

A Feasibility Study on Barriers to Access to Solar Photovoltaic Energy: A Survey Study of Moundou, Chad

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Abstract

It is widely acknowledged that energy sources such as the sun are potential providers of clean, limitless, and free energy that could satisfy energy needs now and in the future. This is particularly relevant when only small amounts of energy are necessary, such as in tiny homes or rural areas. For this study, we conducted a feasibility analysis by surveying local authorities and households in Moundou, Chad. The aim was to identify the barriers preventing households from accessing energy. The key decision-making data in this paper are based on the sample proportion of respondents and the margin of error associated with the five central pillars of the survey questionnaire. These five pillars, along with their proportions and margins of error, are as follows: consciousness and expertise, 96% and 3.14%; adoption-related obstacles, 95% and 3.49%; financial aspects, 98% and 2.24%; technical problems, 91% and 4.58%; and finally, community participation, 98% and 2.24%. The research findings were analyzed using logistic regression, ANOVA, chi-square tests of independence, and descriptive statistics. The significant barriers identified were financial factors and community engagement. To overcome these challenges, we have formulated the following recommendations: develop targeted financial mechanisms, implement awareness and education campaigns, enhance technical capacity building, and improve policy and regulatory frameworks.

Keywords: Performance Analysis, Energy Barriers, Social Assessment, Household, Solar Photovoltaic Systems, Chad.

Introduction

One of the targets in the United Nations (UN) Sustainable Development Goals (SDGs) for 2030 is access to clean, sustainable, and dependable modern energy (SDG#7) (Bandaru et al., 2021). Access to energy is fundamentally linked to human development, as it supports economic growth and industrialization, social transformation, and achieving various sustainable development goals (SDGs) (Sadath & Acharya, 2024). This correlation is evident across multiple dimensions of development, including health, education, living standards, global energy footprint, and economic opportunities (Mulugetta et al., 2019). Globally, around 1.5 billion people lack access to energy for their homes, offices, and healthcare

facilities. Most of these energy-precarious communities are in rural areas, where several factors prevent them from connecting to energy networks (Sokolnikova et al., 2020).

A nation's social and economic development depends on its energy resources (Sindhu et al., 2016a). Energy infrastructure is vital for developing a country because it influences economic growth, energy security, and the enhancement of energy services. The need for sustainable and equitable energy systems in low- and middle-income countries is underscored by the significant political and economic impact that large-scale energy projects can generate.

Chad, a low-income country in Central Africa, has a surface area of 1,284,000 km² and over 19 million people. According to data from the International Monetary Fund (IMF), Chad's government expenditure on projects as a percentage of Gross Domestic Product (GDP) has been as follows: in 2021, it was 13.91%; in 2022, it was 14.01%; and in 2023, it is 18.10%. These data show that public spending in Chad has varied over the years.

Chad has enormous potential for solar energy development. The country's climate is characterized by significant sunlight, though the climate ranges from desert to tropical. Despite this, only 11.3% of Chad's population has access to electricity, making Chad among those countries with the lowest electrification levels and the last in access to the clean energy index (Casati et al., 2023; Kojucharov, 2007). Beyond cities, rural areas show an even more challenging picture, with 1.3% access to electricity (Adoum Abdoulaye et al., 2024). Because no national or regional grid can meet energy needs or potential demands, many cities in Chad experience the same situation. In the Western Logon region of Chad and the city of Moundou (~142,000 inhabitants), Figure 1, the lack of electricity continues to hamper the growth of the local economy and the population's ability to meet its needs.

The problem in Chad is not just access to technology and infrastructure. Significant barriers across the country include technical, social, and economic barriers to energy renovation or transition in rural Chad and the factors households face in adopting solar photovoltaic systems for sustainable development. These challenges make Chad an exemplary case for examining the barriers to energy independence in low—and middle-income countries.

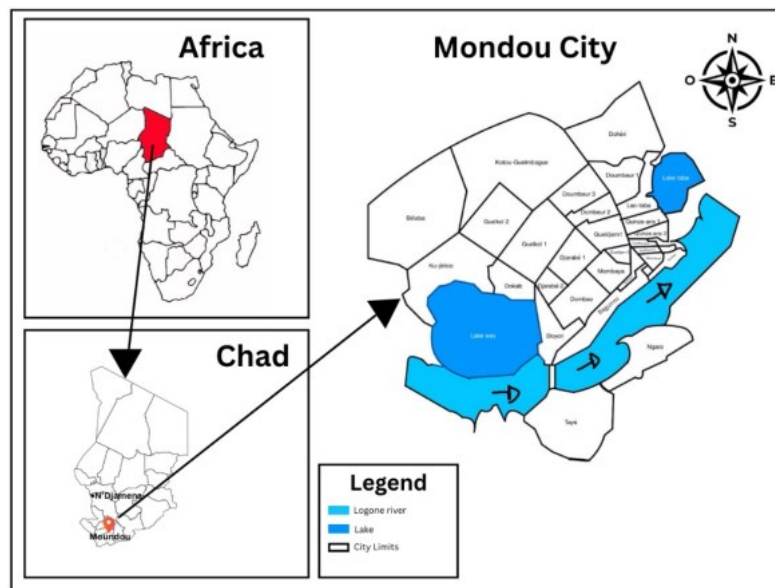


Fig.1: Map of the study site.

This paper explores the social barriers to deploying sustainable energy solutions in Chad, particularly in Moundou. Not only does this solution increase access to electricity for the population, but it also preserves the country's environment and biodiversity. The paper unfolds as follows: we review the existing literature, highlighting the global and regional challenges of PV adoption—financial, technical, community engagement, and policy constraints—while emphasizing the lack of localized studies in sub-Saharan Africa, especially in Moundou. We then outline our research methodology, having surveyed a diverse range of citizens, including households, small business owners, and policymakers, to better understand the challenges in Moundou related to accessing solar photovoltaic systems. The study examines these challenges in light of best practices, such as government subsidies and educational campaigns, and proposes targeted strategies to address these barriers, including policy reforms and capacity-building initiatives. These findings aim to inform energy planning and promote sustainable PV adoption in Moundou and similar contexts.

Although photovoltaic solar energy is a simple solution for the transition revolution, many barriers hinder its widespread adoption. The main obstacles to the broad acceptance of photovoltaic systems are technical, financial, regulatory, social, and political. The adoption of photovoltaic solar energy faces multifaceted hurdles. To overcome these challenges and accelerate the energy transition, an integrated approach combining political incentives, technological advancements, and stakeholder engagement is crucial. The issue we are trying to understand is why Chad has a low rate of access to electricity and what the barriers are to accessing clean energy, specifically photovoltaic solar power. To achieve this, we surveyed the populations of Moundou.

The main objective of this research is to perform a feasibility study through a survey to identify the barriers to access to solar photovoltaic (PV) energy. This principal objective was achieved through the specific objectives:

- *Barrier's identification*
 - Assess the current level of awareness and knowledge about solar energy among the target population.
 - Identify the socio-economic factors (income, education, occupation) that influence access to solar photovoltaic technologies.
 - Examine technical barriers, such as product availability, maintenance services, and technical assistance.
 - Assess financial barriers, including the willingness to invest in solar PV installations, affordability, and access to credit.
 - Identify cultural and behavioral barriers that restrict the adoption of solar photovoltaic technologies.
 - Identify regulatory and institutional barriers, such as government policies, subsidies, or bureaucratic challenges.
- *Analysis of the effects and interactions between barriers*
 - determines which barriers significantly impact the system as a whole and which are most interconnected to prioritize changes.
 - Utilized statistical analytics for testing, including regression analysis, chi-square, and ANOVA tests.
- Assess the needs and views of stakeholders, evaluate the level of acceptance, and consider the expectations of different stakeholders (households, businesses, decision-makers, and installers) regarding solar photovoltaic systems.
- Proposals for solutions and recommendations based on the compilation of respondents' suggestions for actions to address the identified hurdles.

Literature Review

Socioeconomic growth depends heavily on energy access, especially in sub-Saharan Africa. More and more people believe that distributed solar photovoltaic (PV) energy is a practical way to supply electricity to isolated, underdeveloped areas. However, several obstacles prevent its broad use. While solar photovoltaics presents a promising solution for energy access in Sub-Sahara Africa, overcoming financial, infrastructural, and policy barriers is essential for its widespread adoption. Strategic investments, innovative business models, and robust governance can unlock the potential of solar energy to drive socioeconomic growth in the region (Intergovernmental Panel On Climate Change, 2014). Investments in solar PV can stimulate economic growth by providing reliable energy, enhancing productivity in sectors like agriculture, and creating jobs. Aligning renewable energy development with financial objectives and strengthening institutions to coordinate

investments can improve energy access and support sustainable development goals (Chirambo, 2018).

"Energy barriers" describe impediments to energy conservation and efficient use (Hu & Yang, 2024). They may be organizational, social and behavioral, institutional, market-related, economic, technological, or political (Devine-Wright & Sherry-Brennan, 2019).

The issues identified in the research relate to the need for an in-depth understanding of the barriers and factors influencing medium- and long-term energy access in Moundou's Western Logone.

In this literature review, various approaches were adopted to ensure transparency in data collection through the survey systematically. For the search task, the identified key barriers mentioned earlier were used to locate articles that discuss the adoption aspect of energy barriers to accessing electricity. Here, we review the literature on public perceptions and reactions to various energy barriers and new energy technologies.

Based on the work (Hesslink & Chappin, 2019), we focused on six focus areas: demographic information, awareness and knowledge, barriers to adoption, economic factors, technical challenges, and community engagement.

The demographic aspect comprises five questions. These questions provide information about the participants, such as stakeholders (teachers, accountants, students, biomedical engineers, nurses, midwives, translators, educational planners, and renewable energy engineers). The table below summarizes the participant numbers in percentages for this aspect. Table 1 shows the stakeholders during the survey.

Table 1: The stakeholders involved in the study.

Stakeholder	Frequency	Percentage (%)
Teachers	28	19
Accountants	18	12
Students	29	19
Biomedical engineers, Nurses, Midwives	20	13
Translators	16	11
Educational planners	17	11
Renewable energy engineers	22	15
Total	150	100

Source: Survey data

Studies (Irfan et al., 2021), (Alkawsi et al., 2024; Jabeen et al., 2024) have shown that user uptake is significantly impacted by perception, awareness, and knowledge of the advantages of solar energy. Barriers in Moundou include a lack of understanding of solar PV technology and cultural preferences for conventional energy sources. The awareness and

knowledge questions aim to assess what participants already know about the solar photovoltaic system and their commitment to our expectations of them.

Social acceptance greatly influences the adoption of solar photovoltaic technology. This section addresses three questions. Our goal is to identify the obstacles that hinder potential populations from adopting photovoltaic technology, which affects energy access. These questions help us better understand the perceived or actual barriers and identify strategies to overcome them.

The high initial installation cost is one of the main obstacles to the widespread use of solar PV. Studies have shown that many families and small companies in developing nations cannot afford the initial capital needed for PV systems, including purchase, transportation, and installation. Affordability is still a significant obstacle in Chad, where the per capita income is among the lowest in the world (Gafa et al., 2022). This problem is exacerbated by restricted access to funding options. Chad lacks government-subsidized loans and microfinance institutions that have worked well in other nations (Ebissa & Asfaw, 2024). Researchers conducted research that emphasizes how financial mechanisms can lower costs and boost adoption rates. The economic factor comprises six questions. It plays a crucial role in surveys, particularly those linked to almost all human activities. Economic factors provide an indispensable dimension for understanding and analyzing the realities under study. They enable us to interpret the data better and propose solutions adapted to the population's economic reality (Ghaleb et al., 2023).

In rural areas, technical problems like a shortage of qualified workers for installation and maintenance are significant obstacles. According to research (Mondal et al., 2018), inadequate knowledge and experience frequently result in poorly installed systems, which shortens their lifespan and efficiency. Chad's lack of regional technical training facilities further restricts the spread of technical expertise.

Another issue is the absence of a strong supply chain for solar PV components. According to an (*IRENA_RE_Capacity_Statistics_2021 (1).Pdf*, n.d.) IRENA 2021 report, Chad is among many sub-Saharan African nations with restricted access to high-quality solar panels, batteries, and inverters. High transit costs and procurement delays exacerbate the technical difficulties. Incorporating technical difficulties into surveys guarantees a comprehensive grasp of the PV technology environment, opening the door for workable solutions that quicken the switch to renewable energy (Mathew & Nagaraja Pandian, 2024). Technical issues with photovoltaic (PV) technologies are crucial in surveys and research because they shed light on the constraints, possibilities, and possible advancements of solar energy systems (Nuru et al., 2021). It is essential to draw attention to these difficulties in a survey for several reasons: recognizing obstacles to efficiency, difficulties with materials and costs, problems with integration and deployment, sustainability and environmental considerations, and new developments in technology and innovation. The total number of questions in this technical section was seven (7).

The Community engagement barriers consisted of six questions. This section is crucial, as we aimed to determine the extent to which community involvement might also serve as a barrier. This information could assist in the decision-making process.

Some nations have effectively overcome these obstacles by implementing focused measures. For example, off-grid solar power in Rwanda, backed by international aid and government subsidies, has shown notable gains in energy availability (Blimpo & Cosgrove-Davies, 2019). Similarly, low-income households can purchase solar systems thanks to Kenya's creative pay-as-you-go (PAYG) methods (Rolffs et al., 2018).

Chad, particularly Moundou, can learn significantly from these examples, especially concerning the use of public-private partnerships and the implementation of flexible financial mechanisms. To attract private investment, Chad can offer subsidies, tax rebates, or exemptions from import duties on solar equipment. Establishing clear laws and regulations can encourage business participation. Chad can also engage independent power producers (IPPs) to develop large-scale solar farms and supply electricity to the grid. Utilizing solar-powered processing and irrigation equipment can strengthen the local economy. Another flexible financial mechanism is that Chad can access global climate funding tools, such as the African Development Bank's (AfDB) renewable energy initiatives and the Green Climate Fund (GCF). By adapting these strategies, Chad can accelerate solar PV adoption, boost economic development, and improve energy access.

To enhance energy access in sub-Saharan Africa, it is essential to strengthen existing infrastructure, promote energy communities, and attract private investment while addressing climate challenges and social needs (Haou et al., 2024a).

Numerous social, economic, behavioral, and technical factors influence the adoption of photovoltaic solar panels. Several specific adoption frameworks have been developed to enhance the relevance of studies, integrating theoretical, empirical, and technological approaches (Sindhu et al., 2016b). Utilizing suitable adoption frameworks allows for a better understanding and forecasting of PV solar adoption by considering local contexts, consumer behavior, and equity issues (Rebucas et al., 2024).

The Study Site

Moundou, the economic capital of Chad, presents several features that make it an excellent location for studying solar energy photovoltaic (PV) systems. With abundant solar resources, Moundou, like much of Chad, enjoys consistent and intense solar radiation due to its proximity to the equator. The Angstrom-Prescott model estimates an average global solar irradiation of 5.88 kWh/m²/day with a high-reliability score ($R^2 = 0.843$) (Soulouknga et al., 2017). This indicates a strong capacity for solar energy generation. Long sunshine hours contribute to the region receiving sunlight for most of the year, maximizing the potential energy output from solar PV systems (Solano & Affonso, 2023).

Energy demand and access challenges, along with limited grid connectivity, mean that many areas and their surroundings lack a reliable power network. This situation creates a significant need for decentralized energy solutions like solar PV systems. As Moundou serves as an economic hub, energy demand is rising, making it a compelling case study for integrating solar energy in urban and peri-urban settings.

Environmental and climatic conditions, including minimal cloud cover and a relatively stable, dry climate, decrease the variability of solar power output, making it easier to model and assess system reliability (Feron et al., 2020). Examining PV systems in Moundou at high temperatures allows for evaluation under conditions that can impact PV module efficiency and overall system performance.

Off-grid solar installations offer substantial potential for rural electrification and off-grid applications. The surrounding rural communities can benefit significantly, as these systems also act as a practical laboratory for testing standalone systems and microgrids. Community impact studies utilizing PV systems in Moundou enable researchers to analyze socio-economic effects, including enhanced access to education, healthcare, and economic opportunities.

Solar PV systems enhance the region's energy independence and sustainability goals (Obaideen et al., 2023). They promote sustainable development and decrease reliance on fossil fuels while addressing limited access to conventional energy resources (Praveenkumar et al., 2022).

With research and policy opportunities and tailored system designs, Moundou offers a diverse environment for studying various PV system configurations, including fixed, tracking, and hybrid systems. The policy department's insights can inform energy policies and strategies for similar African regions (Adom, 2019).

Focusing on Moundou allows researchers and practitioners to address technical and socio-economic challenges, supporting the broader adoption of solar PV systems in other high-potential regions. Table 2 below shows the key variable in site selection.

Table 2: Key Factors in Site Selection.

Variable	Description	Reference
Economic and demographic importance	Strategic role: Moundou's agro-industrial operations, particularly the manufacture of beer and cotton, have made it a significant regional economic hub. To promote development and production, this calls for consistent availability of energy; Population growth: As the population grows, so does the need for energy for residential and commercial purposes. Therefore, it is an excellent laboratory for researching the difficulties associated with energy access in semi-urban settings.	(Haou et al., 2024b)
Disparities in access to energy	High reliance on conventional energy biomass sources: much of Moundou's population still gets their energy from wood, coal, or oil, just like in many other parts of Chad; Limited access to power: Inequalities arise because, despite their existence, electricity infrastructures are not enough to supply all residences and enterprises.	(Haou et al., 2024b)
Geographic and climatic context	Sahelian climate: with abundant sunshine, Moundou is an excellent location to investigate alternative solar energy options; Natural resource proximity: Although some energy resources, such as biomass and hydraulics, are in the area, their use is still restricted.	(Duman & Güler, 2018)
Infrastructure difficulties	Weak energy infrastructure: frequent power outages and a limited power grid. One of the biggest problems facing both individuals and businesses is access to reliable electricity; High costs: Many people still need help finding solutions like solar panels or other energy sources.	(Jahangiri et al., 2019)
National and regional topics represented	A typical example: Moundou's reliance on imported fossil fuels and lack of investment in the energy sector are issues many other cities in Chad and Sub-Saharan Africa (SSA) face; Possibility of local remedies: examining neighborhood projects in Moundou may yield replicable examples for comparable communities.	(Haou et al., 2024b)
Opportunities for innovation	Pilot projects: because of its size and significance, Moundou is a perfect place to test new energy technologies, including solar mini-grids and public-private energy collaborations; Community mobilization: energy projects may benefit from the active participation of nearby communities in development efforts.	(Nambisan et al., 2018)

In short, Moundou is a microcosm of the opportunities and challenges associated with energy availability in semi-urban sub-Saharan African contexts. Its diverse backgrounds allow us to explore practical ideas that could be applied to other similar locations (Haou et al., 2024b).

Methodology

This study explores the challenges of implementing solar energy in the Sahel region of Sub-Saharan Africa through a case study of Moundou, Chad. To do this, we will:

- Identify the obstacles hindering the implementation of solar photovoltaic energy in rural Chad, particularly in Moundou.
- Identify key barriers: Examine the policy, social, technological, and economic barriers to the region's adoption of solar energy.
- Assess resource potential: examine the solar energy capabilities in Moundou, taking into account solar irradiance, climate conditions, and land availability;
- Encourage sustainable development by offering dependable and clean energy access, essential for raising living standards and stimulating economic growth in rural and isolated places; the ultimate goal is to support sustainable socio-economic development (Mugisha et al., 2021).
- Recognizing governance and policy frameworks: One of the main goals is to determine how institutional, governance, and policy frameworks facilitate or obstruct the use of solar energy. Accelerating electrification entails examining the necessity of stable policy frameworks and the engagement of non-governmental entities.
- Examine technology solutions: The project is to investigate technology developments and innovations, such as inexpensive solar tracking systems and hybrid energy models, that promote the use of solar energy (Jahangiri et al., 2019).
- Propose sustainable solutions: recommendations for overcoming obstacles and enhancing the execution of solar energy projects in Moundou and its surrounding areas.

The graphs below reflect the conceptual findings for the site study, highlighting the most critical challenges in Moundou that need to be addressed.

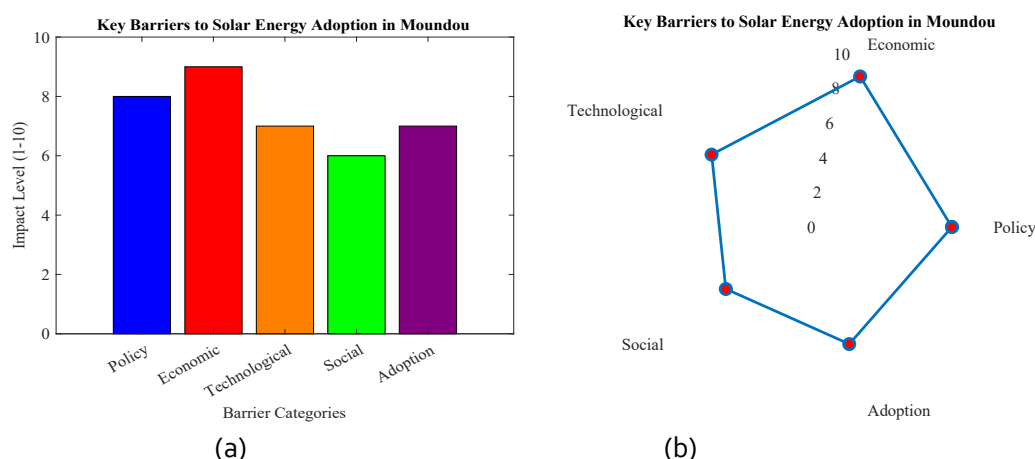


Fig. 2: The graphic illustrates these points, which reflect the conceptual findings

These figures (a) help visualize which areas require the most attention. These graphs were developed to illustrate how points in our literature review reflect the conceptual findings for the site study, highlighting the most critical challenges. A radar chart (b) features five labeled axes representing policy, economic, technological, social, and adoption barriers. The shape of the chart provides a quick visual comparison of the most significant challenges. Here, economic barriers stand out as the most significant challenge. The highest value in the radar chart shows that financial constraints pose the greatest obstacle, followed by policy barriers. Social barriers have the lowest impact, but they must be addressed to ensure equitable energy access. This analysis suggests that a combination of policy reforms, financial mechanisms, and public-private partnerships is essential for accelerating solar energy adoption in Moundou.

We gathered data from April to August 2024. We disseminated the survey to residents of Moundou in four arrondissements through three methods: 1) delivering the survey to households, 2) distributing surveys in areas where people congregated, and 3) allowing some respondents to complete the survey via phone. We communicated with our respondents using local languages (e.g., French, Moundang, Arabic, and Ngambaye). To facilitate this, we visited various centers, including hospitals, schools, universities, town halls, and both private and state-owned companies. Together, these techniques effectively address the diverse challenges to adopting solar PV and guide targeted policy actions and strategies.

We based our strategy for identifying the target population for the survey. As mentioned above, we utilized random sampling, an appropriate sampling technique, to make a sound decision. The aim is to determine whether the sample is representative and to extrapolate (generalize) to the entire population.

Following Bradley et al. (2021), we ensured the validity and reliability of our study by deploying a stratified random sample of the population. Each respondent lived in a

household broken into age groups: 18-25, 26-35, 36-50, 51-65, and over 66. This was used to determine the sample size (Neely et al., 2021). We stratified by age to facilitate data analysis.

We determined that the sample size should be 150 individuals. We calculated the margin of error using the formula below to ensure this is possible (Petersen & Allman, 2019) (Naing et al., 2022). Let MoE be the margin of error expressed as a percentage (%), and use the formula (1) below to compute it.

$$MoE(\%) = Z - value \times \sqrt{\frac{P \times (1-P)}{n}} \quad (1)$$

The sample proportion, or percentage, is denoted by $P = 0.96$. The sample size is $n = 150$. The Z-value is a critical value obtained through the confidence level (Serdar et al., 2021). The Z-values for the typical confidence levels are shown in Table 3 below.

Table 3: Confidence level for Z-value (Arieska & Herdiani, 2018) (Sharma et al., 2020).

Confidence level	Z-value
90%	1.64
95% *	1.96 *
99%	2.58

We used Chi-square and ANOVA tests to analyze the relationships between categorical and quantitative variables. These tests enable us to understand the factors influencing the energy barriers, notably energy transition and consumer responses to energy crises (Adnan & Shahrina, 2021). The chi-square is symbolized as X^2 , and it can be applied only if the following requirements are fulfilled before the test.

- Expected and observed observations must be gathered at random.
- Every participant (or item) in the sample needs to be autonomous;
- There must be a minimum of 10 items in each group;
- There must be a significant quantity of things (at least 50).

Applying the appropriate degree of freedom and significance and consulting a chi-square table can help one ascertain the importance of the chi-square value. The chi-square test has two unique uses: it can determine how well the observed data distribution matches the expected distribution and test the hypothesis that there is no correlation between two or more groups, populations, or criteria (Nihan, 2020). Data analysis is necessary to find the degrees of freedom, expected frequencies, test statistics, and the P-value associated with the test statistic. The following is equivalent to degrees of freedom (DF):

$$DF = (r - 1) \times (c - 1) \quad (2)$$

The level number for the other category variable in this calculation is c , and r is a variable. Expected frequency counts are computed independently for each level of one categorical variable at every level of the other categorical variable. The predicted frequencies yield: $r \times c$.

$$P_{r,c} = (n_r \times n_c) / n \quad (3)$$

Where $P_{r,c}$ is the predicted frequency number for level r of the variable A and level c of the variable B . the total number of sample observations at level r of variable A is denoted by n_r . At level c of the variable B , n_c is the total number of sample observations. The entire sample size is denoted by n .

Test the statistic. The equation below defines the test statistic, a chi-square random variable (X^2).

$$X^2 = \left[(O_{r,c} - P_{r,c})^2 / P_{r,c} \right] \quad (4)$$

$O_{r,c}$ is the observed frequency at variable A 's level r and variable B 's level c .

The probability of observing a sample statistic as extreme as the P-value indicates the test statistic. The chi-square test statistic evaluates the probability linked to the test statistics, utilizing earlier degrees of freedom.

The following is the hypothesis for the chi-square test of independence:

H_0 : The variables of correlation are independent.

H_1 : There is a correlation between significant factors.

We structured open-ended survey responses from Moundou households, company owners, and energy industry stakeholders to collect qualitative data. Purposive sampling was used to select the participants, guaranteeing a range of viewpoints on PV adoption.

Survey

From the literature review, we created five essential pillars for our survey: 1) awareness and knowledge, 2) barriers to adoption, 3) financial factors, 4) technical challenges, and 5) community engagement. We calculated the margin of error for each barrier, knowing their sample proportions to inform our final decision. Based on the percentages of the five essential pillars, we applied a 95% confidence level denoted by stars (*), resulting in a Z-value of 1.96, as respondents indicated 98% agreement, except for technical challenges. Table 4 below supports the conclusion.

Table 4: The standard margin of error and its interpretation (Royal, 2017).

Margin of error (%)	Interpretation
Less than ± 3	Excellent interpretive validity
Between ± 3 -5	Good interpretative validity
Greater than ± 5	Questionable interpretative validity. Value should be carefully understood.

Our survey comprises five dimensions:

- 1) We examined the local challenges by identifying specific barriers to power access in Moundou, such as cost, infrastructure, and regulatory restrictions.

- 2) We assessed energy demand and gathered information about the energy requirements of companies, businesses, and families, ensuring that any proposed solution would align with these consumption trends.
- 3) We assessed socioeconomic impacts by examining the effects of restricted access to electricity on small businesses, healthcare, education, and overall quality of life.
- 4) We recommend that the government and NGOs invest in electrifying Moundou, the economic capital of Chad.
- 5) We examined attitudes toward the viability of successfully deploying renewable energy sources.

They include local government officials, such as representatives from the Ministry of Energy and the local energy department; municipal officers involved in urban planning and infrastructure; traditional chiefs or elders representing local communities; and religious leaders who influence community decisions. Additionally, energy professionals—including solar PV installation companies, technicians, and experts from local universities or technical institutes specializing in energy or environmental studies, as well as representatives from NGOs and international organizations focused on renewable energy in the region—are also key informants (Van Opstal & Smeets, 2022).

Public squares and survey locations included central marketplaces in Moundou and smaller neighborhood markets to ensure diverse socioeconomic representation. Public squares and gathering areas, such as places of independence, notable landmarks, parks, or community centers, are where locals socialize. Bus stations and taxi stands serve as points for interaction with commuters and transport operators. Educational institutions such as high schools, vocational training centers, and universities offer insights into technological adoption from students and educators. Religious institutions, including churches and mosques, act as community meeting points.

To these key informants and the survey locations identified in Moundou, we combined face-to-face, group interviews (Palm, 2017), and door-to-door methods to create a comprehensive approach to data collection on barriers to access to solar PV (Mah et al., 2018).

Survey Design and Participants

The survey included 38 questions, including basic inquiries on demographics, awareness and knowledge, adoption hurdles, technical difficulties, community involvement, and economic (budgetary and financial) elements that would affect possible home energy retrofits.

Participants from diverse professional backgrounds, including those from various energy industry sectors, were grouped to gather insights on barriers. Below, we present some of the experienced participants. The classification below shows the professionals among the 150 respondents:

- Class 1 Scholars and technicians in public administration.

- Class 2 Educational planners and accountants.
- Class 3 Biomedical engineer, midwife.
- Class 4 Students and the lecturer.
- Class 5 Translators.
- Class 6 Teachers' Unions.
- Class 7 EMABIOTEC training center for photovoltaic solar energy.
- Class 8 Directorate of Renewable Energies at the Ministry of Water and Energy.

Ethical Clearance and Informed Consent

Ethical considerations and informed consent in surveys of barriers to access to photovoltaic solar energy. In studies involving surveys with the public about barriers to accessing solar photovoltaic energy, obtaining ethical authorization and explicit consent is crucial. This ensures the validity and integrity of the data collected while safeguarding participants' rights, confidentiality, and dignity. Research on the barriers to adopting solar PV energy often relies on qualitative methods such as semi-structured interviews, household surveys, or expert consultations (Yadav et al., 2020), (Mogrovejo-Narvaez et al., 2024). For this study, we used a household survey. Although the resumes don't specifically detail the ethical approval or consent processes, the nature of these studies typically involves collecting personal information and opinions, which requires careful consideration of research ethics. For this study, everything was clear with the authority of the Republic of Chad before starting the survey. Before agreeing to participate, the participants were informed of the study's purpose, the nature of their involvement, the confidentiality of their data, and their right to withdraw at any time. Modifying consent procedures to account for linguistic, cultural, or educational barriers in isolated or economically disadvantaged communities is essential (Vignon et al., 2025). Using participatory methods and appropriate communication techniques encourages comprehension and adherence to clarified consent.

Results and Discussion

We present the survey results in six steps. First, in Section 5.1, we present the results for participants by age group, including the percentages of men and women and their professions. In Section 5.2, we present the results for awareness and expertise. In Section 5.3, we discuss obstacles to adoption. In Section 5.4, we address the financial factor. Section 5.5 discusses technical issues, and we close with the community involvement factor in Section 5.6. In each section, except the first, we calculate the margin of error by applying the formula above to aid decision-making.

Understanding Demographics

Fig. 1 below presents demographic information about the households that participated in the study. We considered five age groups: 18-25, 26-35, 36-50, 51-65, and over 66. We

established these age groups to enable us to segment the data, facilitate analysis or interpretation, and examine the trend of the issue at hand. The number of participants in each group is 18, 43, 53, 26, and 10. We were fortunate to meet all the individuals in these age groups, which allowed us to visualize them in terms of the number of participants.

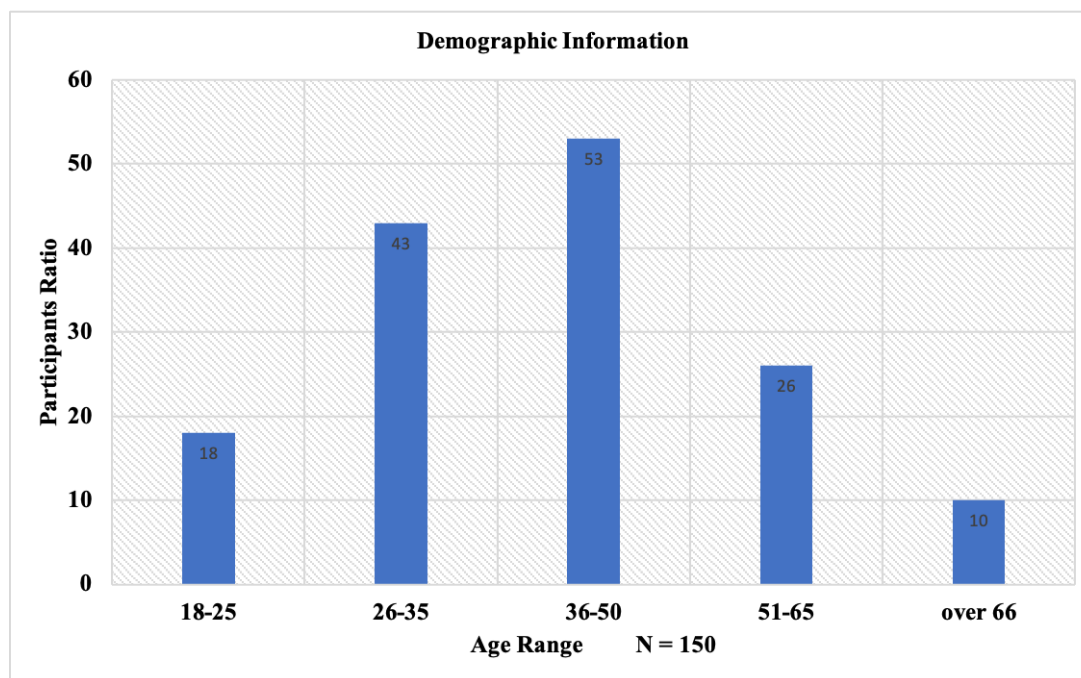


Fig. 3: Demographic Information

In Fig. 2 above, we can see that the 36-50 age group had a significant participation rate of 35.33%. This can be attributed to their dedication, commitment, maturity, and experience in the field of study. Following this age group was the 26-35 age group, which had a participation rate of 28.66%. The 51-65 age group had a participation rate of 17.33%, the 18-25 age group had a rate of 12%, and the over-66 age group had a rate of 6.66%.

Considering the different responsibilities and challenges that men and women confront when surveying obstacles to accessing solar energy is crucial. Although men often dominate the supply side, women's participation is essential for empowerment and effective household energy use. Addressing gender-specific hurdles can enhance the efficacy and reach of solar energy initiatives, promoting wider access and sustainability. The number of men who participated in the survey was greater than that of women. In percentage terms, 71% of men and 29% of women participated. Fig. 4 below shows the different professions of the people we spoke to during our fieldwork.

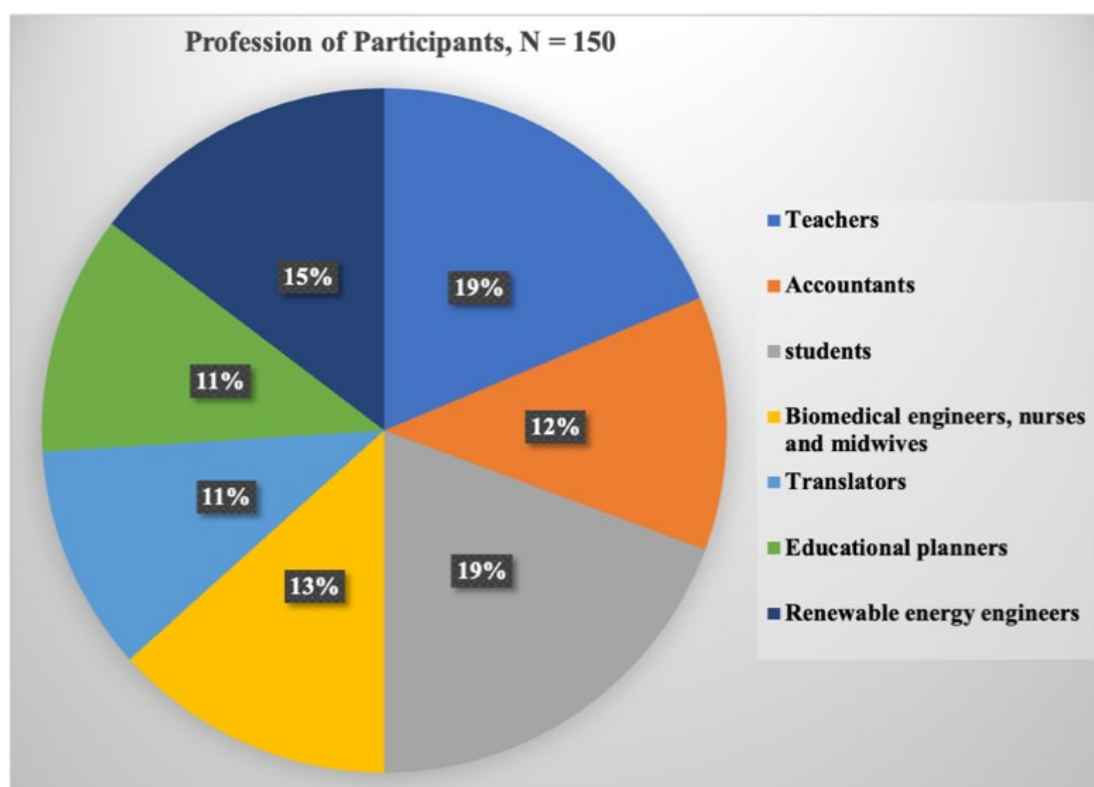


Fig. 4: Profession of participants.

Fig. 4 displays the percentages of the various professions of the participants. The teaching and student professions each account for 19%. This significant number of students arises from some civil servants being granted higher education permits, allowing them to enroll in university. During our survey, they were recorded as students on the survey form. Renewable energy engineers at the Ministry of Oil and Energy represent 15%; biomedical engineers, nurses, and midwives account for 13% at the provincial hospital in Moundou; accountants make up 12% in private companies; educational planners comprise 11% in public and private institutions, and finally, translators also represent 11% in state companies (oil sites).

These socio-demographic parameters (age, gender, and level of education or occupation) are necessary for this study. Firstly, they enable us to determine who filled in the survey form. Secondly, this allows us to assess the survey data and its quality in terms of the study. Third, as we wanted to survey a representative sample of a population on the issue of energy barriers, knowledge of the distribution of our respondents' demographic characteristics is vital. This helps us understand how closely the sample replicates the population. Survey respondents must be categorized according to their professional positions to analyze and comprehend energy constraints. Depending on their experience,

duties, and industry environment, professionals often have different experiences with or perceptions of these barriers.

A summarizes the data from these two figures, which can be found in Table 5 below. It is worth noting that, according to Table 5 of respondents' demographics, all respondents are interested in using solar and photovoltaic energy despite multiple barriers.

Table 5: Demographic profile of respondents (N = 150).

Demographic Variable	Level	Percentage (%)	
Gender	Male	82	55
	Female	68	45
Age	18-25	18	12
	26-35	43	28.66
	36-50	53	35.33
	51-65	26	17.33
	Over 66	10	6.66
Occupation	Teachers	28	19
	Accountants	18	12
	Students	29	19
	Biomedical engineers, nurses, and midwives	20	13
	Translators	16	11
	Educational planners	17	11
	Renewable energy engineers	22	15
Total		150	100

Source: Survey data.

Consciousness and Expertise

This second stage is crucial for completing our work, as it is based on the evaluation of knowledge and skills related to our field of research. To this end, we present the results of five questions. For each question, blue represents the first answer, yellow represents the second, and grey represents the third. Questions with only one color indicate that there is only one answer for that question.

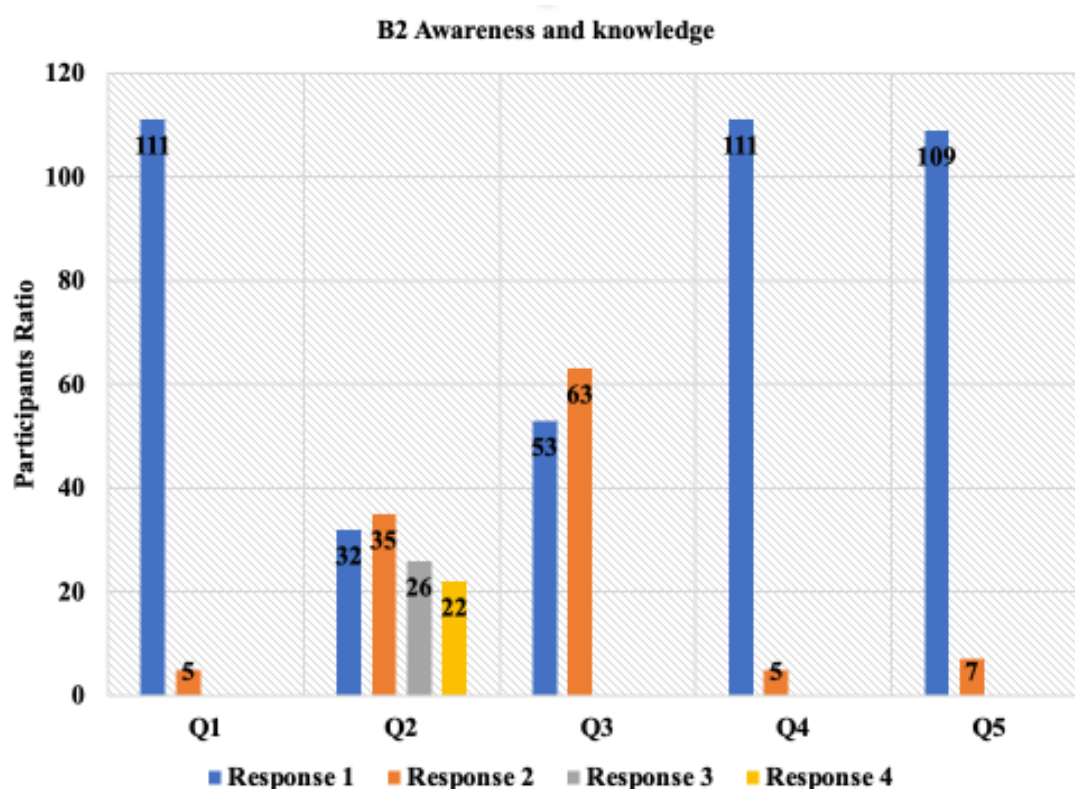


Fig 5. Rate of response for each question regarding awareness and knowledge.

The first question in Fig 5 above asks how many people have heard of solar photovoltaic systems. The answer is 95.68%, with 96% of participants having listened to PV systems and 4.31% having not.

The second question in Fig. 5 above allows us to evaluate the level of understanding of solar photovoltaic technology, divided into four categories: poor, average, sound, and excellent. The results are as follows: 28.44% of the respondents had a low level of understanding of solar photovoltaic technology; 30.17% had an average level of experience; 22.41% had a good level of knowledge of PV technology, and only 18.96% had an excellent level of understanding of solar photovoltaic technology. In short, the level of knowledge regarding this technology still needs improvement to achieve the desired results for sustainable development.

Question 3 presents two response elements based on the information or training received regarding solar photovoltaic systems. The first indicates that 45.68% of participants obtained information or training on solar PV systems through media channels, word of mouth, educational institutions, or non-governmental organizations. Among those who have heard of or received training in solar PV systems, renewable energy engineers possess an acceptable level of experience, although they are fewer in number. Following them are university instructors and students who have a moderate level of expertise in solar PV. The

number of participants who did not receive information or training is greater than those who did, precisely 54.31%. Most individuals lacking experience in solar PV include midwives, nurses, biomedical engineers, translators, and others. This description clearly shows that most participants have not yet received training on solar PV systems.

Question 4 provided two responses, with 95.68% of respondents indicating that awareness and knowledge of solar PV systems could be enhanced in rural communities by implementing solar PV projects, increasing local awareness, and initiating training or workshops on the importance of solar PV for sustainable development.

Question 5 asked whether organizing training sessions or workshops on solar photovoltaic systems would benefit people living in rural areas. This question received two responses. 93.96% of the participants answered affirmatively and suggested topics to be covered during the training sessions or workshops, including the following:

- Advantages of renewable energy for sustainable development.
- Management and maintenance of solar photovoltaic systems.
- Sizing solar photovoltaic system installations.
- Accessibility regarding availability and cost; ecological advantages.
- Advantages and disadvantages of utilizing photovoltaic systems in rural areas.

The number of participants answering no was negligible compared to those answering yes, at 6.03%. Therefore, many individuals are motivated to organize training courses or workshops to promote solar photovoltaic systems.

Let's calculate the margin of error (MoE) using formula (1) to ensure representativeness and to determine whether this data is generalizable. The final decision relies on the value of the margin of error compared to the various values outlined in Table 4. The margin of error is 0.0314 or 3.14%.

A smaller margin of error indicates more accurate estimates of population parameters, while a larger margin suggests less precision. Here, we aim to minimize the margin of error to enhance confidence in our study's results. Regarding the energy barrier results related to awareness and expertise, we have a 96% proportion of participants, accompanied by a calculated margin of error of 3.14%. This margin of error value demonstrates that our data are representative and generalizable.

Barriers to Adoption

This part of the study focuses on the primary barriers to adopting solar photovoltaic systems in rural communities. These barriers typically arise from cultural and economic factors. Fig. 6 illustrates the key obstacles to adopting solar photovoltaics, as described by three questions in rural areas.

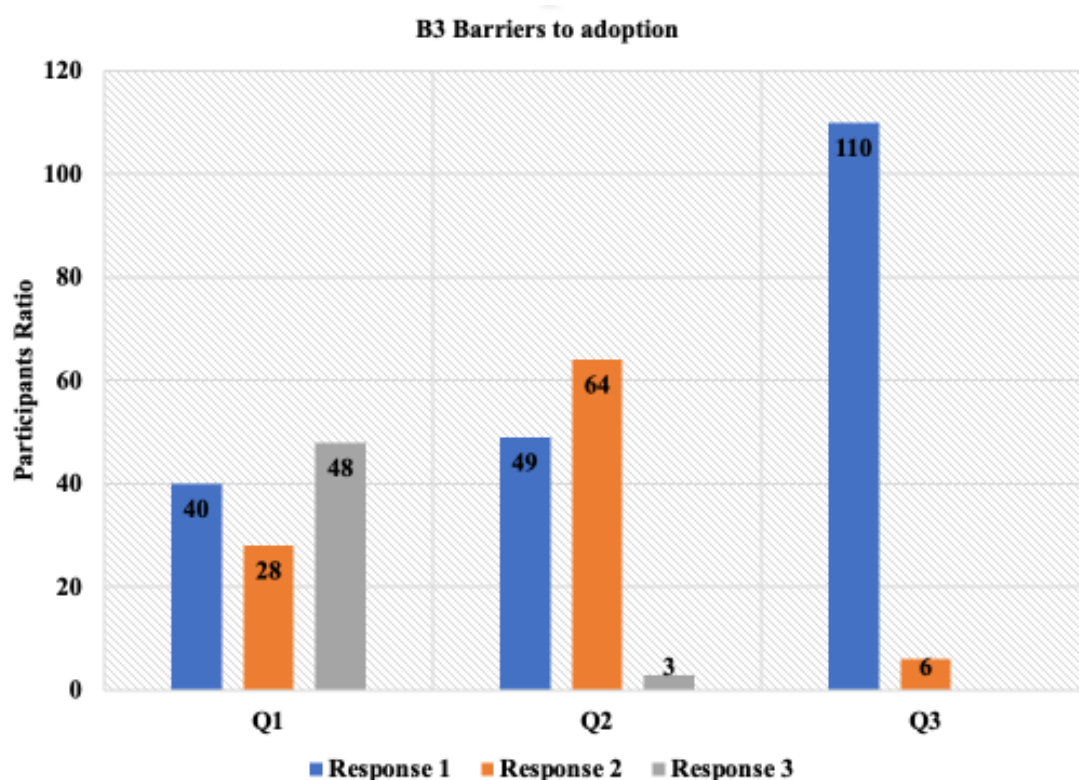


Fig. 6. Response rate for each question regarding barriers to adoption.

The first question consists of five proposed answers: high initial cost, lack of financing options, limited technical skills for installation and maintenance of the solar photovoltaic system, insufficient sunlight, and lack of awareness regarding the benefits of solar photovoltaic energy. Among these five proposed responses, three are illustrated in Fig. 6. The most significant response from participants was the lack of awareness regarding the benefits of photovoltaic solar energy (41.37%, depicted in grey in the figure above). The second is the high initial cost, with a participation rate of 34.48%, represented in blue in Fig. 6, and lastly, the lack of financing options, with a rate of 24.13% of participants.

Question 2 on barriers to adoption can be answered in three ways. The question is whether the initial cost of installing solar photovoltaic systems is prohibitive. 42.24% of participants responded with "strongly agree," represented by the blue color in Fig. 6; 55.17% answered "agree," represented by the yellow color, and 2.58% of participants disagreed, represented by the grey color. This question indicates that, according to most participants, the initial cost of installing solar photovoltaic systems is prohibitive.

Finally, question 3 aims to identify the main difficulties rural dwellers face in accessing accurate information on solar photovoltaic systems. A total of 94.82% of participants, shown in blue in Fig. 6, identified the following challenges: a lack of financing and awareness-raising options; insufficient technical expertise; few conferences and debates on

solar photovoltaic systems; and a lack of information and training structures for the use of clean energy. Meanwhile, 5.17% of participants reported no difficulties encountered.

To verify representativeness or whether these data are generalizable, let's calculate the margin of error (MoE) using the formula (1). $MoE(\%) = 0.0349$ or 3.49%.

The results of the surveys on barriers to access to solar photovoltaic energy regarding adoption, shown in Fig 6, include a 95% proportion of participants. Therefore, the margin of error is 3.49%. This margin of error value indicates excellent data validity.

5.1 Financial considerations.

Economic aspects involve managing, acquiring, and applying financial resources to achieve a company's or research's strategic goals. In addition to risk management, they include forecasting, analysis, planning, control, negotiation, and budgeting. For this study, we have selected a solar photovoltaic system in Moundou city to understand its economic energy barriers. Fig 7 below illustrates the results related to the financial aspects of this system.

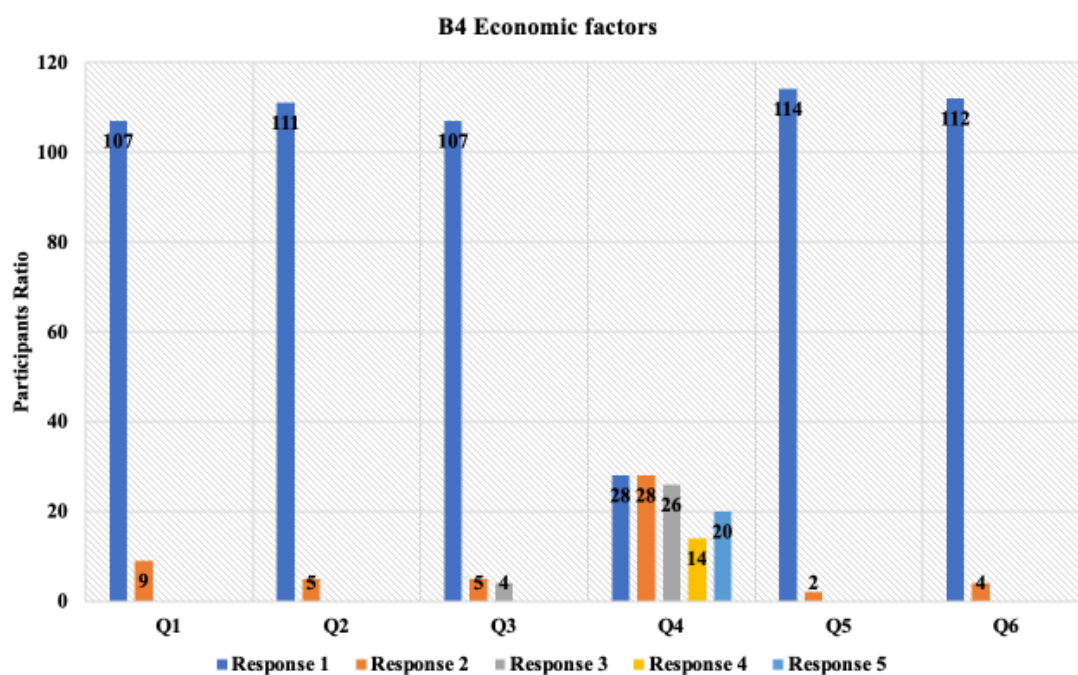


Fig. 7: Response Rates by Question for Economic Factors

The data in the histogram represent the number of response items given by the participants for each question. We expressed the data as a percentage and interpreted the results.

Question 1 of the economic factor is whether the cost of solar photovoltaic systems is affordable for rural households. This question has some elements of an answer, with 92.24% stating that the price of the photovoltaic system is not affordable for rural households, as represented in Fig. 7 by the blue color. Those who feel that the cost is affordable for rural households are in the minority, at 7.75%. From the responses to this

question and the percentage participation rates, we understand that the cost of solar photovoltaic systems is unaffordable for rural households.

Question 2 focused on financing options for purchasing solar PV system components. In Fig. 7 above, most participants (95.68%) are interested in financing options for purchasing the solar PV system. This majority response is represented in Fig. 7 by the blue color for question 2. The minority, 4.31%, disagreed with this financing option. In short, given the participants' motivation, the availability of financing options from the state or non-governmental organizations can help promote solar photovoltaic energy for sustainable development in a developing country like ours.

Question 3 asks which participants plan to install a solar photovoltaic system for their home or business. Out of 116 participants, 107 plan to install a solar photovoltaic system, i.e., 92.24%, represented by the blue color in Fig. 7, compared to five participants, i.e., 4.31%, who do not plan to install a solar photovoltaic system, represented by the yellow color, and four participants, i.e., 3.44%, who are unsure, represented by the gray color. Analyzing the responses, many participants plan to install a solar photovoltaic system but need additional resources.

Question 4 focuses on the benefits of solar photovoltaic systems. This question asks you to tick the benefits listed below: savings on electricity bills, environmental benefits (reduced carbon footprint), energy independence, increased property value, and job creation in the renewable energy sector. 24.13% of participants ticked savings on electricity bills, represented in Fig. 7 by the color blue; 24.13% ticked environmental benefits, depicted in the color storm; 22.41% ticked energy independence, shown in gray; 12.06% ticked an increase in property value, defined in Fig. 7 by the color yellow; and finally, 17.24% ticked job creation in the renewable energy sector, represented in Fig. 7 above by the color sky blue. Overall, participants perceived that the main advantages of using solar photovoltaic systems were the savings on electricity bills and environmental benefits, as these two factors had equal and significantly higher percentages than the others.

Question 5 asked participants how government policies could better support the adoption of solar photovoltaic systems. 98.27% of participants responded that governments could aid the adoption of PV systems in rural areas by providing technical and financial support to rural populations, raising awareness of the economic and environmental benefits, and training specialists in the field. This majority percentage is represented in Fig 7 by the color blue. Orange indicates that 1.72% of participants did not respond.

Question 6 focuses on the suggestions made by participants to address the economic barriers to adopting solar photovoltaic systems in rural areas. A remarkable 96.55% of participants provided positive suggestions, including reducing the initial installation cost by the government, offering more training or workshops on sizing the components of photovoltaic systems for sustainable installation, and providing interest-free loans to rural households. In summary, NGOs and political decision-makers can collaborate to implement

effective strategies that promote renewable energy, specifically solar photovoltaic systems, for sustainable development.

Let us use the following formula (1) to calculate the margin of error (MoE) in order to confirm representativeness or determine whether these data are generalizable. According to Table 4 above, this margin of error can aid in decision-making $MoE \approx 0.0224$ or 2.24%. For 98% of respondents, the margin of error is 2.24%. Furthermore, as the number of respondents increases, the margin of error becomes more significant. This margin of error is excellent for representing our survey data.

Technical Issues

This section examines the technical obstacles, difficulties, and specifications related to solar photovoltaic energy. It includes seven questions, illustrated in Fig. 8 below.

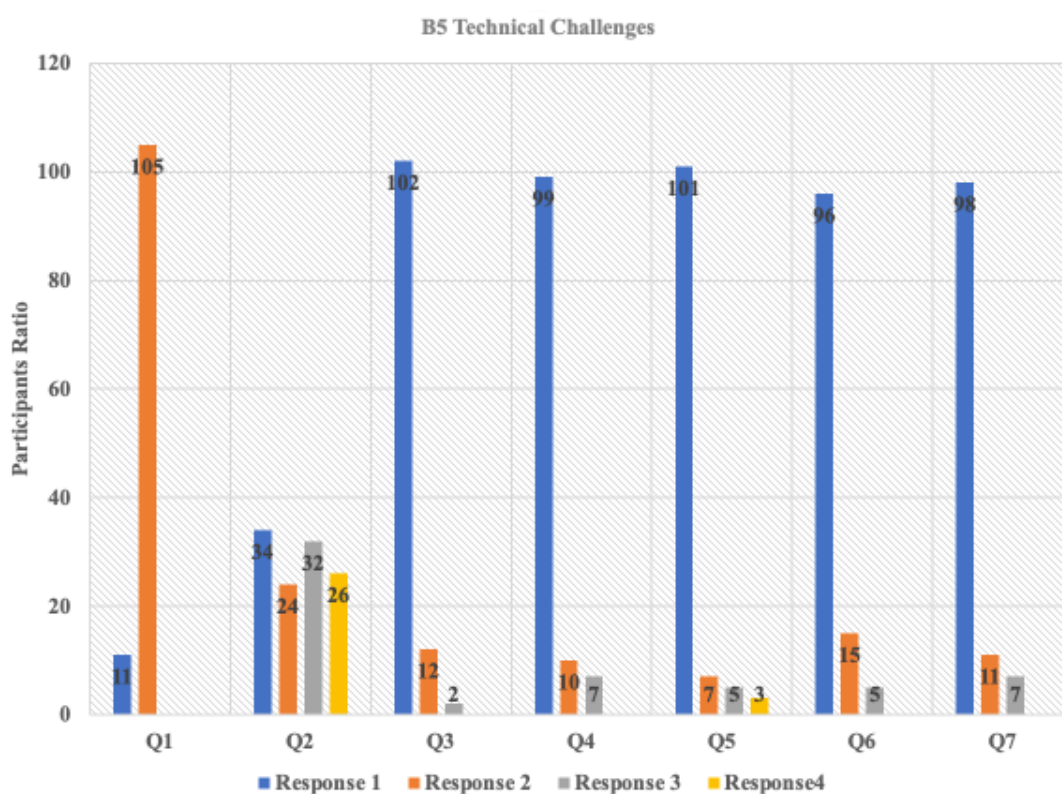


Fig. 8: Response rates for each question about technical barriers

In Fig. 8 above, question one has two response elements. The blue one indicates the number of participants who reported that technical expertise is available locally for installing and maintaining solar photovoltaic systems, i.e., 9.43%. On the other hand, the orange one indicates the number of participants who replied that no technical expertise is available locally for installing and maintaining solar photovoltaic systems, i.e., 90.51%. Therefore,

technical expertise is not available in rural areas to install and maintain solar photovoltaic systems.

Question two of the technical challenge focuses on the adoption of solar photovoltaic systems in rural areas from a technical perspective. This question aims to identify the technical obstacles that hinder progress. Four obstacles have been identified: lack of qualified technicians, limited access to spare parts and equipment, difficulties in maintaining the system, and lack of connectivity to the grid for grid-connected systems. According to the participants' responses, 29.31% indicated a lack of qualified technicians, represented in Fig. 8 by the color blue; 20.68% cited limited access to spare parts and equipment, shown in Fig. 8 by the color orange; 27.58% mentioned difficulties in maintaining the system, represented in Fig. 8 by the color grey; and finally, 22.41% of the participants highlighted the lack of connectivity to the grid for network-connected systems, depicted in Fig. 8 by the color yellow. In conclusion, the shortage of qualified technicians poses a significant technical challenge.

The third question in this section addresses the adequacy of sunshine throughout the year. According to the results, 87.34% of participants stated that sunshine is sufficient during the year, as shown in Fig 8 in blue. 10.34% indicated that it is unavailable throughout the year, represented by orange, and 1.72% abstained. Therefore, we conclude that the availability of sunlight at our study site poses no problem for operating the photovoltaic solar system. Question 4 describes the system's efficiency concerning shading, dust, or other factors. Three elements are illustrated in Fig. 8. A total of 85.34% of participants indicated that the system was inefficient due to shading, dust, or other factors. In contrast, 8.62% stated that the system was not inefficient because of shading, while 6.03% abstained.

Question 5 asks whether there is adequate technical expertise at the local level for installation and maintenance. The figure above shows that 87.06% of participants, represented in blue, state that adequate technical knowledge is necessary. 6.03% indicate that the orange color represents a few inexperienced technicians. The grey color represents 4.31% of participants who state that there are sufficient technicians, while 2.58% abstained. Question 6 has three answer elements, represented in Fig. 8 by the colors blue, orange, and gray. This question asks whether battery storage solutions for off-grid systems present any problems. 82.75% of participants indicated that battery storage poses no issues. 12.93% stated it was problematic, and 4.31% abstained. Therefore, battery storage for off-grid systems poses no problems.

Question 7 addresses system reliability, aiming to determine whether the systems have faced reliability issues with components such as inverters and batteries. 84.48% of participants indicated that the lack of adequate technicians impacts system reliability. 9.48% of participants stated that the system's reliability remains unaffected, while 6.03% abstained.

To determine whether these data are viable, we computed the margin of error using the formula (1). Based on Table 4 above, this margin of error supports decision-making. The margin of error for the 91% of respondents shown in Figure 8 is 4.58%, which is also within a reasonable range. All this data represents stakeholder participation in the energy barrier survey sessions related to numbers and percentages addressing energy challenges.

Participation in the Community

This section examines community involvement in implementing photovoltaic projects. Such participation is highly beneficial for several reasons. It can create a sense of collective ownership and foster a more inclusive and sustainable energy transition. Fig. 9 below shows the survey results from the various stakeholders.

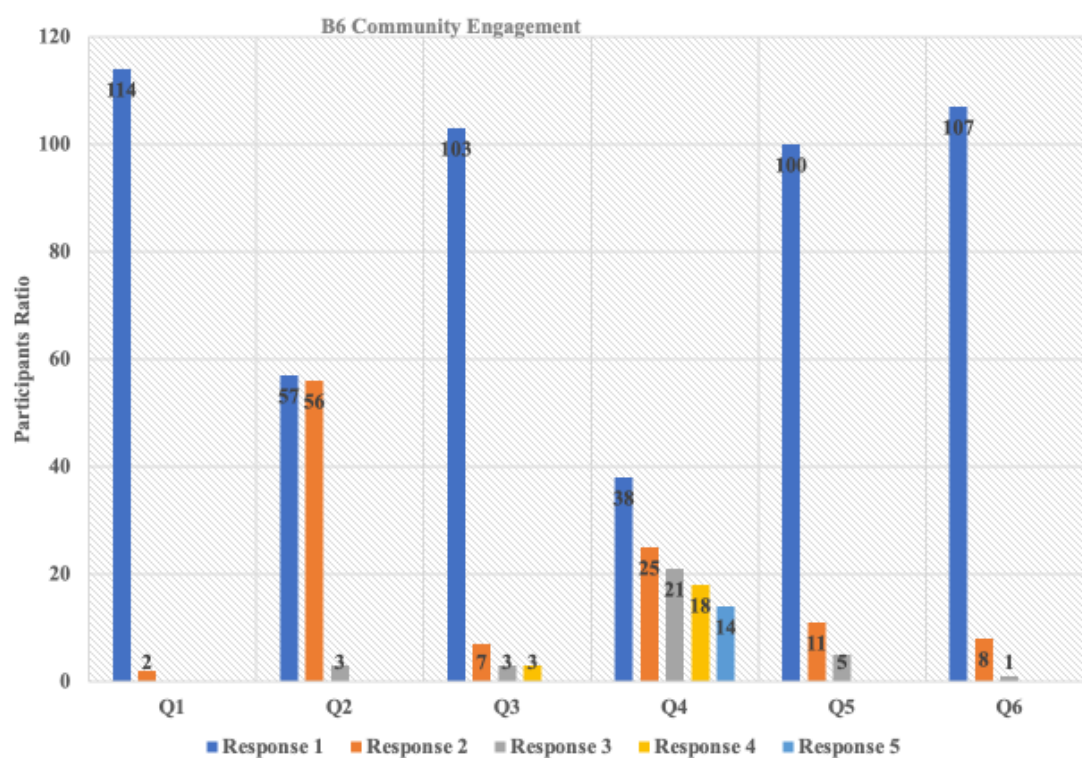


Fig. 9. Response rate for each question related to community engagement.

Regarding the results of the first question in Fig. 9, two types of responses were represented and observed. The first response, indicated in blue, shows the number of participants who answered yes to the question of whether community involvement is essential for the successful implementation of photovoltaic projects, at 98.27%. The second representation, shown in orange, indicates the percentage of people who overlooked the involvement of the rural community in the implementation of photovoltaic projects, at 1.72%. Given these results, community involvement is crucial for the successful implementation of photovoltaic projects.

Question 2 in the community involvement section shows three results. The first result in blue indicates that 49.13% of participants answered yes to using the solar photovoltaic system in their home or community. Additionally, 48.27% of participants, represented in orange, do not use the solar photovoltaic system in their home or community, while 2.58% of participants plan to install it.

Respondents who said "no" or were considering installation justified their delay in using the solar photovoltaic system by citing a lack of knowledge, concerns about its reliability and maintenance, limited access to financing options, and high initial installation costs.

Question 3 examines the importance of community involvement in adopting solar photovoltaic systems in rural areas and yields four results. 88.79% of participants indicated that community involvement in adoption was significant, as shown in Fig. 9 in blue. 6.03% responded that community involvement in adoption was moderately substantial, as shown in Fig. 9 in orange. 2.58% answered that community involvement in the adoption of the PV system is not at all critical, as represented in the figures above in grey and yellow.

Question 4 addresses the main challenges in encouraging rural communities to adopt solar photovoltaic systems. Five response elements were proposed: limited awareness or education regarding solar photovoltaic technology; cultural or social barriers; lack of confidence in the technology or outside entities; insufficient infrastructure for implementing solar photovoltaic systems; and economic constraints. 32.75% of participants identified limited awareness or education of solar photovoltaic energy as the primary challenge in engaging rural communities. This response is represented in Fig. 9 by the color blue, indicating a majority response to this question. 21.55% of participants cited economic constraints as the main challenge, represented in the figure above by the color orange. 18.10% indicated that the main challenge was a lack of confidence in the technology or outside entities, marked in Fig. 9 by the grey color. 15.51% of participants noted that the primary challenge was the lack of infrastructure to implement solar photovoltaic energy, represented on the graph in yellow, while 12.06% stated that cultural barriers are the main challenge, depicted by the light blue color in Fig. 9.

Question 5 examines the various forms of commitment to promoting solar photovoltaic energy. The figure above illustrates three forms of commitment. The first, in blue, is awareness-raising, which was proposed by 100 individuals (86.20%). The second involves forming a group, an association, or a cooperative, proposed by 11 individuals (9.48%). The final form is financial and technical commitment, proposed by two individuals (1.72%).

Finally, question 6 examines community initiatives that could help overcome economic barriers to adopting solar photovoltaics. We have categorized and represented three types of responses in the figure above. The first, in blue, represents 92.24% of respondents who indicated that community initiatives could help address economic barriers to adopting solar photovoltaic energy, compared to 0.86% who said no in orange and 6.89% who abstained in grey. Suggestions from those who answered yes included that communities need to get

organized, develop reliable projects to apply for technical and financial assistance, establish a common fund, and create associations and groups to promote the importance of the solar photovoltaic system.

We employed the following formula (1) to calculate the margin of error for verifying representativeness or determining whether these data are generalizable. The final decision is based on how this margin of error compares to the number in Table 4 $MoE \approx 0.0224$ or 2.24%.

Ninety-eight percent of respondents agreed with the barriers to community involvement shown in Fig 9. The margin of error for this proportion is 2.24%. This margin of error means that the data can be extrapolated to the total population for our study, which aims to identify barriers to access to solar photovoltaic energy.

Table 6 below summarizes the proportions and margins of error for the five pillars of the survey questionnaire on barriers to accessing solar photovoltaic energy, using Moundou as an example.

Table 6: Summary of proportions, error margins, and validity data.

Variable	Proportion	MoE	Interpretation
Consciousness and Expertise	96	3.14	Good representative validity
Adoption-related obstacles	95	3.49	Good representative validity
Financial aspects	98	2.24	Excellent representative validity
Technical Problems	91	4.58	Good representative validity
Participation in the Community	98	2.24	Excellent representative validity

Source: Survey data.

From Table 6, we observe that there is no worst-case representation of the data. Each variable's margin of error was calculated and verified using Python software. These results enable us to establish best practices for overcoming barriers to accessing solar photovoltaic energy.

Statistical tests include logistic regression, the chi-square test, and ANOVA.

Regression analysis is a fundamental statistical method for understanding the relationship between variables. We used linear regression for this study as we assumed a linear relationship between the variables.

Fig 10: (a) Display the regression of energy barriers across age-gender groups. This graph illustrates the relationship between energy barrier scores and different age groups. Higher energy scores (e.g., 98 for financial factors and community engagement) are associated with older groups, while lower energy scores (e.g., 91 for technical problems) correspond to younger groups, indicating potential variations in perception. The regression line clarifies how energy barriers influence various age-gender groups. The regression equation is $y = -$

$4.7517e-15x + 3$. This equation shows that y remains essentially constant at around 3 and that x has no significant effect, indicating an independent variable that does not impact the outcome.

Fig 10: (b) shows the regression of estimated variance across age-gender groups. This graph illustrates how different age groups are associated with varying estimated energy barrier variations. Higher estimated variance values may indicate greater ambiguity or differing perceptions among age groups, while lower variance values suggest more agreement or consistency in perceptions of obstacles. The regression line highlights the effects of estimated variation on these age groups. The regression equation is as follows: $y = 0.64252x + 0.84112$. The positive slope (0.64252) indicates a moderate positive linear relationship between x and y . The data points appear to follow a fairly linear trend.

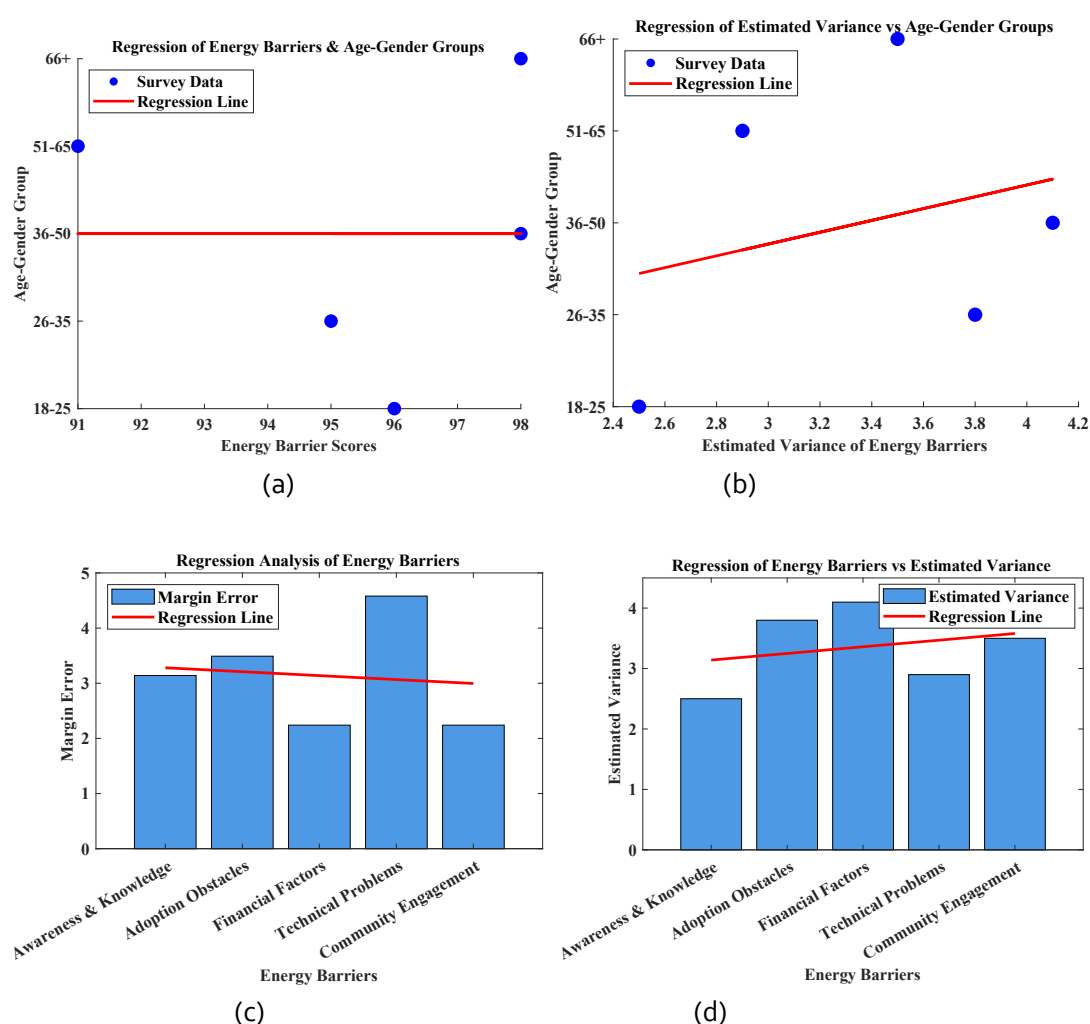


Fig. 10: Regression analysis: (a) regression of energy barriers across age-gender groups; (b) regression of estimated variance across age-gender groups; (c) regression analysis of energy barriers; and (d) regression of energy barriers in relation to estimated variance.

Fig 10 (c) depicts the regression analysis of energy barriers. In this graph, the trend illustrates how various energy barriers contribute to changes in margin error. Technical issues exhibit a higher margin of error (4.58), indicating significant uncertainty. In contrast, financial factors and community engagement barriers show the lowest margin of error (2.24), suggesting more consistent responses. The regression trend provides insight into the evolution of uncertainty across different barriers. The regression equation is $Y = -0.071x + 3.351$. The slope is (-0.071), indicating a negative relationship with a relatively small magnitude, suggesting a weak downward trend. The data points are more scattered compared to the previous plot (for the equation $y = 0.64252 + 0.84112$).

Fig 10 (d) illustrates a regression of energy barriers and estimated variance. The regression equation is $Y = 0.11x + 3.03$. The slope is 0.11, indicating a positive but gentle trend, which suggests a low to moderate positive relationship between x and y. The line aligns with the overall direction of the data but appears somewhat loose, indicating a correlation that is present but not particularly strong. The graph demonstrates how reactions fluctuate based on the energy barrier. Greater variation points to increased disagreement among respondents (e.g., financial factors, 4.1), whereas lower variance indicates more consensus (e.g., awareness and knowledge, 2.5). The estimated variance across various obstacles is represented through the regression trend.

Fig 11 presents survey responses regarding energy barriers by age group. It is important to understand how many people participated in each energy barrier assessment. The color intensity indicates the number of respondents who perceived each obstacle as significant within their age group. Darker blue hues represent lower response counts, while lighter yellow hues indicate higher response numbers. The color bar on the side serves as a reference for converting colors to numerical values.

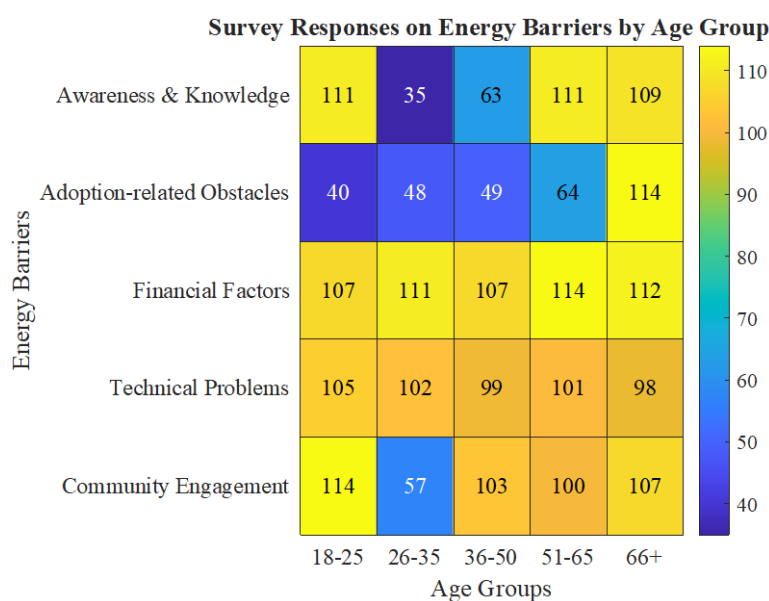


Fig. 11: Heatmap of survey responses regarding energy barriers by age group.

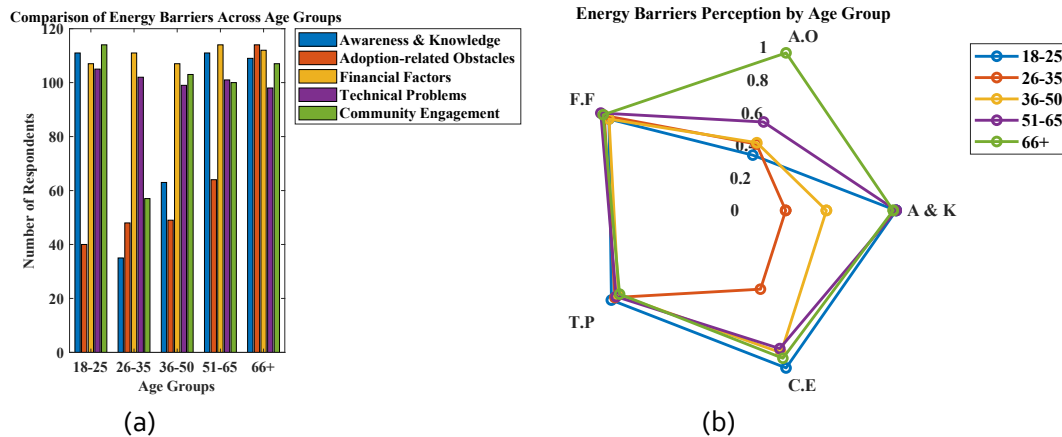


Fig. 12: Energy barriers: (a) Variability among age groups; (b) Perceptions by age group.

Fig. 12(a) illustrates the variability of energy barriers among different age groups. This graph enables us to visualize each barrier by age segment and helps to identify deviations between age groups for specific barriers. The chart displays the distribution of respondents across age groups facing various energy constraints. Except for the 26-35 age group, awareness and knowledge present significant obstacles to electricity access for most age groups. Adoption-related challenges particularly impact individuals aged 66 and older. Financial factors pose challenges that are common to all age groups. Technical issues remain relatively consistent across age groups. The percentage of community engagement varies, but it is notably significant in both the youngest and oldest groups.

In Fig 12 (b), (A.O.) refers to adoption-related obstacles, Awareness & Knowledge (A&K), Community Engagement (C.E.), Technical Problems (T.P.), and Financial Factors (F.F.). This chart displays five axes, each representing an energy barrier. Different colored lines depict each age group. For optimal visualization, the rescaled values range from 0 to 1. The radar chart highlights the differences in the perception of energy barriers among age groups. Groups with higher values on specific axes perceive these barriers as more significant. This spider chart shows that all age groups view financial factors and technical problems as important barriers, followed by community engagement, except for the 26-35 age group. Awareness & knowledge were considered important barriers by all age groups, excluding 26-35 and 36-50. The older age group (66+) recognized adoption-related obstacles as important barriers.

The results of the statistical tests (chi-square and ANOVA tests) confirmed the relationship between energy barriers and age groups. These statistical methods produced consistent results regarding significant perception.

The Chi-square test results were as follows: Chi-square statistic: 92.3638, degrees of freedom: 16, and P-value: 9.1593e-13. These results indicate a significant association between energy barriers and age groups.

Fig. 13 below presents the results of the ANOVA test. This figure highlights an outlier value of 40, marked by a red +. This outlier corresponds to the adoption-related obstacles in the first age group (18-25), located in column two, row two of the matrix. Five age groups responded to the five main energy barriers. The red line represents the median value; at the top, it indicates the upper adjacent value, while at the bottom, it shows the lower adjacent value based on respondents.

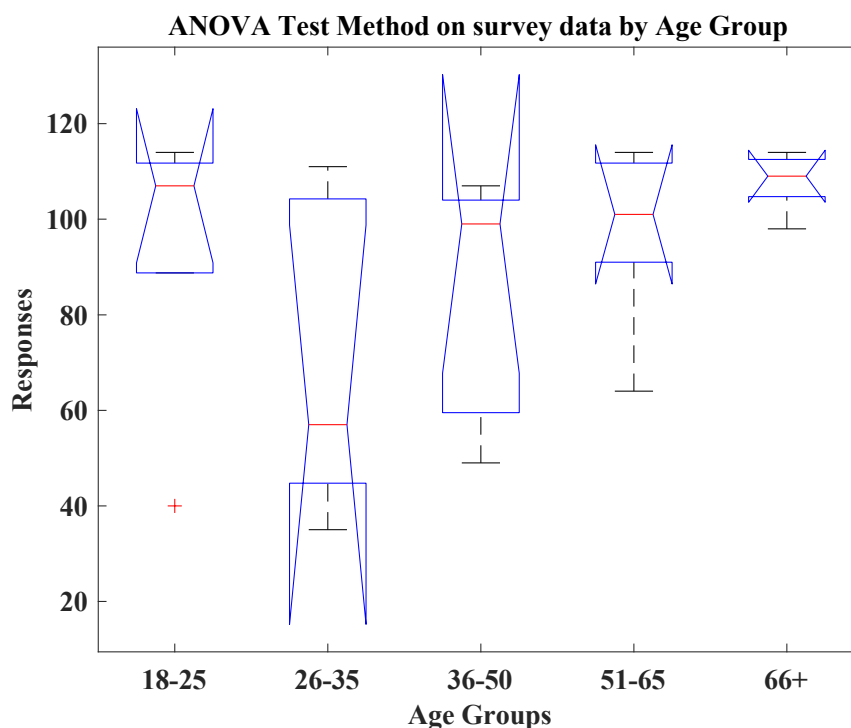


Fig. 13: ANOVA test method applied to survey data by age group.

Table 7: Recapitulated ANOVA test method on survey data categorized by age group.

Age group	Upper adjacent	Median	Lower adjacent	Max	Min	Finite outlier	NaN
18-25	114	107	89	114	40	1	0
26-35	111	57	35	111	35	0	0
36-50	107	99	49	107	49	0	0
51-65	114	101	64	114	64	0	0
66+	114	109	98	114	98	0	0

Source: Survey data.

According to Table 7 from the graph ANOVA test method on survey data, it was found that the first age group has a significant gap between the lower adjacent and minimum values,

which makes the finite outlier appear different from zero (lower adjacent = 89, min = 40, finite outlier = 1). One outlier for the first age group is below the lower adjacent value (i.e., a data point significantly lower than expected). For the other age groups, each lower adjacent value corresponds to the minimum value, and the finite outlier is zero; no extreme low values were detected. Thus, there are no outliers in this case, meaning all values are within an expected range.

With NaN (Not a Number) treated as 0, the dataset has no missing values, suggesting a well-distributed dataset with no extremely low values. The table from the ANOVA test corresponds to the values in the heatmap Fig. 11 concerning upper, lower adjacent, and median values. In conclusion, there was no significant difference in energy barrier perception across age groups.

This section employs logistic regression, chi-square, and ANOVA tests to analyze the statistical assessment. The logistic regression revealed that financial factors and community engagement barriers present the lowest margin of error (2.24), indicating more consistent responses. The chi-square test uncovered a significant association between energy barriers and age groups, leading to the use of ANOVA tests.

The qualitative data regarding this energy barrier focuses on insights from open-ended surveys, focus groups, and observations. This data explores participants' experiences, perceptions, and opinions on accessing solar PV systems.

Data were cross-checked with expert opinions and quantitative survey results to ensure the validity of the findings. Participants underwent member checking to confirm that their viewpoints were accurately represented.

Best Practices

A thorough literature analysis was conducted to determine how the project linked to energy issues was conceived, formulated, and implemented, involving Indigenous people and sharing technological know-how while citing problems and solutions. This illustration represents the best practice for expanding solar photovoltaic energy access and the effective strategies implemented to overcome energy barriers at our study site.

Table 8: Obstacles to specific best practices.

Type of barrier	Description	Example of good practice
Awareness and knowledge Barrier	- The rate of poor or average understanding of photovoltaic technology is very high compared to good understanding; - The number of people who have received training or information on the solar photovoltaic system is very negligible compared to those who have not received training or information.	- Organize an awareness-raising or training campaign on clean energies, in this case photovoltaic solar power. - Launch a solar photovoltaic project to improve electrification and energy efficiency in low-income areas (rural areas), with strong community involvement.
Barriers to adoption	- Lack of awareness and training in rural areas on the benefits of clean energy; - The initial cost of installing a photovoltaic system is prohibitive; - Lack of information and training structures on the use of clean energy; - Lack of technical skills.	- The initial cost of installation must be made affordable to the rural population; - Train competent technicians to manage large-scale solar photovoltaic energy projects.
Economic factors barriers	- Lack of financial resources; -The cost of the photovoltaic system is not affordable for rural households	- Subsidizing the price of solar kits and financing installations; - The government must provide technical and financial support to the rural population.
Technical challenges	- Lack of adequate local technical expertise for the installation and maintenance of photovoltaic systems. - Limited access to spare parts and equipment.	- To provide the rural population with technical expertise in the installation and maintenance of photovoltaic systems; - subsidies solar photovoltaic system components in rural areas.
Barriers to community involvement	- The lack of community involvement in the implementation of solar photovoltaic projects; - Lack of knowledge about the solar photovoltaic system; - Concerns about reliability and maintenance.	- Involvement of the local community in implementing solar photovoltaic projects; - Provide adequate infrastructure to raise awareness and educate the rural community about the benefits of solar photovoltaic energy (both economically and ecologically).

Strategies to Overcome Barriers

Several technological, sociocultural, and financial obstacles must be addressed for solar photovoltaic energy to become widely accessible. The following strategies emerged from our survey:

- *Community Involvement and Education*

Educating and training local communities is an effective method for overcoming socio-technical obstacles. Communities can more effectively and sustainably manage and maintain energy solutions (Nuru et al., 2021) by involving Indigenous people and sharing technological know-how.

- *Awareness and knowledge*

It is essential to raise understanding and awareness of energy-efficient technology. Many obstacles arise from needing more knowledge or accurate information about its advantages and access (Kamal et al., 2019). Information sharing and educational initiatives can close this gap and promote the broader (Yeatts et al., 2017).

- *Financial and Policy Assistance*

Financial assistance and policy changes are essential for removing economic obstacles. Institutional and governmental backing can reduce the cost of energy-efficient technology, increasing its accessibility to a larger audience. This strategy is crucial for encouraging energy-saving technologies (Johannsen et al., 2020).

Therefore, this systematic study aimed to identify and synthesize the following factors: Obstacles affecting access to energy by the population of the Western Logone province. We review the results of our investigation and the future progress of the technology. We also present a framework for technology adoption, constraints, barriers, and the possibility of wider ramifications arising from the widespread use of solar photovoltaics. However, because we have considered several important factors and depended on reliable criteria, measuring barriers to energy access is best practice. A survey highlighting obstacles to energy access immediately helps SDG 7: "Access to clean, affordable energy for all," which we have also associated with sustainable development goals (Shulla et al., 2021). Other SDGs include reducing poverty (SDG 1) (Walker, 2021), enhancing health (SDG3), and halting climate change (SDG 13) may also be impacted (Chankseliani & McCowan, 2021). This survey enabled us to identify specific problems (technical, economic, social, and political) and to find appropriate solutions.

The following suggestions are put forth in light of the feasibility study's findings, which highlighted several significant obstacles to obtaining solar photovoltaic energy, such as a lack of awareness, financial limitations, a lack of technical know-how, insufficient regulatory support, and supply chain difficulties:

- Develop targeted financial mechanisms.
- Implement awareness and education campaigns.
- Enhance technical capacity building.

- Enhance policy and regulatory frameworks.
- Promote pilot projects and demonstration sites.
- Encourage community involvement and ownership.

Addressing the barriers identified in the survey, these recommendations aim to accelerate the adoption of solar photovoltaic energy, promote sustainable development, and enhance energy access, particularly for underserved populations.

Conclusions

Chad must prioritize renewable energy resources, enhance energy efficiency, and build sustainable infrastructure to foster social and economic progress. Developing renewable energy resources, such as solar, is critical for addressing energy shortages and achieving sustainable development. Solar energy is emphasized as a viable and sustainable option due to its inexhaustible and non-polluting nature. Strategic energy policies that incorporate social, economic, and environmental factors are essential for achieving sustainable development goals. Access to energy is unavoidably correlated with development, and no nation has reduced unemployment or poverty rates without reliable energy sources.

This study provides insight into the specific obstacles and recommendations based on experiences from field visits that led to the completion of the survey form. According to the demographics of the respondents, there is widespread interest in utilizing solar and photovoltaic energy, despite several barriers. The related question on awareness and knowledge emphasizes that many people are eager to organize training courses or workshops to promote solar photovoltaic systems. The identified obstacle to adoption indicates that rural dwellers encounter significant challenges in accessing accurate information about these systems. The financial aspect was crucial to this study; most participants indicated that governments could facilitate the adoption of PV systems in rural and urban areas by offering technical and financial assistance to the populations, promoting awareness of the economic and environmental benefits, and training specialists in the field. Consequently, there is a lack of technical expertise in rural areas to install and maintain solar photovoltaic systems. Regarding community engagement, participants acknowledged that community involvement is essential for the successful implementation of photovoltaic projects.

The proportion of respondents enabled us to analyze the challenges and opportunities associated with adopting solar energy in the region. Given Chad's high solar potential and its low electrification rate, this study becomes essential, making Moundou a vital case for understanding the broader barriers to energy access in developing regions.

The survey covered a limited number of cities, which may not fully represent the diversity of socio-economic and geographic conditions across the country of interest. Due to logistical and resource limitations, the sample size may not have been large enough to generalize the findings to the broader population with high statistical confidence. Additionally, some key stakeholders, such as policymakers, private sector investors, or

marginalized groups (e.g., nomadic populations or off-grid communities), may have been underrepresented.

Recurring suggestions for future research on barriers to accessing solar photovoltaic energy. Several consistent recommendations emerge in this article to address gaps identified in existing studies and to enhance our understanding of the obstacles that prevent individuals from accessing solar photovoltaic energy. These recommendations include methodological advancements, a greater emphasis on marginalized groups, the incorporation of behavioral science perspectives, more targeted policy and regulatory studies, and the exploration of technological innovations and business models.

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The sources listed in the article provided the data used for the study.

Conflicts of Interest:

The authors declare no conflict of interest.

Appendage

<i>Nomenclature.</i>		<i>(continued)</i>	
Acronyms			
UN	United Nations	SDGs	Sustainable Development Goals
IMF	International Monetary Fund	GDP	Gross Domestic Product
PV	Photovoltaic.	PAYG	Pay-as-You-Go
IPPs	Independent Power Producers	AfDB	Africa Development Bank’s
GCF	Green Climate Fund	MoE	Margin of Error
ANOVA	Analysis of Variance	DF	Degree of Freedom
NGOs	Non-Governmental Organizations	AO	Adoption-related obstacles,
A&K	Awareness & Knowledge	C.E	Community Engagement
T.P	Technical Problems	F.F	Financial Factors
NaN	Not a Number	SSA	Sub-Saharan Africa

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