFPRI's DSG Unit, based temporarily in Cairo. **Khalid Siddig** is Senior Research Fellow in IFPRI's DSG Unit and the Leader of IFPRI's Sudan Strategy Support Program, based temporarily in Nairobi and an Associate Professor at the University of Khartoum.

ACKNOWLEDGMENTS

This work was carried out under the CGIAR Initiative on NEXUS Gains, which is grateful for the support of CGIAR Trust Fund contributors: www.cgiar.org/funders. Funding for the SSSP is graciously provided by the United States Agency for International Development (USAID).

The Sudan Strategy Support Program (SSSP) is managed by the International Food Policy Research Institute (IFPRI) and is financially supported by the United States Agency for International Development (USAID). This publication has been prepared as an output of SSSP and has not been independently peer reviewed. Any opinions expressed here belong to the author(s) and are not necessarily representative of or endorsed by IFPRI.

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email: ifpri-sudan@cgiar.org | https://sudan.ifpri.info/