Assessment of Solar Powered Water Pumping System Challenges for Rural Water Supply: A Case of Pinyudo Town of Gambella, Ethiopia

Bahiru Tefera Bezabih

A Thesis Submitted to the Department of Water Resource Engineering (WRE),

School of Civil Engineering and Architectural (SOCEA).

Presented in partial fulfillment of the requirement for the degree of master's in water supply and environmental engineering

Office of Graduate Studies

Adama Science and Technology University

October 2024

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DECLARATION

I hereby declare that this Master Thesis entitled "Assessment of Solar Powered Water Pumping System Challenges for Rural Water Supply: A Case of Pinyudo Town of Gambella, Ethiopia" is my original work idea. That is, it has not been submitted as a proposal to do the final thesis work for the award of any academic degree, diploma, or certificate in any other university. All materials used for this thesis proposal have been duly acknowledged through citation.

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Name of the student Signature Date

RECOMMENDATION OF ADVISORS

We, the major advisor and the co-advisor of this thesis, hereby certify that we have read the revised version of the thesis entitled "Assessment of Solar Powered Water Pumping System Challenges for Rural Water Supply: A Case of Pinyudo Town of Gambella, Ethiopia" prepared under our guidance by Dr. Keneni Alemu the major advisor. Therefore, I recommend the submission of the revised version of the thesis proposal to the department following the applicable procedures.

Dr. Keneni Alemu	____________________	____________________
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Co-advisor/Co-Supervisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned members of the Board of Reviewers of the proposal open defence by Bahiru Tefera Bezabih have read and evaluated the thesis proposal entitled "Assessment of Solar Powered Water Pumping System Challenges for Rural Water Supply: A Case of Pinyudo Town of Gambella, Ethiopia" and assessed the understanding of the candidate about the proposed research. This is, therefore, to certify that the thesis proposal is accepted and we recommend the implementation of the proposal.

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Finally, the thesis's approval and acceptance are contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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LIST OF ACRONYMS

AC	Alternating Current
ADD	Average Daily Demand
ACLED	Armed Conflict Location and Event Data
AUDA	African Union Development Agency
CA	Comparative Analysis
CI	Confidence Interval
CSA	Central Statistical Agency
CAPEX	Capital expenditure
CBA	Cost-Benefit Analysis
DC	Direct Current
DT	Design Tool
FDRE	Federal Democratic Republic of Ethiopia
GPS	Global Positioning System
IWMI	International Water Management Institute
KAPs	Knowledge-Attitude-Practices
MCA	Multicriteria Analysis
MCDA	Multicriteria Decision Analysis
MCDM	Multicriteria Decision Making
MDD	Maximum Daily Demand
MoWE	Mistry of Water and Energy
MPPT	Maximum Power Point Tracker
MS	Microsoft
NEPAD	New Partnership for Africa's Development
NGOs	Non-Government Organizations
PA	Potential Assessment
PDT	Pump Design Tool
PHD	Peak Hour Demand
PNT	Positioning, Navigation, and Timing

PV	Photovoltaic
PVWPS	Photovoltaic Water Pumping System
RSI	Renewable Solar Inverter
SDG	Sustainable Development Goal
SPGWSS	Solar Powered Ground Water Supply System
SPV	Solar Photovoltaic
SPGWPS	Solar-powered groundwater pumping system
SPSS	Solar Power Solar System
SPWPS	Solar Power Water Pumping System
SPWSS	Solar Power Water Supply System
TDH	Total Dynamic Head
t-TEM	Towed, Transit Electromagnetic System
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund
USEPA	United States Environmental Protection Agency
VBA	Visual Basic Application
VFD	Variable Frequency Drive
VIF	Variance Inflation Factor
VSD	Variable Speed Drive
WB	World Bank
WPS	Water Pumping System
WSM	Weighted Sum Method
WM	Water Mission

ABSTRACT

In Ethiopia, solar-powered water pumping systems (SPWPS) present a promising solution for rural water supply, yet they encounter challenges such as inconsistent energy availability, high initial costs, limited technical expertise, and difficulty accessing maintenance. Solar energy has thus become a practical alternative for groundwater pumping in regions affected by frequent power shortages, such as Gambella-Pinyudo. However, differences in system design and the lack of a standardized implementation framework have resulted in performance challenges. This study aimed to assess the challenges of solar-powered water systems, focusing on design inconsistencies, socio-environmental impacts, operational limitations, and community engagement. Research data was collected from the respondents via semi-structured interviews, open-ended questions, survey questionnaires, document reviews, and direct field observations. The data analysis proceeded with descriptive analysis, reliability & normality tests, Multi-Criteria Analysis (MCA), Comparative Analysis (CA), and a Spearman correlation. Accordingly, the study revealed that the intertwined miscellaneous challenges include technical issues, design inconsistencies, operator skill gaps, guideline non-compliance, and socio-environmental impacts like land acquisition and wildlife disruption. Regarding the design tools, Grundfos' designs are the most efficient, followed by MoWE, WM, and Lorentz design tool. The research identified various challenges affecting the solar-powered water supply system for rural communities, such as deforestation risks and malfunctioning solar arrays, with several SPWPS units reported as non-operational. The community also faced management challenges, including inconsistent performance and maintenance difficulties. However, strong community engagement fostered ownership despite technical issues affecting user satisfaction. So, it was concluded that the solar power-driven water supply system offers benefits to rural communities, but addressing technical, operational, and socio-environmental challenges is crucial for long-term success. A holistic approach with community involvement is key to improving system performance and effectiveness.

Keywords: PV system, Design Tool, Environmental Impact, rural community, module orientation

CHAPTER ONE

INTRODUCTION

1.1. Background

Water is essential to life on earth, crucial for social and economic development, and it directly impacts health and living standards. Despite significant global investments, 1.2 billion people still lack access to safe water, with rural areas in developing countries being the most affected. Furthermore, access to safe water remains limited, particularly in rural areas of developing countries, where 84% of the population depends on unsafe water sources and often travels long distances to collect it (Kibret & Tulu, 2014). Approximately 300 million people in Africa lack safe drinking water, and 313 million do not have sanitation facilities. Among sub-Saharan African countries, Ethiopia has some of the lowest access rates to safe drinking water and sanitation services (Hlongwa et al., 2024).

Conversely, effective groundwater management is crucial for enhancing resilience in vulnerable areas of the Horn of Africa. In regions where surface water is limited due to high temperatures, groundwater provides a dependable water source and aids in adapting to climate variability(MoWE, and MoIL, 2022).

Although Ethiopia possesses more surface and groundwater resources than are required to meet current water supply demands, it still ranks among the lowest in Africa regarding access to freshwater (World Bank Group, 2020) . Moreover, in remote rural lowlands of Ethiopia, pastoralist communities are underserved with basic infrastructure such as roads and electricity. As a result, they heavily rely on diesel power to pump water from deep wells, but transporting diesel to these areas adds significant costs, further challenging the community (DT Global, 2019).

Alternative methods and energy are crucial for pumping water in areas lacking electricity. Solar photovoltaic systems have been shown to significantly lower greenhouse gas emissions, fuel (diesel) costs, and environmental pollution, helping to address the global challenges associated with nonrenewable energy sources(Kayode et al., 2019).The solar photovoltaic (PV) energy is considered the safest and most environmentally friendly alternative among various renewable resources (Kazem et al.,2021) Solar power solutions offer several benefits for water supply systems, including easy design, eco-friendliness, affordability, and low maintenance requirements (Rakotomalala, 2020). These systems offer off-grid access to water, providing benefits such as reliable and cost-effective irrigation, better drinking water access, reduced effort in water collection, and increased energy availability (Nuttall, 2023).

Ethiopia, with its abundant solar radiation and subsurface water sources, has the potential to provide rural areas with access to safe drinking water through solar-powered systems (Girma et al., 2015a). Solar energy is particularly viable in Ethiopia due to its proximity to the equator and the availability of sufficient solar insolation (Kabade et al., 2013).

In rural off-grid communities in Ethiopia, residents have historically borne the full cost of diesel fuel to pump drinking water. To cover fuel and operational expenses, communities charge a tariff (typically 2-3 Birr per 20-liter jerrycan, as of 2023), setting aside a small amount for repairs. While this system works well when the diesel generators are new, after about 10 years, maintenance costs become too high for the tariff to cover, leading to more frequent breakdowns. When this occurs, households—mainly women and school-age girls—must return to walking to fetch water from the nearest river, which can take up to two hours each way (Holthaus et al., 2023). While solar-powered water pumping systems provide a sustainable solution for rural water supply, they also present several challenges. Addressing these challenges requires a holistic approach by integrating technical solutions with community engagement, standardized national guidelines and policies, capacity building, and long-term funding sources. By overcoming jointly anticipated and unforeseen complications, these systems can significantly improve access to safe water for rural communities while promoting environmental sustainability.

With the growing popularity of solar power as a green energy source for pumping water from wells, these systems have been widely implemented across various regions of Ethiopia, including Gambella and specific locations like Pinyudo, by the local government, non-governmental organizations (NGOs), and private sector entities. Nonetheless, implementers and users are confused because different stakeholders use diverse design approaches, working modalities, and materials. Furthermore, the distinct benefits, diverse techniques, and optimal techniques of each design methodology have not been properly acknowledged leading to a lack of understanding among users. Additionally, stakeholder engagement and user satisfaction with these technologies have not been thoroughly examined. Therefore, there is a need for scientific research to address these technical issues and ensure the effective and efficient use of solar-powered water supply systems in Ethiopia.

A thorough evaluation of the challenges associated with solar-powered water pumping systems for rural water supply is essential for understanding and addressing these issues. This evaluation should encompass technical, financial, operational, social, and environmental factors to develop effective plans for the system performance improvement, technology's adoption and long-term viability.

1.2. Statement of the Problem

Various factors influence the design and operation of solar-powered water supply systems, and even well-engineered systems can experience operational issues that reduce their water pumping capacity. The output of solar-powered water systems is influenced by various factors that must be considered in design and operation. Many PV water stations, despite sound engineering, underperform due to insufficient attention to environmental and technical issues impacting their operation and water output (Ahmed et al., 2023). While off-grid solutions for rural electrification in developing countries have been widely studied, no comprehensive review or framework now exists. Such an analysis could establish a common reference for implementation settings, create a taxonomy for off-grid technologies, and organize existing literature within this framework (Mandelli et al., 2015).

In Ethiopia, the challenges of designing and implementing these systems are heightened by factors such as intermittent power generation, limited energy storage, geographical diversity, water source sustainability, technical expertise, financial constraints, community engagement, policy frameworks, and monitoring systems. Effective collaboration with local stakeholders, government bodies, and communities is essential for developing tailored solutions that meet the unique needs of each region.

Access to safe and reliable water is a fundamental human right, yet many rural communities struggle to maintain a sustainable water supply. So, this has become a pressing challenge for communities like Pinyudo Town. In recent years, solar-powered water pumping systems have been increasingly adopted as a sustainable solution to address water scarcity. However, despite their potential, these systems often face various operational, technical, and socio-economic challenges that can undermine their effectiveness. In Pinyudo, the adoption of solar-powered water pumping systems has not fully resolved the community's water supply issues, raising concerns about the sustainability and efficiency of these systems.

In Pinyudo Town, various organizations have installed multiple solar-powered groundwater pumping systems, each using different design methods, sizing tools, and mounting structures. This has led to significant discrepancies in system components and performance. The absence of a unified framework for designing and implementing these systems has resulted in inefficiencies. Similarly, at the national level, significant research gaps exist in evaluating solar-powered water pumping systems for rural supply, including technological feasibility, socio-cultural dynamics, operational challenges, and policy frameworks. These gaps highlight the need for further investigation to improve understanding and guide policy development, investment decisions, and sustainable implementation. Addressing these issues can enhance community access to clean water in rural areas.

This research aims to assess, the challenges faced in implementing and operating solar-powered water pumping systems for rural water supply in Pinyudo Town. It also seeks to identify unforeseen technical, socioeconomic, and environmental factors that contribute to inefficiencies and limitations in these systems. By analyzing these challenges, the study intends to provide insights into potential improvements and strategies to enhance the systems' performance, reliability, and sustainability, paving the way for the efficient and sustainable deployment of solar-powered water supply systems in rural communities.

1.3. Objectives of the Study

1.3.1. General Objective

The primary objective of this study was to assess the challenges faced by solar-powered water pumping systems used in rural water supply systems within the Pinyudo Town.

1.3.2. Specific Objectives

- To evaluate the basic differences of solar-powered water supply system (SPWPS) design tools used in Pinyudo Town.
- To identify the social and environmental implications of utilizing solar-powered water pumping systems in the rural community
- To assess the operational challenges and limitations faced in implementing and managing solar-powered water pumping systems in rural settings
- To evaluate the level of community engagement and their satisfaction with the installed solar-powered water pumping systems.

1.4. Research Questions

- How do the solar-powered water supply system (SPWPS) design techniques vary in community water supply project designs within your locality?
- How does the use of solar-powered water pumping systems impact the social and environmental aspects of your community?
- What challenges and limitations are faced in operating and managing solar-powered water pumping systems?
- How does the level of community involvement and satisfaction with the solar-powered water pumping systems installed in the area?

1.5. Significance of the Study

This research enhances the scientific understanding of solar-powered water pumping systems for rural water supply, focusing on Pinyudo Town, Gambella, Ethiopia. It identifies key challenges, such as technical difficulties in installation and maintenance that require specialized skills often lacking in rural areas, and highlights differences in system designs, with some proving more efficient and reliable than others. These insights guide the selection of appropriate designs tailored to specific environmental and community needs, ensuring optimal performance and sustainability. The study also examines the socio-environmental impacts of the systems, uncovering operational challenges faced by the community, and provides valuable information for stakeholders, designers, and policymakers to develop effective solutions and improve national strategies.

Thus, the study benefits the community by identifying challenges and opportunities with solar-powered water pumping systems in Pinyudo town, Gambella-Ethiopia. It highlights technical difficulties, efficiency variations, and socio-environmental impacts, helping ensure more effective and sustainable installations. Accordingly, the research supports the development of tailored solutions to improve water access and sustainability in the community. Moreover, the findings offer a replicable model for other rural communities, promoting sustainable development and improved access to safe water through solar-powered technologies.

1.6. Scope of the Study

This study focused explicitly on the Pinyudo town of Gambella, Ethiopia assessing challenges related to solar-powered water pumping systems for rural water supply within a defined time frame. The research employed a mixed-method approach, integrating qualitative and quantitative data collected between February 1, 2024, and June 20, 2024. While it addressed technical design variations, socio-environmental implications, operational difficulties, and community engagement, it did not examine broader aspects such as regional or national policy impacts, long-term financial sustainability, or comparative analysis with other renewable water supply systems. Excluding these areas allows the study to concentrate on local, immediate concerns specific to Pinyudo town, providing tailored insights and actionable recommendations for this community. Expanding the scope to include broader or comparative analyses would require additional time, resources, and potentially a different methodological approach, which could dilute the focus on the immediate challenges experienced by the Pinyudo town residents. As a result, the findings, conclusions, and recommendations are specific to the Pinyudo town and should not be generalized to all similar rural settings in the region.

1.7. Limitations of the Study

The study encountered several limitations that should be considered when interpreting its findings. Although a larger sample size was initially planned to better represent the diversity within the rural community, logistical and resource constraints limited the number of participants, which may impact the generalizability of the conclusions. Data collection was also affected by unforeseen challenges, such as limited access to some areas and respondents' and data collectors' language barrier, potentially impacting the accuracy and reliability of the data. Data collection time constraints due to conflict further limited the research, reducing its ability to capture long-term trends or changes, which had initially been part of the research plan. Moreover, a key limitation was the lack of a baseline survey in assessing the social and environmental impacts, making it difficult to measure long-term effects and address potential challenges effectively. Additionally, the study focused on specific variables within a defined scope, which excluded certain external factors like economic changes, the shallow depth of the design tools, and policy shifts, narrowing the analysis. Although efforts were made to minimize bias, some interpretive biases may have arisen due to researchers' perspectives and methodological constraints. Finally, differences in geographic, cultural, and socio-economic contexts across rural communities may limit the applicability of these findings and recommendations beyond Pinyudo town, as the study was not gratified to account for these broader variations.

1.8. **Organizational Structure of the Study**

This study is organized into five major chapters. Chapter One introduces the research by outlining the background, problem statement, research questions, objectives, significance, scope, and limitations. Chapter Two covers the literature review, which includes key concepts, theoretical and empirical literature, and relevant studies related to the objectives. Chapter Three describes the study, and explains the research methodology, including the research approach, data sources, population, sampling techniques, sample size determination, collection methods, and data analysis techniques. Chapter Four presents the results and discussion based on the data analysis. Finally, Chapter Five provides the study's conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

This section presents a comprehensive analysis of past research scholars work to connect this study with prior efforts. Relevant studies were carefully selected to strengthen the foundation of this research.Hence, the results of this study were compared to previous research endeavors by a comprehensive evaluation of pertinent literature. This section is organized into four categories: key concepts,theoretical literature,empirical literature, and specific studies related to the objectives of the research,and the detail chronologically presented in detail below.

2.1. Concepts and Definitions of Key Terms

Kiprono and Llario (2020) explain that a solar water pumping system (SPWS) consists of three primary components that generally account for approximately 60% of the total system cost, with the remaining 40% attributed to the balance of system components, including DC accessories, cabling, and drop pipes.Thus, solar-powered water system typically consists of a DC side, an AC side, or both.The entire system that generates and transfers DC power is the DC side and includes all DC-related components.Likewise, there is the AC side which comprises the full part of the PV system that begins after the conversion of DC power to AC power,this includes the AC pumps, AC switches,changeover switches, and AC cables. Overall, the Water Pump, Controller, and Solar module are the main components of the SPWSS.

2.2. Theoretical Literature Review

2.2.1. Rationale of Solar Powered Water Supply System

In water pumping systems, electrically or diesel-powered pumps are commonly used for various applications, such as irrigation and rural or urban water supply. On the other hand, pumping systems that use renewable energy sources must be the main focus due to issues like high diesel pumping prices, the unreliability of the grid, and lack of availability. Recent global concerns about the environment and sustainable development have sparked interest in water pumping devices that run on renewable energy. As a result, solar energy is the renewable energy source that water pumping systems use the most. Utilizing solar energy to pump water declines dependence on diesel-electric generators or the grid system. Photovoltaic (PV) technology, which uses sunshine to create power to pump water, is the base of the solar photovoltaic water pumping system (SPVWPS) (Sekmen et al., 2022).

Although the initial investment cost for a solar-powered water pumping system (SPWPS) can be relatively high, this environmentally friendly and widely adopted solution remains viable due to its zero carbon emissions, silent operation, and low operational and maintenance costs. Therefore, one of the greatest solar energy-powered water pumping systems for meeting the global demand for clean drinking water is the Solar Photovoltaic (SPV) system, which draws water from deep wells. Ethiopia has enough subsurface water sources and an abundance of solar radiation to enable rural areas to have access to safe drinking water (Girma et al., 2015).

Africa faces unique difficulties in the water-energy nexus. The availability of abundant solar radiation and enough underground water sources in Ethiopia can be combined to make clean drinking water available to rural communities (Girma et al., 2015) . It is not viable to adopt solar PV electrification for rural populations because there hasn't been a proper solar feasibility and potential assessment (PA) in this area (Feleke et al., 2023).

As solar panel prices have decreased, policymakers, technicians, and consumers finding solar pump technology increasingly appealing (Wesselius, 2022). The primary parameters that impact the functionality and efficiency of photovoltaic water pumping systems are solar radiation, panel temperature, and component efficiency. Solar radiation has minimal impact on the voltage of solar panels, which remains relatively stable, but it directly and uniformly affects the current output. Additionally, the panel's efficiency decreases by 0.48% for every 1°C increase in temperature (Ahmed et al., 2023).

2.2.2. Design and Sizing a Solar-Powered Water Supply System

Any water system must be designed and built in complete accordance with all codes, standards, and laws of the governing bodies that have enforceable jurisdiction over the place where the water system would be installed, regardless of the system's power source (Water Mission, 2020). Many variables affect how much power is generated through solar modules, which in turn affects how much water in a solar pumping system pumps out. The components are solar panel/array, water supply, pipelines, pump motor, tank, and converter. Sunlight can be converted into direct current electrical energy by the photovoltaic cells of solar modules (Kiprono & Llario, 2020).

The energy is sent to the pump via a pump controller if the pump is DC-powered, or via a variable frequency drive (VFD) if the pump is AC-powered, which can convert DC to AC. The solar water pumping system's sizing is determined by considering the long-term system operation, technical, environmental, and financial aspects (Elrefai et al., 2017).

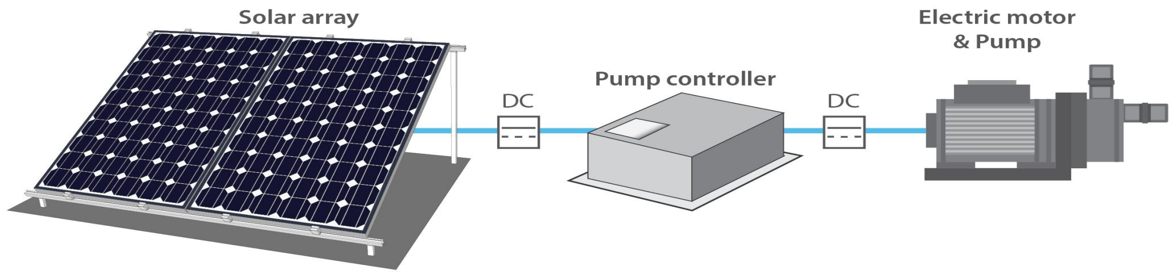

Figure 2. 1: DC-powered Pump model (Wade, 2019).

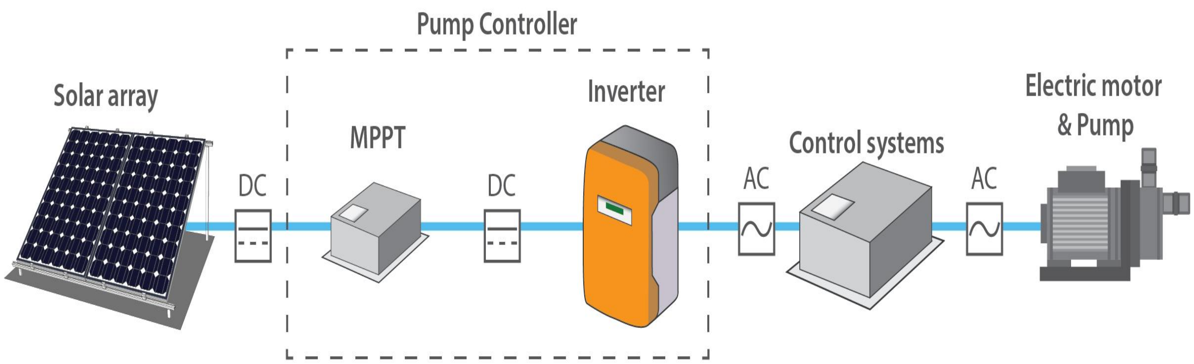

Figure 2. 2: AC-powered pump model (Wade, 2019).

2.2.3. Applicability SPWPS Design Methods and Sizing Tools

The use of solar energy for groundwater pumping offers enormous potential to increase the sustainability of water supply systems. Experience, however, also demonstrates that the adoption of such schemes is being impeded by a lack of knowledge, ability, and skill in their design and implementation (Kiprono & Llario, 2020).

Any water system must be designed and constructed in full compliance with all codes, standards, and laws of the governing bodies with jurisdiction over the installation site, regardless of the system's power source (Water Mission, 2020). Kiprono and Llario (2020) state that numerous variables influence the power generated by solar modules, which in turn affects the water output of a solar pumping system. Designing a solar pumping system manually becomes challenging and less accurate, as most of these factors vary depending on the time of day and season.

The sizing of a solar water pumping system is based on long-term operation, technical, environmental, and financial considerations (Elrefai et al., 2016). According to Habib et al. (2023), the performance of a photovoltaic array is affected by the surface temperatures of the module's top and bottom sides, the surrounding air temperature, and solar radiation intensity. These variables fluctuate seasonally in a given area. When sizing and designing the main components of the water pumping system (WPS), these seasonal variations are considered. Proper sizing of pumps and equipment is essential for an efficient water supply system over the design period.

The MS Excel-based development took into consideration some locations' patchy or slow internet access. Microsoft Excel Visual Basic Applications (VBA) is used to program the Excel-based version. With no complicated software installation needed, this application is incredibly useful and portable, and it works on any computer system (Mali et al., 2022).

2.2.4. SPWPS Design and Sizing Considerations

A solar pumping system is composed of an AC or DC pump, a solar panel to supply the pump's power requirement, and several sequentially connected regulatory and storage devices for system functioning (Mali et al., 2022) . It is challenging to optimize sizing in solar-powered schemes without the aid of solar design software due to the wide range of parameters/factors influencing water output (Kiprono & Llario, 2020) . Technical, environmental, financial, and long-term operational factors must be considered when sizing a solar water pumping system. Also, it needs to discuss the solar-powered water pumping system's performance and evaluation (Elrefai et al., 2017).

Design Considerations

The components of a solar pumping system include an AC or DC pump, a solar panel to supply the pump's power needs, and several sequentially connected regulatory and storage instruments for system functioning (Mali et al., 2022). Components like solar panels/arrays, converters, pump motors, water sources, pipes, and tanks are included in the proposed solar powered pumping system schematic (Palanivel et al., 2020).

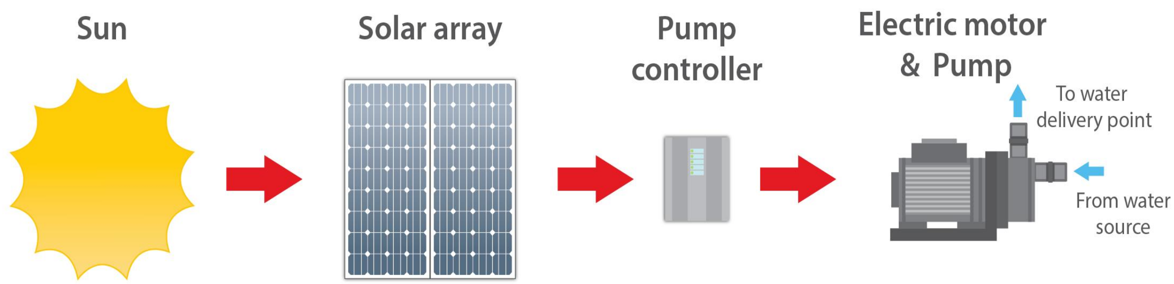

Figure 2. 3: Typical Solar Water Pumping Systems (Wade, 2019).

Different components of a solar PV system should be selected based on the proposed system type, site location, and application. According to Lundborg (2020), the general design factors for a solar pumping system can be broken down into several key steps. First, the daily water demand must be determined, followed by assessing the quantity and quality of water available from the source(s), such as boreholes. If necessary, the required tank storage size should be identified. The next step is calculating the daily design pumped flow, accounting for "catch-up" capacity during cloudy days. The pump's operating head, or Total Dynamic Head (TDH), should then be estimated.

When determining the size of the solar pump, controls, and solar array, there are two options: manual calculation or applying modeling software. For manual calculation, designers need to find the solar resource, select PV panels, and model their output hourly and seasonally, then determine the required average pump flow rate and select a preliminary pump model. TDH must be evaluated based on the chosen pump's curve. Alternatively, designers can use pump manufacturers' modeling software to input preliminary design data and recalculate TDH based on pump selection. Once this is done, the solar array should be sized and designed.

Final confirmation of the system requires attention to several details: ensuring that the maximum instantaneous flow does not exceed the source's design yield, confirming that pipes and fittings are appropriately sized based on maximum flow, and verifying that the array's output voltages fall within the acceptable range for the pump or pump inverter.

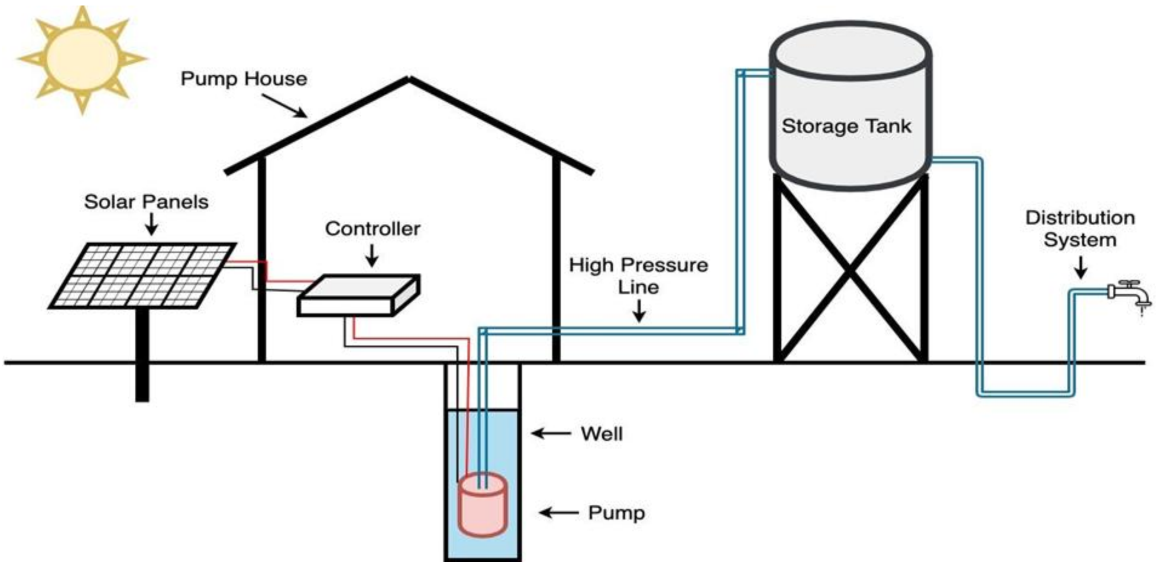

Figure 2.4: Key Features of a Standalone SPWPS (Lundborg, 2020)

2.2.5. Evaluation of SPWPS and Design Tools

Various technological and environmental factors influence the efficiency and operation of solar-powered underground water pumping systems. Research into these factors is essential to ensure system reliability and to account for their impacts throughout the development process (Ahmed et al., 2023).

Predictions of the long-term system performance are essential for the technically and financially effective SPWPS design. Evaluating the variables required for effective technical performance is part of the design and component selection process for SPWPS. To ensure the sustainability of the SPWP system, the relevant characteristics must be thoroughly examined before selecting the system and its components, and determining the optimal size for the PV system, motor pump-pipe system, and storage. Key considerations include site conditions, water demand, total dynamic head (TDH), pump type, solar irradiation, and cell temperature (Moholo, 2020).

Alternatively, factors such as the angle of incidence, cell temperature, dust accumulation on the PV module surface, and PV module degradation have the greatest impact on the performance of solar PV systems. The effectiveness of SPWPS is significantly influenced by three complex variables: mismatch, self-shading, and shadowing. These factors require further research, and designers should prioritize minimizing or eliminating their impact. Nonetheless, the primary hindrance in operating solar water pumping technology is the installed system's cost per watt, which must be met while satisfying load demand. When designing a PVWP system, several factors are considered, including the size and configuration of the PV array, the size of the motor pump and pipe system, the capacity of the storage tank, and a life cycle cost analysis. A poor sizing of the SPWPS components would affect the system's reliability, and performance and develop a shortfall (Moholo, 2020).

2.3. Empirical Literature Review

Girma et al. (2015) noted that solar photovoltaic (SPV) water pumping systems are among the most effective ways to harness solar energy to pump water from underground wells and provide clean drinking water globally. Ethiopia, with its abundant solar radiation and substantial groundwater resources, presents a significant opportunity to use this technology to provide rural communities with access to clean water. The study also highlighted the challenges of extending electric grids to all areas in underdeveloped countries like Ethiopia, where communities are often scattered across diverse and difficult terrains.

Numerous studies have explored the use, feasibility, and design of solar PV water pumping systems for water delivery. For instance, Tahiru et al. (2023) reviewed Ethiopia's renewable energy landscape. Hailu and Kumisa (2020) examined the country’s renewable energy potential and current state. Feleke et al. (2023) conducted a feasibility and possible assessment of solar resources in North Shewa Zone, Amhara, Ethiopia. Tekile (2014) focused on modeling solar radiation and performing a GIS-based multi-criteria analysis to assess solar energy resources in Ethiopia. Getie and Jember (2022) evaluated the potential and performance of floating solar photovoltaic systems on the Great Ethiopian Renaissance Dam. Bezabih (2021) studied solar energy use and evaluation activities around Bahir Dar, while Tadesse and Merkneh (2020) designed a solar PV water pumping system for household water consumption in Bilate Basin, Ethiopia.

2.4. Literature Review on Research Objectives

2.4.1. Challenges associated with SPWPS Usage

Challenges in the energy and water sectors include high costs of renewable energy technologies, insufficient financial resources, poor coordination between policies and stakeholders, a shortage of skilled human resources, political interference, corruption, ineffective community water management models, and limited access to information. Regarding the Solar Powered Water Pumping Systems (SPWPs), issues such as inadequate stakeholder coordination, misalignment with policies, environmental degradation, and planning and budgeting difficulties were identified, alongside a lack of information and awareness.These factors have contributed to non-functional systems, substandard installations, the presence of counterfeit products, dependency on external aid,slow technology adoption, unsustainable systems, and poor resource management (Phiri et al., 2023).

Solar energy development has been hindered by various obstacles, including technological, financial, political, and social factors. Technical challenges are a major barrier to its implementation, and socio-cultural issues impede the process (Abdullahi, 2021). Solar water pumps have emerged as a game-changer in the fight for effective and sustainable water management. Nevertheless, the widespread adoption of this technology faces several challenges. These include high initial costs and financing difficulties, gaps in technical expertise and knowledge, maintenance and repair issues, intermittent sunlight and seasonal variations, concerns about water quality and pump suitability, lack of supportive government policies and regulations, and issues related to water rights and ownership(Hussain et al., 2023).

Solar-powered water pumping technology offers a promising and affordable solution with extensive potential. Nonetheless, they face several challenges, including technical issues, financial constraints, skill development gaps, and policy barriers. Consequently, a detailed study is essential to evaluate their feasibility and uncover these challenges (Hussain et al., 2023b). Solar energy has become a focal point as a potential solution to the complex energy and development challenges facing the regions known as the "Global South. The Global South, which includes economically disadvantaged countries, faces numerous challenges, such as unreliable access to electricity, insufficient safe water resources, limited industrialization, and food insecurity. Solar energy, a sustainable and abundant resource, holds significant potential to address these issues. However, this potential cannot be realized in isolation; extensive collaboration is crucial. Governments must lead by establishing supportive policy frameworks, providing incentives, and offering regulatory clarity. Local and international organizations also play a vital role by delivering technological expertise, financing solutions, and implementing capacity-building initiatives. Communities must seize this opportunity to drive local adoption. Despite its vast potential, several barriers persist, including limited awareness, inadequate infrastructure, challenges in technology adoption, and financial constraints. Nevertheless, these obstacles also present growth opportunities (Ukoba et al., 2024).

2.4.2. Evaluation SPWPS Design Tools Technique Disparities

2.4.2.1. Evaluation of SPWPS Design Tools

Based on the essentiality of water for human survival, the quality of life in any country depends on the quantity and quality of its water resources. Solar Water Pumps (SWPs) use solar energy, converted through solar modules, to pump water from various sources. With growing awareness of the energy crisis, SWPs have garnered significant research interest. There are many design possibilities for developing these systems. Key factors that influence the performance of a Solar Water Pump system include the effective and efficient design of its components: the solar module, the pump head, the control system, and the water reservoir (Sinaga et al., 2023).

Sub-Saharan Africa holds great potential for renewable energy, but rural areas often face significant challenges with electricity access. Common design errors for the African context further depend on the situation. While developing micro-hydro and micro-solar energy plants, it is important to consider local limits and apply lessons learned from the past. Key considerations include proper sizing, selecting suitable technology and components, effective maintenance, and capacity building. A thorough assessment of the socioeconomic and cultural context is essential for successful energy development (Overcoming local constraints when developing renewable energy systems for the electrification of remote areas in Africa (Kenfack et al., 2020).

Access to water is crucial for human survival, health, ecosystem restoration, and sustainable social and economic development. Even with advancements in providing clean drinking water, many people, particularly in rural areas, continue to face shortages of this critical resource. Solar photovoltaic-powered water pumping systems provide a sustainable solution for water delivery. However, despite their widespread use, a standardized approach for selecting optimal sites and determining appropriate system sizes has not yet been established (Solar photovoltaic water pumping system: A software tool development-based optimal configuration investigation for system installation location, sizing, and deployment (Rengma et al., 2023).

When designing a solar pumping system, various guidelines must be followed. This guide offers the necessary information for accurately selecting the pump, sensors, solar array, wiring, and piping (Kayode et al., 2019) . Various environmental and technical factors shape the performance and reliability of solar-powered underground water pumping systems. A thorough assessment of these factors is crucial during the design and development stages to ensure optimal system effectiveness(Ahmed e al., 2023).

2.3.2.2. SPWPS Design Techniques The solar PV water pumping system is the supreme solution for remote areas with unavailable grid access. Using simulation software in the design process optimizes resource utilization and helps identify potential issues before field installation. Various software packages are available for designing solar PV water pumping systems (SPVWPS). The key components of the design include solar panels, a motor pump set, a controller, interconnected cables, earthing, a PV module mounting structure, rods, and a lightning arrester. In some cases, a water storage tank is also included, depending on the need (Ashraf, 2021) .Overall, from the data analysis results and their interpretation, the challenges associated with SPWPS for rural water supply in the study area summed up as a technical capacity gap among local operators, improper application of local knowledge, and lack of alignment with the national SPWPS working manual, unavailability of compatible spare parts in the local market, extensive vegetation cover, poor quality of installed materials, disparities, and deficiencies in construction and installation practices, weak operation and maintenance approaches, dispersed community settlements, erratic power generation, and energy storage during the wet season, difficulties in finding suitable water sources and determining optimal locations, and issues of theft and vandalism.

The broad range of factors influencing water output in solar-powered systems makes it difficult to optimize sizing without specialized design software. Solar software from various manufacturers is becoming increasingly popular and accessible. However, clear data and sound design criteria are essential for creating an efficient system. Many software packages, such as those from Grundfos, Lorentz, and Wellpumps, can assist with this process. These tools calculate the necessary factors based on selected components and geographic locations, suggesting designs that include solar module layout, power requirements, cable sizes, inverter or control box models, pumps, and other system elements. They also ensure that the performance and electrical characteristics of the components align to achieve the expected water and energy outputs(Kiprono & Llario, 2020).

2.4.3. Social and Environmental Implications of SPWPS

Solar power is a central topic in sustainable development discussions as the world increasingly embraces renewable energy sources (Akter & Mitu, 2024). Solar pump projects offer affordable water services that can benefit the economic status of beneficiaries. However, most studies have focused on system design and modeling, with limited evidence of socio-economic impacts. In the Solar Water Pumping Systems (SWPS) project, while communities gained valuable knowledge and skills in renewable energy, the economic benefits did not significantly improve overall welfare. This suggests that in poor rural areas, small-scale renewable energy projects alone may not drive economic growth. Stakeholders should therefore integrate these projects with broader programs to achieve meaningful socio-economic outcomes (Rahmani et al., 2022).

Decisions about land use for energy are critical as global demands for land, ecosystem services, and energy rise. The shift to renewable energy, while necessary for climate mitigation and sustainability, requires significant land for solar energy collection, raising concerns about impacts on ecosystems and biodiversity. Solar energy development, particularly utility-scale projects near protected areas, can lead to habitat fragmentation, species isolation, and ecological disruptions. However, strategic site selection can minimize environmental harm and even provide co-benefits (Hernandez et al., 2015).

The growing global demand for energy, driven by modernization and population growth, necessitates promoting renewable energy sources to meet future needs while advancing sustainable development and economic stability. Many sectors, including agriculture and farming, have increasingly turned to renewable energy-based water pumping systems due to frequent rises in fossil fuel prices and environmental pollution. In recent years, solar photovoltaic water pumping systems (SPVWPS) have become a preferred solution, offering practicality and cost-effectiveness for users. However, several technical challenges exist, such as high initial costs, efficiency, orientation, auxiliary storage, head, and payback period. Moreover, social challenges such as transportation difficulties, a lack of skilled labor, theft, vandalism, and political factors can hinder the widespread adoption of solar pumps. Despite these barriers, increased subsidies, training, tax incentives, and remote monitoring could enhance the accessibility and adoption of this technology (Gunasekaran & Chakraborty, 2023).

The solarization of water pumping systems greatly reduces CO_2 emissions compared to diesel-powered systems over their operational lifetime, which is crucial in mitigating global climate change. However, other important potential impacts that have not been fully addressed include environmental hazards from excessive abstraction due to prolonged pumping hours, additional forms of emissions, and the emissions associated with the manufacturing and transportation of electromechanical or solar equipment (Yalew, 2022).

2.4.4. Operational challenges and limitations of SPWPS

The world's population is growing faster than ever, and technology has made more people need electricity. The reliance on fossil fuels, which emit large amounts of CO_2 and significantly impact climate change, has prompted many countries to turn to clean, renewable, and sustainable energy sources, such as solar power(Ahmed et al., 2023). Rural water supply faces challenges like poor economic conditions, settlement in fragile environments, and varied cultural management models, which affect cost recovery. The dispersed nature of settlements complicates infrastructure provision, leading to deteriorating systems due to technical, financial, and managerial issues. As a result, rural communities often rely on contaminated local water sources (Salom & Khumalo, 2022)

As traditional energy resources used for electricity generation are finite, the future presents significant challenges in terms of resource availability. Solar energy, however, offers a promising solution to this limitation. Unlike coal and other fossil fuels, solar energy is renewable and sustainable. By harnessing the sun’s power, we can address the constraints posed by limited energy sources. One major advantage of solar energy is its versatility; it can serve as a primary source of electricity and power systems such as water purification. Despite its potential, solar energy faces challenges, including high initial investment costs and intermittent generation due to weather conditions (Kundu, 2023) . Hence forth, various environmental and technical factors influence the operation and effectiveness of a solar-powered underground water pumping system. To ensure the system operates reliably, it is crucial to investigate and account for these factors during development (Ahmed et al., 2023).

2.4.5. Community Engagement and Satisfaction with SPWPS

Community involvement is based on the idea that including stakeholder engagement in different forms in the decision-making process regarding their local communities and broader social issues offers significant social, political, and economic benefits (Jha et al., 2019). In low-income nations, community engagement is becoming the standard form of governance for rural water systems. Thus, in sub-Saharan Africa, community management remains the predominant model for overseeing rural water resources. It is widely believed that the community management model inherently incorporates principles of community engagement (Shields et al., 2021).

Community involvement in the process is crucial for the long-term success of community projects. To achieve the intended results effectively, critical initiatives such as the water project require greater participation in project planning and throughout the project cycle to enhance ownership of the projects, for successful implementation and sustainability (Bakari & Mbunda, 2022) The degree of community engagement indicates how much everyone will benefit from any project implemented in the locality. By lowering tensions and fostering greater community collaboration, effective stakeholder involvement, particularly for water supply projects, helps effective project delivery. Thus, all people or their representatives must fully participate in all project management phases to ensure the sustainability of the system (Ugbah et al., 2017). One key element of community involvement is their role in monitoring and evaluation, which greatly increases the sense of ownership and acceptance of the project among the intended beneficiaries. Including the community in projects is a powerful way to support their development and progress (Munene, 2020).

Indeed, active community involvement in project development can greatly enhance project success. By including the community in decision-making during the planning phase, they can benefit from opportunities like employment and business growth. This strategy is based on the notion that, with careful planning, rural communities can utilize their resources and efforts to enhance their general well-being (Laurent & Safari, 2021). Effective community participation involves a diverse spectrum of stakeholders to establish long-term, sustainable solutions for complicated situations. Approaches to community participation vary, and various goals are frequently incorporated into their design. Some focus on building social capital and strengthening relationships and trust within the community, though others target specific issues by tapping into the collective power of individuals working together (Waters et al., 2015).

Decentralized renewable energy projects, such as solar photovoltaic water pumping systems, have been implemented to improve water access in rural areas with active local community involvement. However, there has been insufficient study on how communities benefit from these projects, with more focus on the establishment process. Additionally, relevant research from developing countries is limited (Rahmani et al., 2022).

CHAPTER THREE

MATERIALS AND METHODS

3.1.Description of the Study Area

The study was conducted in Pinyudo Town, located in Pinyudo town, one of the rural towns in the Gambella region of Ethiopia. According to UNICEF, Pinyudo is a rural area that relies heavily on agricultural activities, with farming and livestock herding being the primary livelihoods for its population. The Region is 766 kilometers away from Addis Ababa and in Ethiopia's southwest, is home to an estimated 463,000 people, according to population data based on a 2007 projection. Gambella has an abundance of resources and arable land. Nonetheless, the area experiences frequent floods and droughts, and it is home to 337,421 South Sudanese refugees—nearly twice as many people as its own (UNICEF, 2022).

According to the 2024 World Weather and Climate Report, Pinyudo has a tropical wet and dry (savanna) climate. Google Earth data places Pinyudo's coordinates between Latitude 7.750283° to 7.748612° and Longitude 34.425008° to 34.42944°. The town is situated 461 meters above sea level. Pinyudo experiences an average annual temperature of 32.56ºC, which is 10.33% higher than the national average for Ethiopia. The area receives 132.25 wet days annually (36.23% of the time) and averages 68.43 millimeters of precipitation per year.

The rainy season typically occurs from May to October, followed by a dry period from November to April. This seasonal variation affects both, water availability and the energy demand for water pumping in the community. The terrain of the study area is predominantly flat, with some low-lying areas prone to flooding during the rainy season. The community is not connected to the national electrical grid, making it heavily dependent on alternative energy sources, such as diesel generators and solar power, for essential services, including water pumping. Given its off-grid status, access to clean and reliable water is a critical challenge, particularly during the dry season when groundwater levels drop and the demand for water increases.

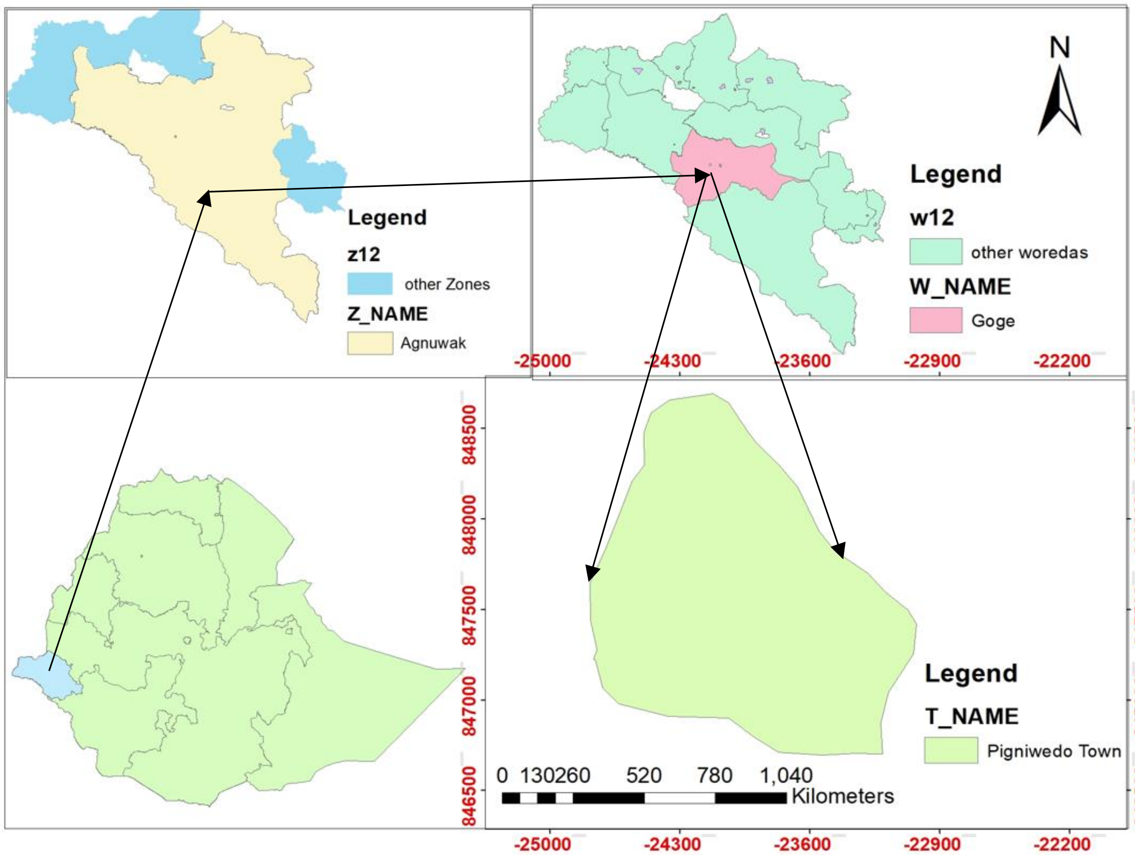

Figure 3. 1: Location Map of Study Area (Researcher made)

In Pinyudo town, the water supply infrastructure is limited, with only a few boreholes and hand pumps servicing the community. Due to the reliance on diesel-powered pumps, operational costs are high, and breakdowns are frequent, leaving many households, especially women and children, responsible for collecting water from distant sources, including rivers and seasonal streams.

3.2. Research Design and Approach

The study focused on identifying the key challenges of solar-powered water pumping systems (SPWPS) from the perspectives of the user community, technical personnel, and the systems themselves. It addressed difficulties in installation and maintenance, technological barriers faced by the rural community, system reliability under adverse weather conditions, and local involvement throughout the project cycle. Additionally, the study compared the technical differences between various SPWPS design techniques, assessing their impact on system performance and sustainability. Also, the research examined the operational limitations and challenges faced by the community, exploring technical, logistical, and resource-related obstacles. Socio-environmental impacts, including the effect of the systems on the local environment, health, and social dynamics, were also evaluated. Furthermore, community engagement and satisfaction with the installed systems were assessed, including the extent of participation and the overall benefits.

To collect the necessary data, several methods were used including conducting site observations for direct assessment, reviewing documents to analyze relevant reports and feedback, and carrying out physical surveys to gather information on infrastructure and operational status. Open-ended questionnaires and narrative interviews provided qualitative insights from community members and stakeholders, while semi-structured interviews offered detailed perspectives from key informants. Secondary data analysis of existing studies and records complemented these methods, ensuring a comprehensive evaluation of the solar-powered water pumping systems and their associated challenges and impacts.

The study also integrated primary, and secondary, quantitative and qualitative data. Quantitative methods were used to collect and analyze numerical data, identify patterns, and make predictions. Structured techniques such as surveys with large, representative samples, frequency descriptive analysis, Likert scale statistical analysis, field observations, and correlational designs were employed to measure variables and describe their relationships.

Furthermore, the qualitative research approach aimed to gather and analyze non-numerical data to gain insights into concepts, respondents' thoughts, and experiences with technical expertise. This was done using flexible and adaptive methods such as interviews, open-ended questions, document reviews, and case studies involving small, purposeful samples. The goal was to explore phenomena and understand the underlying reasons and motivations. By combining this with quantitative methods in a mixed methods research design, the study achieved a comprehensive analysis, utilizing the strengths of both approaches to provide a more thorough understanding of the findings. Regarding the research design and approach for each objective the detail discussed below.

3.2.1. Challenges associated with SPWPS Usage

To achieve this objective, the study utilized a triangulated research approach to assess the challenges of solar power-driven water supply systems (SPWPS) in the target community, integrating qualitative and quantitative data collection techniques. Data were gathered through open-ended questioners posed to twenty technical staff members, including engineers from government agencies and NGOs, these questions focused on the technical and implementation issues of the system. A survey questionnaire, featuring a seven-item and quantified with a Likert scale, was administered to the community members. Additionally, field observations were used in this regard, to obtain firsthand insights into the challenges associated with the system.

3.2.2. Evaluation of SPWPS Design Tools Difference

A mixed-methods approach was employed to evaluate differences between various solar-powered water pumping system (SPWPS) design techniques used in the study area. The methodology included a multicriteria analysis (MCA) using a structured questionnaire with ten questions based on predefined parameters. A Comparative Analysis (CA) was also conducted using a fifteen-question survey. Additionally, open-ended survey questions were used to provide further insights, and a field survey was conducted to observe differences between the design and as-built systems. Eventually, the document desk review also allowed for an unbiased differentiation of the tools.

So, in this paper, the Weighted Sum Method (WSM) was employed to determine the respondents' preferred SPWPS design tool. The alternatives were assessed based on their score values and assigned weights, using equation 3.1 (Dean, 2022).

$$\mathrm{V(di)} = \sum_{i=1}^{n} (\mathrm{Rdi} \ * (\mathrm{Wi} \ * \mathrm{Xi})) \text{-----------} \ (3.1)$$

Where;

- Rdi is the first level weight of the domain di,
- Wi is the second level weight of the criterion i,
- Xi is the arithmetic mean score of the design tool concerning criterion inquiry i, and
- V(d) is the resultant value of the domain di.

The total weighted sum for each design tool is calculated using the equation 3.2.

$$V_{DT} = \sum_{i=1}^{n} (V_{di}) \text{------------------------------} (3.2)$$

Where;

- V_{DT} is the total weighted sum of each design tool-DT,
- V_{di} is the resultant value of the domain di; (TeD, SoEnvD, & EcoD).
- TeD- technical domain
- SoEnvD- socio-environmental domain
- EcoD-economical domain, thus

$$TeD = R_1 w_{11} * (x_1+x_2+x_3+x_4+x_5+x_6) \text{---} (3.3)$$

$$SoEnvD = R_2 w_{22} * (y_1+y_2)$$

$$\Rightarrow EcoD = R_3 w_{33} * (z_1+z_2) \text{---} (3.4)$$

$$R = R_1 + R_2 + R_3 = 1 = 100\% \text{)--} (3.5)$$

$$\Rightarrow (DT) = TeD + SoEnvD + EcoD) \text{---} (3.6)$$

Henceforth, the final decision to differentiate the SPWPS design tools was made using these equations. Additionally, qualitative and quantitative data were used, with standardization applied to convert all scores into a uniform unit and computable system. The selected criteria for identifying differences were technical, social, environmental, and economic. These pillars were represented by three domains or parameters: the technical domain with six corresponding criterion inquiries, the socio-environmental domain with two corresponding criterion inquiries, and the economic domain with two corresponding criterion inquiries.

Concerning the SPWPS design tools, four design approaches were employed for groundwater pumping system design and installation in the Pinyudo town: The Ministry of Water & Energy (MoWE) design tool, the Water Mission design tool, the Grundfos pump sizing tool, and the Lorentz pump sizing tool, all customized for the community water supply system. For clarity, the design outputs are illustrated in the image below, providing a visual reference before proceeding with the data analysis.

1) The Mistry of Water and Energy (MoWE) SPWPS Design Tool

The MoWE SPWPS design toolkit was developed in December 2013 by the Ethio-Resource Group a guiding design manual and an Excel-based worksheet to facilitate the design process by organizing and manipulating input data. This tool helps determine key parameters, ranging from water requirements to equipment pricing.

According to MoWE design (2018), the design and implementation manual was created for solar and wind water pumping systems, targeting developers, including regional and local government offices. It assists developers in assessing the viability of solar and wind systems compared to other alternatives, while guiding them through the design, implementation, operation, and maintenance phases. The primary goal is to promote proper system design and encourage the wider adoption of these technologies as sustainable solutions for rural water supply in Ethiopia.

The manual covers essential stages of the project cycle, such as resource availability, site selection, system design, implementation, operation, and maintenance. It is mainly intended for local development workers in the energy and water sectors, both government and non-government, including private-sector developers, can also use it for system design and implementation. It enables users to evaluate the feasibility of photovoltaic (PV) water pumping, create initial designs suited to local needs, understand installation and service requirements, and estimate procurement costs.

The system design process involves ten key steps, starting with data collection on location, elevation, water source characteristics, and community needs, and concluding with the sizing of the power source and conditioning equipment. These steps include gathering basic information, determining water requirements and sources, calculating storage needs, developing the pumping system layout, estimating solar insolation, determining the Total Dynamic Head, calculating the Hydraulic Energy Requirement, sizing the pump motor, determining the solar array size, and sizing the pump inverter.

The tool comprises eight workbooks: an introductory tab featuring organizational details and information about the design tool developer, including a daily water requirement calculator for community water demand, livestock needs, and location specifics. It also includes a hydraulic power requirement calculator with 31 inquiries for static head and head loss calculations, a solar resource estimator for PV array sizing, a Bill of Quantities, and a Bill of Cost tab for financial analysis to assess the system's feasibility. Lastly, there is a summary tab for consolidating the designed solar pumping system component. This design approach resulted in installing solar-powered water supply systems in the Pinyudo host communities, as depicted in the images below.

Figure 3. 2: MoWE SPWPS Components at Pinyudo High School Site

1) The Water Mission (WM) SPWPS Design Tool

Water Mission (WM) is a non-profit Christian engineering organization based in Charleston, South Carolina, USA, that provides sustainable safe water and sanitation solutions. The organization focuses on implementing community-managed safe water projects powered by solar energy. After the project is completed, managing and maintaining these systems is transferred to the community, ensuring local ownership and long-term sustainability (Longwe et al., 2019).

The Water Mission (WM) SPWPS design toolkit, created in 2019, is based on the guidelines and technical standards outlined in the International Electrotechnical Commission (IEC) International Standard 62253, titled "Photovoltaic Pumping Systems – Design Qualification and Performance Measurements." This toolkit was intended to guide the key design components required for delivering safe water via solar-powered water supply systems. The design tool clarifies that the Excel spreadsheet is not intended to replace sound engineering judgment. Instead, its purpose is to assist designers in thinking through, understanding, and making informed decisions about the key components of solar-powered water supply projects.

The tool features a user manual and an Excel spreadsheet designed to streamline the design process by organizing and processing the input data provided by the designer. It includes user entry tabs, operational calculator tabs, and reference tabs with technical information. The tool is organized into five key sections: Water Demand Calculator for population and demand estimates; Water Supply System Component Evaluator for sources, treatment, and storage; Hydraulic Design for system layout and TDH calculations; Pumping Sizing Tab for pump selection and electrical details; and Solar Panel Sizing for power, output, and PV sizing.

Furthermore, the tool also includes calculators for household, institutional, and future water demands, along with a design summary covering water demand, supply, hydraulic design, pumping, and solar PV sizing. The Water Mission design approach offers guidelines such as groundwater surveys, solar rack design, financial sustainability, and assessment worksheets. It is integrated with the Grundfos pump sizing tool, and the outcomes from this tool in Pinyudo are shown below.

Figure 3. 3:Water Mission SPWPS Related Works at Pinyudo Town

1) **The Grundfos SPWPS Pump Sizing Tool**

As the company website declared, Grundfos, founded in 1945, is one of the world's leading pump manufacturers, operating in more than 80 companies across over 55 countries, helping to bring pumps to every corner of the world. The company aims beyond the pump production to make water more accessible, reduce energy waste, and increase efficiency. The Grundfos Foundation called the Poul Due Jensen Foundation (PDJF) works on donations for water-related works to create access to drinking water for communities in need, research and learning initiatives, environments,individuals within technical and natural science disciplines, and support inclusions in community engagement grants for causes across the globe.

Grundfos offers a comprehensive range of reliable solar water solutions, including systems designed for large-scale water supply, with all the necessary components for a complete solar-powered setup. As a global company with a strong local presence, Grundfos has a longstanding history of developing solar water technologies. Since introducing its first off-grid water supply system in 1980, the company has remained at the forefront of innovation in off-grid technology.

The Grundfos solar-powered water supply system design combines the pumps, controls and monitoring, solar panels, and components required for a complete solar-powered water supply system. The Grundfos Product Center is a free digital product catalog and sizing tool, starting the interface with an inquiry about the product. The pump sizing tool, available on both computer and mobile applications, assists design engineers in selecting and evaluating pumps. This user-friendly calculator, based on pump design, application, and performance requirements, ensures the right pump choice has to be made.

The Grundfos pump sizing tool streamlines pump selection, helping you quickly find a pump that meets your duty points and application needs. In three simple steps, you define application requirements by entering the duty point and selecting parameters (e.g., energy consumption), evaluate and compare compliant pumps based on life cycle cost, and choose the desired pump while reviewing key data such as sizing results, curves, and dimensions. A PDF printout of essential details can also be generated as needed. Also, the Grundfos Solar Water Pumping System Design Manual is organized into three concise sections for easy reference.

The first module introduces solar water pumping systems, the second outlines the features and benefits of selected Grundfos pumps, and the third covers the sizing and selection of a Grundfos solar water pumping system. These modules training resources. This approach has resulted in installing solar-powered water supply systems collectively direct the design engineer to the company’s web-based solar pump design tool and in the Pinyudo town refugee camps and host communities, as shown in the images below.

Figure 3. 4: Grundfos SPWPS Related Works at Pinyudo Town

1) The LORENTZ SPWPS Pump Sizing Tool

According to the Lorentz pump company's website, LORENTZ is the global leader in solar-powered water pumping solutions. Established in Germany in 1993, LORENTZ has been at the forefront of innovation and excellence in the engineering and manufacturing of solar-powered water pumps. Now, LORENTZ operates in more than 130 countries through a network of dedicated professional partners.Leveraging LORENTZ's expertise and engineering capabilities, a diverse range of products for specialized pumping applications has been created. These products, marketed under the LORENTZ Energy brand, include pumps for oil extraction, landfill liquid removal, and remediation applications.

Lorentz offers proprietary solar pump design software COMPASS, designed to help the users accurately size and specify solar pumping systems, as highlighted on their website. COMPASS is a PC-based application with advanced modeling features and comprehensive information on the full range of LORENTZ products. Thus, it allows Lorentz partners to design solar water pumping systems tailored to client needs. By entering basic data like **location, water demand, and total dynamic head**, the software recommends the appropriate Lorentz solar pump model and provides installation details, including wiring diagrams. It also suggests compatible accessories and offers performance forecasts using NASA meteorological data, ensuring year-round accuracy. COMPASS also suggests compatible accessories, giving clients flexibility in customizing their system's capabilities.

Beyond design, the software can forecast hourly, daily, and monthly system output using NASA meteorological data, that accounts for seasonal variations, providing accurate performance expectations year-round. Lorentz also offers two Android™ apps—Pump Scanner and LORENTZ Assistant—designed to help installers, customers, and technicians easily configure, monitor, and control pump systems. These apps improve system management and facilitate real-time adjustments.

The COMPASS PC-based software simplifies pump sizing for SPWPS in four steps: General Information – Select pump type, location, and optimal solar panel angles. Discharge Side – Determine total dynamic head (TDH). Output Requirements – Enter daily water demand, size for the month with the least solar power, and input borehole safe yield. Discharge Side – Calculate static head, measure pipe length, and select pipe type from the menu, using the worst-case scenario if uncertain. Finally, by clicking "Report," the system characteristics (pump, number of panels, etc.) will be displayed. The designer can also generate a PDF document containing essential information, such as accessories for the selected pump, and system layout, at the Pinyudo town refugee camps, as seen in the pictures below.

Figure 3. 5 Lorentz SPWPS Related Works at Pinyudo Town

3.2.3. Analysis of Social and Environmental Impacts in the Local Context

The thesis used a mixed-method approach to identify the impact of the installed solar-powered water pumping systems on the socio-environmental aspects of the study area. The methodology incorporated both qualitative and quantitative data collection techniques to capture a comprehensive view of the impacts. A structured survey questionnaire with seven questions was administered to 450 community members, utilizing a five-point Likert scale to quantify their perceptions of the social and environmental effects of SPWPS. Additionally, semi-structured interviews with scheme operators were conducted to gather qualitative insights. Field visits to SPWPS sites were made to directly observe the environmental changes and how people interact with the systems.

3.2.4. Analysis of Operational Challenges and Limitations

Some techniques were used to assess the operational difficulties and constraints associated with overseeing and using the solar-powered water pumping system in the research region. These included open-ended questions for technical staff, a survey questionnaire for the user community, and field observations. A six-question survey titled “Operational Challenges & Limitations Faced in Implementing and Managing the Installed SPWPS by the Local Community” was distributed to 450 randomly selected individuals using a five-point Likert scale. Furthermore, field observations were conducted, and simultaneously no-structured interviews with local operators were carried out at each site. This approach provided insights into the operational difficulties experienced by the community.

3.2.5. Community Engagement and Satisfaction with SPWPS

Various data collection methods were employed to achieve the research objectives through data analysis. Open-ended questions were tailored for technical staff, and a survey questionnaire was developed and administered to the user community. Additionally, a researcher-designed survey comprising six questions was distributed to 450 randomly selected individuals through data collectors. So, this survey was employed to assess community perspectives on their engagement levels and satisfaction using a five-point Likert scale.

In conclusion, various factors were considered to evaluate how challenges in using solar-powered water pumping systems (SPWPS) for rural community water supply correlate with social and environmental impacts, local community engagement levels throughout project cycles, and operational constraints faced during SPWPS implementation. The analysis utilized coefficients from -1 to 1 to indicate the strength and direction of these relationships, with a 95% confidence interval. Results are presented in the table below, followed by a detailed discussion.

3.3. Data Source and Collection Method

3.3.1 Data Source

The data sources for this study included the user community, engineers and technical staff (from local government office,implementing and operating NGOs, and scheme technicians), scheme operators from community water points and SPWPS sites. The technical managers and engineering staff generally hold a BSc or MSc degree, most specializing in water supply, environmental, civil, or hydraulic engineering. Technicians working with NGOs and government offices typically have a minimum qualification of 10+4 or a diploma in electromechanical studies. However, in some Solar-Powered Water Pumping Systems (SPWPS), technicians have educational levels ranging from grade 8 to grade 10.

The town community consists of the host population and refugees from the Pinyudo camp, divided into two sections: Pinyudo 1 and Pinyudo 2. Additional data sources comprised meeting minutes, letters, design documents, and various digital and non-digital materials. Digital sources encompassed websites, social media platforms, digital databases, electronic books, journals, and publications. Non-digital sources included literature, research works, printed books, reports, minutes, government documents, and researcher-made questionnaires. Accordingly, the study utilized primary and secondary data sources and incorporated qualitative and quantitative data types.

3.3.3. Data Collection Method

The primary and secondary data for the study were collected from various sources as previously outlined. Relevant data was obtained through field observations at existing solar pump installation sites. Additionally, open-ended surveys were conducted to allow respondents to freely express their knowledge, feelings, and understanding without the constraints of predefined options. This was also complemented by in-person interviews, survey questionnaires, review of design documents and meeting minutes, examination of archived correspondence, and gathering secondary data from digital sources. Overall, the complete research design and approach are designated in the research process conceptual framework attached in the annex.

3.4. Study Population and Sampling Technique

3.4.1 Study Population

For a range of planning, research, and policy objectives, as well as to inform important issues and investment choices, small-area population estimates are extensively utilized by both government and business. The small area population forecasting toolkit, however, is more limited than that of large subnational regional, and national forecasting (Wilson et al., 2022).

According to the Ethiopian Central Statistical Agency (CSA) projection report of July 2020, Pinyudo town without a refugee community estimated about 20,874 for the year 2022. From this number of males is 9,987 and female-10,887. As mentioned, Pinyudo town is the home of South Sudanese refugees. It has a population of as of November 30/2023, at Pinyudo-1 51,219, at Pinyudo-2 11,385, and a population of 62,092 refugees(United Nations High Commissioner for Refugees, 2024).

3.4.3. Sampling Technique and Sample Size Determination

Simple random probability and judgmental sampling methods were used to identify population representatives. To ensure efficiency, representativeness, dependability, and flexibility, the ideal sample should be chosen from the target population. The Ethiopian Central Statistical Agency reported in July 2013 reported that Gambella's growth rate (r) is around 4.4%.

As a result, the overall population of Pinyudo town includes both the inhabitants of the host c ommunity and the camps housing refugees. Therefore, the Ethiopian Central Statistics Agency's population forecasting method is applied to estimate the population of the host community (Mekonnen, 2018).

$P_n = P_o * e^{(r*n)}$

Thus, the total population from the host community and the refugee camp is about 83,905. And which considered a 95% confidence interval (CI) and 5% margin of error. To determine the sample size used the formula: $n = \frac{(Z^2 * p * (1-P))}{E^2}$; (Taherdoost, 2017).

Where **n** is the required sample size, **P** is the percentage occurrence of a state or condition, **E** is the percentage maximum error required (5%), and **Z** is the value corresponding to the level of confidence required (1.96 for 5% Confidence Level)

Thus, Sample Size becomes, = $\left(n = \frac{(1.96^2 * 0.5 * (1-0.5))}{0.05^2}\right) = \underline{384.16 \sim 385}$. Accordingly, 385 samples were selected using simple random probability sampling. To account for sampling error, the number of respondents from the target community increased to 450. Additionally, 20 technical and managerial individuals were chosen through judgmental sampling, bringing the total number of samples to 470 for the study.

3.5. Materials Used

Some tools and materials were employed to assess the on-site technical challenges of solar-powered water pumping systems (SPWPS). A GPS (Global Positioning System) was used to acquire positioning, navigation, and timing (PNT) data for the solar panels. An electric tester checked the electrical current in circuits, solar cables, solar arrays, control boxes, and other components, ensuring that SPWPS electrical connections were safe and fully operational. An AC/DC digital clamp meter measured the current, while a clinometer determined the tilt angle of the solar panels. Additionally, a steel meter was used to obtain precise size measurements.

3.6. Method of Data Analysis

As stated, the study employed a mixed research methodology. All qualitative and quantitative data were initially; checked for completeness and consistency, then coded, organized, and analyzed according to the study's objectives. Quantitative data, measured using the Likert Scale, underwent reliability testing (Cronbach's alpha-α) and normality tests using SPSS-IBM and MS-Excel for frequency descriptive analysis and other tests. These tests assessed whether the scale items consistently measured the same dimensions and verified the data's distribution. Qualitative data underwent content analysis. For decision-making purposes, Multicriteria analysis utilized the Weighted Sum Method (WSM), while comparative analysis employed frequency descriptive analysis. Overall data distribution was analyzed using Spearman's correlation, with a 95% confidence interval (CI) to assess association strength, and a p-value < 0.05 to determine statistical significance in analyzing the correlation result.

CHAPTER FOUR

RESULTS AND DISCUSSION

To achieve the intended objectives of the thesis and to respond to the formulated questions the data collection tools are branded like a data collection tool for engineers & technical staff (staff from the local government office, the implementing & operating NGOs, and the scheme technicians), for the community and checklist for the researcher field observation. So, the data analysis was conducted meticulously, and the findings and the overall process are chronologically discussed below.

4.1. Challenges Associated with SPWPS Usage

To assess the challenges associated with solar power-driven water supply systems (SPWPS) as mentioned a set of open-ended survey questions, consisting of five inquiries directly addressing the issue, were devised as a data collection tool, land was distributed to twenty technical staff members, including engineers from government agencies (regional and woreda water and energy bureaus), NGO workers (like UNHCR, ARRA, Oxfam, PIE, and UNICEF) involved in SPWPS installation, operation, or monitoring, as well as technical managers and staff from community SPWPS water schemes. Out of all the questionnaires distributed, only sixteen (80%) were returned to the researcher with responses.

The key issues identified in this area included a technical capacity gap among local operators, a lack of adherence to national experience during the installation of the solar system components, and the unavailability of SPWPS spare parts in the local market. Major concerns that emerged include extensive vegetation cover, poor-quality installed materials (such as RSI, which burned out, and solar panels that cracked and broke shortly after installation), inadequate construction practices (like weak foundation work), oversized solar panel mounting structures, and the lack of competence among local technicians in operating and maintaining the systems. Challenges were also exacerbated by theft, vandalism, and the scattered nature of community settlements.

Furthermore, 75% of respondents reported a lack of awareness about national standards or policies regulating the quality and durability of solar-powered water pumping system designs and installations in the area. In contrast, 25% were aware of a national manual created by the FDRE Ministry of Water and Energy, which also identified as a challenge for the system. Components limiting the sustainability of the current SPWPS included RSI, solar batteries, high siltation, pump failures due to dry running, poor-quality solar panels, and issues with motor and pump covers and power controllers.

When discussing the community's cost concerns, most respondents noted the substantial investment required for the systems. However, the community did not contribute to the investment costs, also fully covered by the government or NGOs. Therefore, aside from operation and maintenance costs, demonstrating how the investment costs affect the local community might be impractical at this stage.

Respondents suggested the Grundfos pump design solution due to its enduring performance, user-friendliness, and economical design. Challenges related to using solar-powered water supply systems and design tools included difficulties in obtaining spare parts locally, technical knowledge gaps in installing new technologies, and issues with the supply chain for components like chlorine tablets, RSI, solar pumps, and controllers. Other concerns included insufficient space for mounting solar panels, theft and vandalism, a shortage of skilled manpower, investment cost issues, and the incompatibility of new design tools with national standards.

Secondly, a survey titled 'Challenges in Installing and Implementing Solar-Powered Water Pumping Systems (SPWPS) in Rural Communities' was conducted to address critical concerns related to the establishment and operation of SPWPS. The questionnaire focused on several communities concerning the SPWPS technology establishment critical aspects, including installation investment costs, the technical expertise required for installation and maintenance, community involvement in executing design outputs, road quality and accessibility for transporting large technology components, satisfaction with daily water delivery services, identification of suitable water sources, optimal system placement, and the impact of inconsistent power generation and energy storage on water delivery.

The survey consisted of seven targeted questions designed to evaluate respondents' perceptions of the challenges and their experiences with SPWPS in rural water supply contexts. Participants responded using a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Trained personnel facilitated data collection for a survey of 450 community members.

The Cronbach's alpha (α) reliability test yielded a score of 0.671 and was considered acceptable. The test results table is provided in the annex. This indicates that the survey questions assessing the user community's opinions on challenges related to SPWPS in rural water supply systems demonstrated reasonably consistent internal coherence, strong correlation, and reliability.

The normality test conducted for the installation and implementation challenges of solar-powered water pumping systems (SPWPS) in rural communities, with a confidence interval of 95%, revealed the significance p-values below 0.05. This indicates a notable departure from the normal distribution, suggesting that the data are not normally distributed in the case of Shapiro-Wilk. However, despite this deviation, the data remained statistically significant and the measurement of the frequency distribution test did regardless of this result.

After conducting reliability and normality tests, a frequency descriptive analysis was performed to describe the occurrence of each value within the data set. The results, indicating how often each value appeared in the observations, are presented in Table 3 below. Among the 450 respondents, 158 (35.1%) agreed that the investment cost for the solar-powered water pumping systems (SPWPS) was difficult. Additionally, 160 respondents (35.6%) emphasized the importance of having SPWP installation and operation technicians but acknowledged that their unavailability in remote areas posed a significant challenge. Conversely, 133 respondents (29.6%) disagreed with the notion that a lack of community engagement and a sense of ownership would not impact the sustainability of the SPWPS.

Furthermore, 142 respondents (31.6%) agreed that during the wet season, the installed SPWPS sometimes required additional system (power) support to meet daily demand due to inconsistent power generation and energy shortages. Also, 120 respondents (26.7%) reported that finding suitable water sources and determining the optimal location and space for installing SPWPS and solar panels were issues in rural communities. Finally, 120 respondents (27.1%) noted that due to erratic power generation and energy storage issues throughout the wet season, the installed SPWPS could not always meet the daily water demand.

Table 4. 1: Frequency Analysis of SPWPS Challenges

S/No	Variable Description	1 (SD) (%)	2 (DA) (%)	3 (N) (%)	4 (A) (%)	5 (SA) (%)
1	The investment cost for purchasing and installing solar-powered water pumping systems (SPWPS) equipment can be difficult for rural communities.	55 (12.2)	105 (23.3)	29 (6.4)	158 (35.1)	103 (22.9)
2	Proper installation and maintenance of solar-powered water pumping systems (SPWPS) require technical expertise, and unavailability in rural areas might cause hindrances in the water supply system.	58 (12.9)	125 (27.8)	51 (11.3)	160 (35.6)	56 (12.4)
3	Lack of community engagement during project development and empowering ownership is a challenge in our locality and impacts the long-term sustainability of installed solar-powered water pumping systems (SPWPS).	53 (11.8)	133 (29.6)	84 (18.7)	103 (22.9)	77 (17.1)
4	Because of the poor quality and inaccessibility of the roads, transporting tools and supplies to isolated rural locations while installing and maintaining solar-powered water pumping systems (SPWPS) components can be difficult and expensive.	56 (12.4)	85 (18.9)	73 (16.2)	159 (35.3)	77 (17.1)
5	The installed solar-powered water pumping systems (SPWPS) sometimes needed help to satisfy the daily water delivery service requirements due to inconsistent power generation & energy shortages during the wet season.	55 (12.2)	79 (17.6)	74 (16.4)	142 (31.6)	100 (22.2)
6	Identifying suitable water sources, and determining the optimal location, and space for Solar panel mounting for installing solar-powered water pumping systems (SPWPS) is a challenging issue in the rural community.	68 (15.1)	97 (21.6)	79 (17.6)	120 (26.7)	86 (19.1)
7	The installed solar-powered water pumping systems (SPWPS) could not satisfy the daily water delivery service requirements due to erratic power generation & energy storage throughout the wet season.	101 (22.4)	99 (22.0)	84 (18.7)	122 (27.1)	44 (9.8)

Thirdly, field observations were conducted at twelve solar-powered groundwater pumping units in the study area were examined during this assessment. The observed challenges included several issues: The solar panels were installed far from the community's residential areas and were protected by only a single security guard, making the systems vulnerable to vandalism and theft. The solar panel mounting systems and structural elements—such as the foundation, tilt angle, mounting direction, and support type—varied significantly among different systems. This variation led to some systems having short mounting structures, poor foundation quality, and minimal tilt angles, which increased their susceptibility to failure. During the field visit, it was noted that more than five out of the twelve solar-powered community water supply systems had become nonfunctional. Additionally, vegetation shading the solar panels, combined with weak operational and maintenance practices, significantly reduced the efficiency and reliability of the solar-powered systems. Furthermore, the lack of spare parts and technical skills posed substantial challenges in effectively maintaining and repairing the SPWPS.

From studies on SPWPS challenges, Phiri et al. (2022) emphasize the need for the national government to create a supportive environment for stakeholders to implement Sustainable Water Projects (SWP). They identify key challenges such as policy gaps, inadequate monitoring, poor coordination, and stakeholder misconduct, which hinder the effectiveness of water and energy services. These issues result in insufficient water provision, characterized by unequal access, non-functional systems, reliance on donations, and low-quality renewable energy products.

Overall, from the data analysis results and their interpretation, the challenges associated with SPWPS for rural water supply in the study area summed up as a technical capacity gap among local operators, improper application of local knowledge, and lack of alignment with the national SPWPS working manual, unavailability of compatible spare parts in the local market, extensive vegetation cover, poor quality of installed materials, disparities, and deficiencies in construction and installation practices, weak operation and maintenance approaches, dispersed community settlements, erratic power generation, and energy storage during the wet season, difficulties in finding suitable water sources and determining optimal locations, and issues of theft and vandalism.

4.2. Evaluation of SPWPS Design Tools Difference

To evaluate the differences between various solar-powered groundwater pumping system design techniques used in the study area, a decision-making tool called Multi-Criteria Analysis (MCA) was employed to determine overall preferences among alternative options. Likewise, Multi-Criteria Analysis is a powerful tool that supports informed, balanced, and transparent decision-making in complex scenarios. Additionally, MCA offers a holistic approach that allows decision-makers to consider multiple factors and perspectives concurrently.

This results in more comprehensive and balanced decisions. Despite the differences among the design tools, a Comparative Analysis (CA) was conducted to evaluate their strengths and weaknesses. Thus, combining the MCA and CA result analysis achieves a comprehensive approach, offering an evidence-based foundation for making optimal decisions aligned with the applied design tools.

A questionnaire was developed for both methodologies to gather first-hand information about the output details of each SPWPS design tool. Consequently, Multi-Criteria Analysis (MCA) was used to compare, contrast, and select among the diverse design tool alternatives based on predefined criteria. These criteria encompassed three key parameters, each with multiple factors assigned different weights: technical domains with six inquiries, socio-environmental domains with two inquiries, and economic domains with two inquiries.

Similarly, the Comparative Analysis (CA) includes fifteen (15) questions aimed at identifying subtle uncertainties that affect the outcomes of decision alternatives regarding the differences in design tools. Additionally, the researcher included three open-ended questions for the technical team in the data collection tool. Consequently, the questionnaire was distributed to twenty technical staff members: engineers from the regional and Woreda water and energy bureaus, NGO employees, technical managers, and technicians involved in community SPWPS water scheme development. Out of the total, sixteen participants (80%) completed and submitted the document. Following the collection and coding of data from the study area, the results of the investigation utilizing MCA and CA were interpreted as detailed below.

Multicriteria Analysis (MCA)

First, Reliability (Cronbach's alpha, α) and normality tests were conducted on SPSS-26 for the collected data, as the questions were measured using a Likert scale. Thus, the details as shown in the attached annexes, the Cronbach's alpha (α) for the MoWE design tool was 0.883 which ranges a perfect internal consistency, for the WM-0.902, for Grundfos-0.909 and Lorentz design tools- 0.978, as a result, the collected data for both the three design tools had an excellent internal consistency.

The above reliability analysis demonstrated outstanding results and revealed that all measured parameters indicate high internal consistency across the data set. Consequently, the test results were stable, consistently evaluating the same underlying dimensions. These results confirm the robustness and dependability of the measurement tool used for the Multicriteria Analysis (MCA) method in this study.

Soon after, the normality test for the Multicriteria Analysis (MCA) tool concerning the SPWPS design techniques was conducted and the result indicated that the data were normally distributed. The p-values for the Shapiro-Wilk and Kolmogorov-Smirnov tests were greater than 0.05, suggesting no significant deviation from normality. Additionally, the skewness and kurtosis values fall within acceptable ranges referred to in the table in the annex. These findings validate that the data satisfies the normality assumption, and allow us to proceed to further analysis for the above four design tools.

Moreover, The MCA tool analysis aimed to identify the most preferred design tool by the user community, with differences assessed in technical, socio-environmental, and economic aspects using a five-point Likert scale ("1" for "Very Poor", "2" for "Poor", "3" for "Fair", "4" for "Good", and "5" for "Very Good").

The applied MCA method used the weighted value for technical, Socio-Environmental, and economic domains to evaluate the difference of the applied diverse design tools for the respondent's response to the research questions. Hence, the first-level domain weight for the domains (aspects) and the second-level sub-domains weight for the criterion inquires (corresponding attributes or indicators inquiries) for each main domain and the detail was revealed in the following table.

Table 4. 2: Variable description and a given first-level weight (R)

S/No	Parameter Description (Domain)	First Level a given Weight	
1	Technical Domains (Technical Aspect)	$R_1 = 50\%$	0.5
2	Socio-Environmental Domain (Socio-Economic Aspect)	$R_2 = 25\%$	0.25
3	Economical Domain (Cost Aspect)	$R_3 = 25\%$	0.25
	Total		1

Using the provided formulas, the proposed domains, and the assigned first-level and second-level given weights for the domains, an analysis for the Weighted Sum Method (WSM) of the SPWPS design tools was conducted based on respondents' responses in the Excel-based MCA model. The results were interpreted and displayed in the graph below, and the detailed calculations are provided in the attached annex.

Table 4. 3: Domain Criteria with Sub-domain Weights (w)

S/No	Parameter Description (Domain)	First Level a given Weight (%)		Second Level a given Weight (%)	
1	**Technical Domains (Technical Aspect)**	$R_1 = 50$	**0.5**		1
1.1	The designed solar panel energy and pump efficiency against the running (actual) efficiencies of the installed SPWPS.			$w_{11} = 35$	0.35
1.2	Communities' daily water demand versus supply concerning the national standard (water supply reliability).			$w_{12} = 25$	0.25
1.3	Storage Capacity and daily production rate with the national guidelines to satisfy the community's daily water demands.			$w_{13} = 12$	0.12
1.4	Ease of operation, maintenance, and system management with local knowledge.			$w_{14} = 8$	0.08
1.5	SPWP System integration with the grid or diesel system (Hybridization compatibility).			$w_{15} = 10$	0.10
1.6	SPWP System installation complexity for the local experts.			$w_{16} = 10$	0.10
	Total-1			**100**	**1**
2	**Socio-Environmental Domain (Socio-Environmental Aspect)**	$R_2 = 25$	**0.25**		1
2.1	SPWPS infrastructure installation requirements social & environmental impacts (land, vegetation removal, waste material handling, etc.)			$w_{21} = 30$	0.30
2.2	SPWPS end-users and other beneficiaries like technical personnel’s satisfaction level, with the technology.			$w_{22} = 70$	0.70
	Total-2			**100**	**1**
3	**Economical Domain (Cost Aspect)**	$R_3 = 25$	**0.25**		1
3.1	The investment cost for the full installation package of the SPWPS system concerning the national standard.			$w_{31} = 65$	0.65
3.2	Yearly maintenance requirements and system-specific spare part availability in the local servicing market.			$w_{32} = 35$	0.35
	Total-3			**100**	**1**
	Sub-Total	**100**	**1**		

Consequently, the multicriteria analysis (MCA) results for the aforementioned parameters, the reflection, and the summary of the technical staff's responses included:

1) Technical Domain

The technical domain considered for comparison six aspects: designed solar panel energy and pump efficiency, water supply reliability, storage capacity, daily production rate, ease of operation, maintenance, system management, hybridization compatibility, and system installation complexity for local experts or knowledge. These technical domains were weighted at 50%, with the Grundfos design tool scoring the highest at 34.14%, followed by the MoWE design tool at 32.65%, the WM design tool at 30.51%, and the Lorentz design tool with the lowest score of 25.69%.

2) Socio-Environmental Domain

The socio-environmental domain in contrast included two aspects: infrastructure installation requirements and social and environmental impacts (such as land use, vegetation removal, and waste material handling), as well as the satisfaction level of end-users and other beneficiaries, including technical personnel, with the technology. With these domains weighted at 25%, the Grundfos design tool achieved the highest score at 18.83%, followed by the WM design tool at 18.13%, the MoWE design tool at 16.82%, and the Lorentz design tool with the lowest score of 14.81%.

3) Economical Domain

The economic domain included two aspects such as the investment cost for the system's full installation package and annual maintenance requirements, along with the availability of system-specific spare parts in the local market. This domain was weighted from 25% and the Grundfos design tool scored the highest at 16.4 %, the MoWE design tool earned the second-highest score of 15.20%, the WM design tool ranked third with 12.77%, and the Lorentz design tool scored the lowest with 12.67 %.

Overall, based on total scores across technical, socio-environmental, and economic domains using the Weighted Sum Method, the Grundfos tool ranked first with a score of 69.37%, followed by MoWE at 64.67%, WM in third place at 61.41%, and Lorentz in fourth at 53.17%, making it the least preferred tool in the area. However, there is potential to improve the most efficient SPWPS design tool for national use by integrating the strengths of each tool across these domains, ultimately benefiting the community.

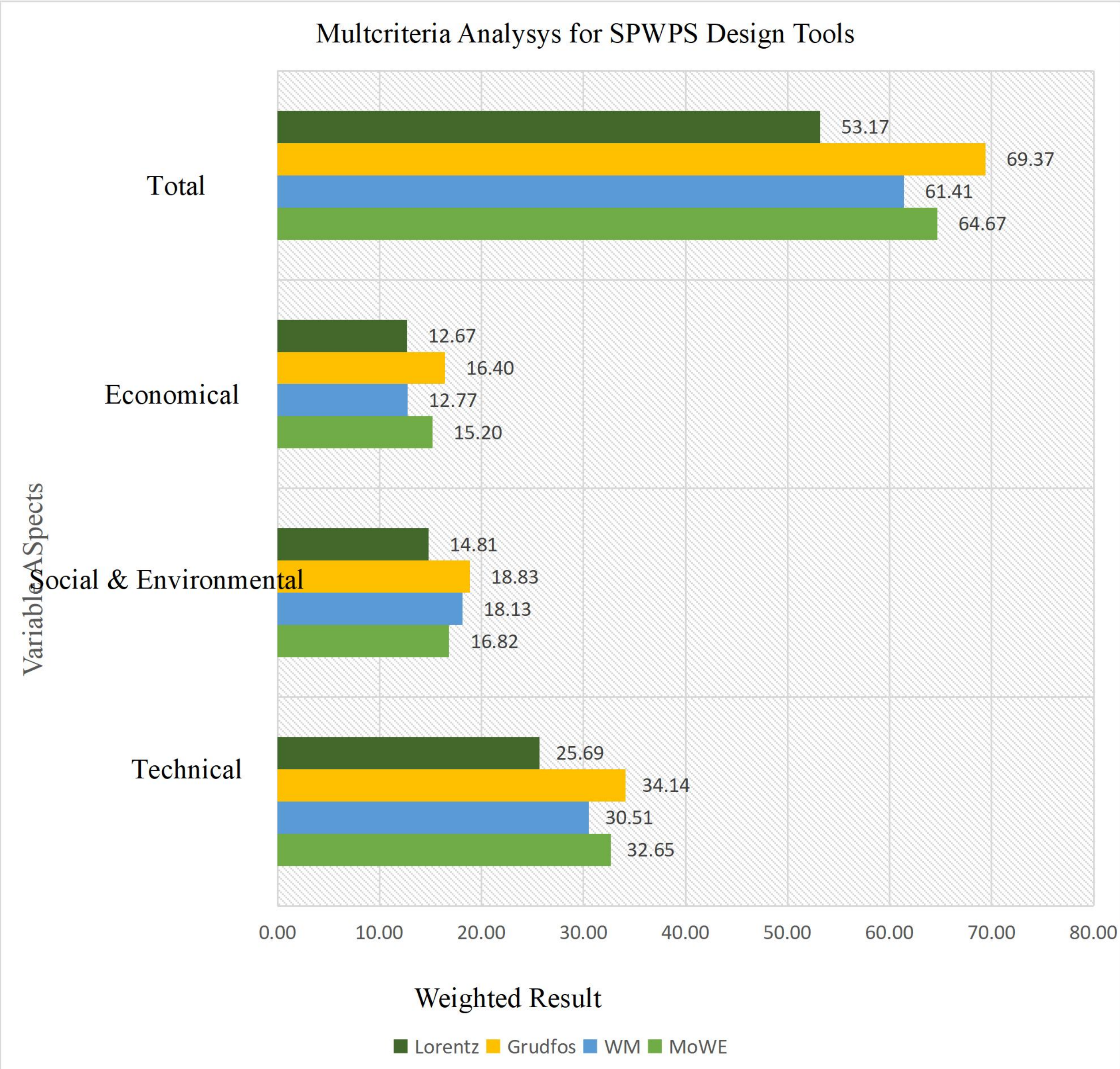

Figure 4. 1: MCA Results Graph for SPWPS Design Tools

Comparative Analysis (CA)

Next to the MCA, to proceed with the CA as mentioned a researcher-made questionnaire containing fifteen (15) technical questions gauged through the five-point Likert scale: “1” for Absolutely Unacceptable, “2” for Unacceptable, “3” for Neutral, “4” for Acceptable, & “5” for

Very Acceptable. The questionnaire was distributed to 20 technical staff and 16 documents were completed and returned to the researcher. Henceforth, the reliability, and normality tests for respondents' responses were conducted.

Thus, the Reliability-Cronbach's alpha (α) and normality tests were conducted on SPSS-26 for the collected data, which were measured using the Likert Scale. The test results are shown in the tables attached in the annexes, to the scale for Cronbach's alpha (α) or the result for the MoWE design tool was 0.841- evaluated as very good, for the WM design tool the result was 0.734 – regarded as good, for the Grundfos design tool the internal consistency result was .927- and for Lorentz design tool was 0.934, both was appraised as excellent.
Overall, both results revealed that the reliability analysis conducted for the Comparative Analysis (CA) data demonstrated outstanding results. All the measured parameters fell within an acceptable range, indicating relatively high internal consistency across the data set. Therefore, the test results were stable and reliably measured the same underlying dimensions. These results confirm the robustness and dependability of the measurement tool used in this study.

From the normality test regarding the Comparative Analysis (CA) data shown in the table tables attached in the annexes, the Shapiro-Wilk result for MoWE, WM, and Grundfos SPWPS design tools declared that the p-value > .005 at 95% CI. Thus, those normality test results indicate that the data distribution approximates a normal distribution. The values for skewness and kurtosis fall within acceptable ranges, suggesting no significant deviations from normality. Additionally, the Shapiro-Wilk and Kolmogorov-Smirnov tests returned non-significant p-values, further confirming the normality of the data. The normality test for subsequent statistical analyses is validated for the MoWE, WM, and Grundfos SPWPS design tools.

However, the normality test conducted for the Lorentz SPWPS design tool in the comparative analysis (CA) yielded a score of 0.035, less than the p-value threshold of 0.005 at a 95% confidence interval. This result indicates a significant departure from a normal distribution, suggesting that the data are not normally distributed. Despite this deviation, no hypothesis test was required in this study, making a non-parametric test unnecessary. On the other hand, the data remained statistically significant, enabling frequency distribution measurement, which was then used to perform a frequency analysis to support the comparative analysis. So, the frequency analysis of the collected data was performed to facilitate the comparative analysis.

From this point of view, the frequency distribution results for the arithmetic mean values of each SPWPS design tool in the Comparative Analysis (CA) are detailed below. Among the key variables and performance metrics used to differentiate solar-powered water supply project (SPWPS) design tools, the Grundfos design tool attained the highest arithmetic mean score of 55.6 (74.1%). This was attributed to the highest scores on eight (8) from fifteen performance metrics to factors such as its user-friendly interface, SPWPS component sizing capabilities, compatibility between system components, the level of community participation and satisfaction using the technology, the system yields factor or systems panels power output, system performance availability rate, inverter availability and performance efficiency, module efficiency, and operation and maintenance frequency. As a result, this design approach was the most frequently selected tool by technical staff.

Following Grundfos, the FDRE Ministry of Water & Energy (MoWE) design tool ranked second, with an arithmetic mean score of 53.60 (71.5%). The MoWE tool performed the highest scores from all tools particularly on two (2) items from fifteen performance metrics because of its system accuracy and precision, and options for modification or customization option and trends. The technical staff most frequently chose this design approach, second only to the Grundfos design tool.

The Water Mission (WM) Design Tool secured third place, with an arithmetic mean score of 53.21 (70.9%). It was noticed and got the highest score on five (5) domains from fifteen performance metrics for its strong performance in interface availability for water points, mounting structure design, availability for solar irradiance & mounting direction determination and accuracy, water discharge rate, availability of water at the lowest irradiance of the day and the month with the expected quality to meet the demand, and solar modules efficiency. The technical staff preferred this design approach, ranking it third after the Grundfos and MoWE design tools.

In contrast, the Lorentz Design Tool ranked fourth, with an overall arithmetic mean score of 48.20 (64.3%). It did not excel in any specific parameters and was the least preferred option among the design tools evaluated by the technical staff.

Table 4. 4: Frequency Results for CA of SPWPS Design Tool

S/No	Key Variables and Performance Metrics	MoWE DT (%)	WM DT (%)	Grundfos DT (%)	Lorentz DT (%)
C-1	The interface of the Solar Powered Water Pumping System (SPWPS) design tools is easy to use (user-friendly interface).	3.29 (65.8)	3.13 (62.6)	4.00 (80)	3.08 (61.6)
C-2	The Solar Powered Water Pumping System (SPWPS) storage sizing, pump & solar module sizing tool components.	3.67 (73.4%)	3.07 (61.4)	3.73 (74.6)	3.08 (61.6)
C-3	The Solar Powered Water Pumping System design tools interface availability for water points & mounting structure design interface.	3.43 (68.6)	4.00 (80)	3.60 (72)	2.77 (55.4)
C-4	The Solar Powered Water Pumping System design tools interface availability for solar irradiance & mounting direction determination.	3.29 (65.7)	3.67 (73.4)	3.27 (65.4)	2.77 (55.4)
C-5	The Solar Powered Water Pumping System (SPWPS) compatibility and integration between the various parts of the system.	2.86 (57.2)	3.60 (72)	3.67 (73.4)	3.15 (63)
C-6	The Solar Powered Water Pumping System (SPWPS) design tool accuracy and Precision.	4.00 (80)	3.40 (68)	3.87 (77.4)	3.54 (70.8)
C-7	The Solar Powered Water Pumping System design tool modification or customization option & trends.	3.93 (78.6)	3.47 (69.4)	3.67 (73.4)	3.31 (66.2)
C-8	In the Solar Powered Water Pumping System (SPWPS) project development, the level of community participation in the entire process & Satisfaction using the technology.	3.25 (65)	2.47 (49.4)	3.40 (68)	2.77 (55.4)
C-9	Water Discharge Rate (Volume of water flow over unit time in the system).	3.21 (64.2%)	3.93 (78.6)	3.67 (73.4)	2.69 (53.8)
C-10	Availability/production of water at the lowest irradiance of the day and the month with the expected quality to meet the daily demand	3.75 (75)	3.93 (78.6)	3.47 (69.4	3.15 (63)
C-11	The system Yield Factor or Systems Panels Power Out Put (The total energy generated by the solar plant over a specific period. This is the most fundamental Key performance Indicator indicating the plant's output)	3.64 (72.8)	3.75 (75)	4.00 (80)	3.35 (67)
C-12	System Performance Availability Rate (The percentage of time the plant is operational and producing energy. High availability is crucial for	3.75 (75)	3.21 (64.2)	4.00 (80)	3.93 (78.6)

	maximizing output)				
C-13	Inverter Availability and Performance Efficiency (Availability & The efficiency with which inverters convert DC power from the PV panels to AC power. Inverter performance can significantly impact overall plant efficiency)	3.67 (73.4)	3.65 (73)	4.00 (80)	3.21 (64.2)
C-14	Solar Module Efficiency (The efficiency of the solar modules in converting sunlight into electrical energy. Regular monitoring can indicate degradation or issues with specific modules).	3.93 (78.6)	4.00 (80)	3.25 (65)	3.75 (75)
C-15	Operation & Maintenance Frequency (Total costs associated with running and maintaining the plant. Effective cost management is vital for financial sustainability).	3.93 (78.6)	3.93 (78.6)	4.00 (80)	3.65 (73)
Total		53.60 (71.5)	53.21 (70.9)	55.60 (74.1)	48.20 (64.3)

Eventually, in this section, open-ended survey questions, document evaluation, and field observation were employed to distinguish the core disparities among the SPWPS design tools applied in the study area. Hence, the set of open-ended questions, comprising three inquiries, facilitated technical personnel in assessing the disparities, alongside MCA and CA requests, among the different solar-powered groundwater pumping design tools employed in the study area for system development. The queries were given to twenty technical staff members, but only sixteen questionnaires, representing 80%, were filled out and sent back to the researcher. Afterward, the responses were investigated, arranged, and logically discussed.

Respondents reported that among the installed solar-powered water supply (SPWPS) systems in the area, the one repeatedly experiencing failures was a system designed using the Lorentz pump design tool. The components most prone to failure included the solar panel, powered by polycrystalline silicon PV cells known for their low output efficiency, and the RSI, lightning arrester, DC connector, breakers, and control boards.

According to the respondents' response, more than twenty (20) SPWPS were installed in the study area. Of course, there was no new local innovation, but all were installed in the company products. However, there were new emerging technologies including durable and sustainable solar panel mounting structures (the solar panel power made of monocrystalline silicon PV cells which have high DC voltage output efficiency), inline chlorination system coupled with the SPWPS both designed by Water Mission and installed by Plan International Ethiopia.

The Water Mission, Grundfos, and MoWE design tools were preferred by most technical staff as the most user-friendly options because they are easy to use and compatible with the system. These tools were arranged more understandably. In contrast, while Lorenz-designed SPWPS systems were popular, they often faced sustainability issues and did not operate effectively for their design periods.

Furthermore, to get thorough information about the installed SPWPS and the design tools a field observation and document review were conducted by investigating the design review workshop minutes, the institutions' design tool documents, and government offices' design review feedback. As a consequence of this, the identified basic differences are discussed below.

The FDRE MoWE design tool, in collaboration with Water Mission, shares many similarities in most aspects, but significant disparities exist at specific critical points concerning national standards. Several of these distinctions are outlined below.

The national design tool incorporates the maximum daily demand for designing pressure mains, treatment plants, and reservoirs, as well as the peak hour demand for the distribution system. In contrast, the Water Mission design tool employs the average daily demand for designing the entire system. Similarly, the WM design tool considers 15 years of total population at once, while the FDRE MoWE design tool requires future population forecasts to be generated from 5 years of consecutive data.

From the hydraulic design point of view, the MoWE design tool considers parameters like velocity in a range of 0.6-2m/s and pressure range of 10-80 Pascal, but WM has no clear criteria regarding this. As best practice and lesson learned, to prevent future damage to electric cables beneath the solar panels, the WM design and installation method packs the subbase with a geomembrane and gravel surfacing to shield the solar mounting structures from weed growth and rat breeding.

In summary, to identify differences between various solar-powered water pumping system (SPWPS) design techniques used in the area, the study applied methods such as MCA (a decision-making tool) and Comparative Analysis (CA), along with frequency distribution, reliability, and normality tests to evaluate participant responses to questionnaires. Additionally, open-ended survey questions, field observations, and document reviews were conducted in this section.

Primarily, the results from the Multicriteria analysis (MCA) tool refereeing the parameters of the technical domain, the socio-environmental domain, and the economic domain: the Grundfos design tool emerged as the most preferred with a result of 69.37%. Following closely, the MOWE design tool attained an aggregate score of 64.67%, making it the second preferred design technique. The Water Mission SPWPS design tool ranked third with a preference score of 61.41%, while the Lorentz SPWPS design tool, with an aggregate score of 53.17%, was identified as the least preferred by the technical staff.

Secondly, the Comparative Analysis (CA) was conducted using the pretests and the frequency descriptive analysis of the participants' responses. As a result, based on the proposed ten key technical, social, environmental, and economic variables and performance metrics the analysis result stated that the Grundfos design tool attained in aggregate first but with six items the highest score. The FDRE Ministry of Water & Energy (MoWE) tool ranked second aggregate first but with two items the highest score. The Water Mission Design Tool also secured the third position in aggregate but with two items with the highest result. Contrariwise, the Lorentz Design Tool claimed the fourth position in aggregate with the evaluations of key variables and performance metrics. Additionally, it failed to excel in each specific parameter and was deemed the least preferred among the options.

Thirdly, through open-ended technical questions, document review, and field investigation, it was acknowledged that the Grundfos, Water Mission, and MoWE design tools share a lot of design interface similarities in their design tool and were preferred by most technical staff as best user-friendly options because they are easy to use and compatible with the system since the tools were arranged more understandably. In contrast, the Lorentz-designed SPWPS systems were the least preferred due to frequent failures in the study area. Key components prone to failure included the solar panel, RSI, lightning arrester, DC connector, breakers, and control boards, often facing sustainability issues and not operating effectively over their design period.

Moreover, the design interface between Grundfos and WM is largely aligned on pump sizing. However, the WM design tool is more advanced, offering a comprehensive interface for all system components, making it the preferred choice for assessing technical differences with the national design tool. Icons for the tools are attached to the back of this paper. Reviewing the design documents, user feedback and workshop notes revealed discrepancies between the MoWE and WM design criteria for rural water supply, discussed below.

Daily water demand The national tool uses maximum daily and peak hour factors to design and project population growth over 15 years. In contrast, the Water Mission (WM) design tool relies on average daily demand (ADD) and projects population growth in 5-year intervals. The MoWE tool fully accounts for climate and socio-economic factors in its maximum daily and peak hour calculations, although the WM design tool does not consider these factors in its ADD calculations.

Pump and System Sizing

The national tool uses maximum daily demand (MDD) to design pumps, transmission lines, and peak hour demands (PHD) for the distribution system. In contrast, the WM design tool relies on average daily demand (daily water demand) to design pump size, distribution lines, and pressure lines, without considering peak hour demand.

Solar Rack Design

The national design tools emphasize cost-effectiveness in the design of solar rack mounting steel structures, while the Water Mission (WM) design tool is seen as excessively expensive and unaffordable for the local community. Additionally, the necessary materials for the WM tool are often not readily available in the national market. Despite this, the foundation work of the WM design tool is highly commendable, whereas the national tool requires some modifications in this area. Furthermore, the mounting direction for the MoWE tool is South-West (SW), while the WM design tool mounts in a North-West (NW) direction with various azimuth angles. This difference arises because the WM design tool accounts for the month with the lowest irradiance of the year, ensuring consistent power output even during cloudy days.

Water Treatment Design

The MoWE design tool lacked a specific interface for chlorine treatment design. In contrast, the WM design tool includes an interface for designing an inline chlorination system integrated with the solar-powered water supply system's raw water intake to the reservoir. This inline chlorination method is free from frequent hand contamination and uses chlorine tablets for the treatment.

Electrical System Design

Water Mission incorporates a sub-base with a geomembrane cover and gravel surface to avoid weed growth and discourage rat breeding to protect electric cables. However, the regional water bureau has commented that the proposed electrical components for the systems are too expensive compared to the design and installation of the solar power-driven system's electrical features.

In conclusion, based on the technical team's preferences, Grundfos was ranked first, followed by MoWE in second place, WM in third, and Lorentz in fourth, according to the total score derived from the SPWPS design tools data analysis. However, there is potential to develop a more efficient SPWPS design tool for the country by combining the strengths of each tool across technical, socio-environmental, and economic aspects, ultimately benefiting the community through the improved outputs.

Above all from the previous research works regarding SPWPS design tools, Gevorkov et al. (2022) emphasized that system dimensioning and component selection are critical for determining both the initial investment and long-term performance of solar-powered water pumping systems. The study highlights the importance of selecting and optimizing design tools, as they significantly impact investment costs and overall sustainability. Similarly, I. M. Mahmoud et al. (2024) focused on renewable energy sustainability by developing an online tool to optimize photovoltaic water pumping systems. This tool, which has been tested, validated, and evaluated, aims to enhance system sizing efficiency and reduce financial waste. Mustafa Elrefai et al. (2016) also stressed the need to consider technical, economic, and environmental factors in SPWPS design. They recommended performance evaluation using three key metrics: yield factor (YF), wire-to-water energy efficiency (WWEE), and system performance index (SPI), along with implementing a comprehensive monitoring system to assess operational performance.

Table 4. 5: Summary of Technical Differences Among Design Tools Used

Item	Aspect	MoWE DT	WM DT	Grundfos DT	Lorentz DT
1	Designing Pressure mains, Treatment plant, reservoir, and transmission lines	Maximum Daily Demand (MDD)- also considers climate & socio-economic factors	Average Daily Demand (ADD)- not consider climate & socio-economic factors	Flexible approach	Flexible approach
2	Designing Distribution System,	Peak hourly Demand (PHD)	ADD	Flexible approach	Flexible approach
3	Pump & System Sizing	MDD	ADD	Flexible approach	Flexible approach
4	Population forecast	5 years of consecutive data	15 years	Flexible approach	Flexible approach
5	Hydraulic parameters point of view	Velocity, 0.6-2 m/s; Pressure 10-80 pascal	Has no clear criteria	Flexible approach	Flexible approach
6	Solar Module Mounting Structure	South West (SW)	North West (NW)	South West (SW)	South West (SW)
7	Infrastructure protection	Not having practical action	Gravel packing, electric cables wiring system,	Not Assigned	Not Assigned
8	Water Treatment System	Not Assigned	Inline Chlorination	Not Assigned	Not Assigned
9	Technical Team Preference	Second	Third	First	Fourth

4.3. Social and Environmental Implications of SPWPS Components

To identify the impact of the installed solar-powered water pumping systems (SPWPS) on the social and environmental aspects of the study area, a plan was developed to collect and investigate data to draw evidence-based suppositions. Therefore, survey questionnaires for the community and field observation techniques for direct touch with the system components were employed, and then the collected data was evaluated through a comprehensive analysis.

The survey questionnaire entitled 'Implications of Social and Environmental Features Due to Installed Solar-Powered Water Pumping Systems (SPWPS) Infrastructures' was prepared for the user community and distributed to 450 randomly selected samples by data collectors. The survey questionnaire has seven queries positioned to measure a respondent's reflection and agreement towards the consequences of the installed solar-power driven water pumping systems components on the community's social and environmental features through a five-point Likert scale (1 for Strongly Disagree, 2 for Disagree, 3 for Neutral/Fair, 4 for Agree and 5 for strongly Agree). Afterward, statistical tests were conducted to ensure the reliability and validity of the questions, followed by a normality test to check the regularity of the data distribution. A descriptive analysis was then performed to determine the frequency of responses to each item.

A reliability test was first conducted on the data regarding the social and environmental implications of installed solar-powered water pumping system (SPWPS) components. The Cronbach's alpha (α) for the items designed to measure the consequences was 0.631, as shown in the annexed table 3.1.1. So, the result indicates that the seven anticipated inquiries had acceptable internal consistency, making it a reliable and effective tool for assessing the thought.

Secondly, a normality test was conducted with 95% CI to assess the regularity of the data distribution using the Shapiro-Wilk and Kolmogorov-Smirnov tests, with a sample size of 450 (df=450). The results indicated that the p-values for both tests were less than 0.000 ($p < .000$), as shown in the annex, suggesting a significant departure from normality. The result implies that non-parametric statistical methods may be more appropriate for further analysis of this data set. Despite this deviation, the data remained statistically significant, and the frequency distribution measurements were considered valid. After conducting reliability and normality tests, a frequency descriptive analysis was performed to describe the occurrence of each value within the data set. The results are shown in the following table.

Table 4. 6: Social and Environmental Implications of SPWPS Infrastructure

S/No	Variable Description	1 (SD) (%)	2 (DA) (%)	3 (N)(%)	4 (A) (%)	5 (SA) (%)
1	The availability of clean water from the installed solar-powered water pumping systems (SPWPS) enhanced the daily lives of the community.	36 (8.0)	66 (14.7)	31 (6.9)	190 (42.2)	127 (28.2)
2	Concerns about land usage, cultural disruption, or other environmental issues are directly related to constructing solar-powered water pumping systems (SPWPS).	48 (10.7)	86 (19.6)	73 (16.2)	154 (34.3)	89 (19.8)
3	The local communities can save money and invest in other necessities for household activities since the installed solar-powered water pumping systems (SPWPS) have decreased operational expenses for fuel and spare parts for daily water pumping.	28 (6.2)	90 (20.0)	97 (21.6)	149 (33.1)	86 (19.1)
4	In addition to ensuring rural communities' long-term social and environmental advantages, the solar-powered water pumping systems (SPWPS) successfully met the local water demand.	28 (6.2)	56 (12.4)	78 (17.3)	182 (40.4)	106 (23.6)
5	The installed solar-powered water supply (SPWS) projects influence the local community's quality of life, social integration, and well-being.	22 (4.9)	50 (11.1)	92 (20.4)	158 (35.1)	128 (28.4)
6	The presence of solar-powered water supply projects in my locality has improved the standard of living of the entire community.	21 (4.7)	69 (15.3)	70 (15.6)	170 (37.8)	120 (26.7)
7	Installation and operation of solar-powered water pumping systems (SPWPS) in the rural community can still have environmental impacts, such as habitat disruption, and afforestation which may be of concern in rural areas.	75 (16.7)	99 (22)	56 (12.5)	142 (31.6)	78 (17.3)

Out of 450 respondents, 190 (42.2%) agreed that the water collected from the installed solar-powered water pumping systems is clean and enhances their daily lives. Additionally, 154 respondents (34.3%) expressed concerns regarding land usage, cultural disruption, or other environmental issues related to the SPWPS. A total of 149 respondents (33.1%) agreed that the local communities save money and invest in other household necessities due to the decreased operational expenses for fuel and spare parts, thanks to the solar-driven water supply. Additionally, 182 respondents (40.4%) agreed that the SPWPS effectively met local water needs while delivering lasting social and environmental benefits to rural communities. Meanwhile, 158 respondents (35.1%) noted that the existence of SPWPS projects in their locality positively influenced the community's quality of life, social integration, and overall well-being. Out of the total respondents, 170 (37.8%) indicated that their quality of life had improved due to the presence of SPWPS. On the other hand, 142 respondents (31.6%) expressed concerns about the negative environmental impacts of SPWPS installations, such as deforestation and habitat disturbance in rural areas.

Soon after, the data analysis for a field observation about the socio-environmental implications of SPWPS component installations in the study area was conducted. Some solar-powered water pumping systems (25%- 42% of the investigated) are not functioning properly due to various reasons, such as cracked and abundantly faded solar panels that hinder solar irradiation collection, equipment failures like RSI & DC connectors, breakers, and control board collapses, a shortage of local technical personnel, and inadequate operation and maintenance services. Consequently, the solar panels installed are considered solid waste (SW) in the area. Moreover, the community lacks knowledge and guidelines for maintaining, reusing, or removing the solar panels that cover the wide area.

Indeed, there are new and innovative technologies have emerged in the vicinity due to the SPWPS in the area including durable and sustainable solar panel mounting structures, gravel-surfaced packing with a geomembrane to protect the array wiring system from rats and rodents, an inline chlorination system employing chlorine tablets to prevent manual contact, and t-TEM hydrogeological survey technology for underground water investigation. However, many systems suffer from ineffective scheme management, limited access to spare parts, and uncertainty regarding community settlement patterns. As a result, without enhancing local expertise and management systems, and improving access to local supplies, these systems may face complete failure and impose burdens on the community.

Concerning the socio-environmental implications of SPWPS, Ahmed et al. (2023) noted that the performance of solar-powered underground water pumping systems is influenced by environmental and technical factors, which must be considered for reliable operation. Kumar (2020) highlighted that renewable energy can reduce harmful emissions, create jobs, improve health, and raise living standards, though challenges like seasonal fluctuations require advanced designs. In addition, Adanma and Ogunbiyi (2024) found that renewable energy adoption supports job creation, stabilizes energy prices, and cuts emissions, emphasizing the need for strong policies, international agreements, and technological innovation to drive the transition.

In summary, installing solar-powered water pumping systems (SPWPS) in rural communities has significant social and environmental implications in the study area. These implications include solid waste from non-functional solar arrays, gaps in local knowledge and guidelines for SPWPS waste management like removal, unnecessary land acquisition, high siltation in the inline chlorination room, deforestation, wildlife disruption, a weak management system, and doubts about the system's sustainability. On the positive side, the impacts include exposure to innovative technologies, durable solutions for the community water supply, access to safe water, cost savings on operations and maintenance compared to diesel or grid systems, enhanced quality of life, social integration, and overall well-being.

4.4. Operational challenges and limitations in managing SPWPS

To identify the operational challenges and limitations that the community had in controlling and executing the installed solar-powered water pumping system in the study region, the researcher employed a variety of data-gathering techniques. These included open-ended questions for the technical staff, a survey questionnaire for the user community, and field observations to gain authentic insights into the system components. Consequently, the following sections provide an overview of the data analysis processes, outcomes, and discussions of the findings.

The initial data collection tool consisted of researcher-designed open-ended questions, comprising three inquiries directed at technical staff and distributed to twenty randomly selected individuals from various sectors, including the two sections mentioned earlier. Out of all the questionnaires distributed, sixteen (80%) were completed and returned. The individual responses were consolidated, revealing several operational challenges and limitations encountered during the implementation and management of the solar-powered water pumping systems (SPWPS), as identified by the technical staff. Primarily, issues include low power output and water service interruptions on cloudy days, delays in recording daily water demand, difficulties in maintaining regular checklists, non-payment by users, dust accumulation on solar panels, shading, damage from stones thrown by children, difficulties in obtaining spare parts, and a lack of adequately trained local technical personnel.

Additionally, technological complexity poses challenges, particularly in understanding RSI error reports and troubleshooting. Other concerns include the high cost of spare materials, a shortage of operation and maintenance experts, insufficient focus on post-construction monitoring and management capacity-building, immediate service failures after commissioning, maintenance difficulties for local experts, low awareness about the design tools, and issues with acquiring land for solar panel installation.

Furthermore, affordability issues arise from the need to source spare parts and professionals exclusively from the capital, Addis Ababa, which leads to delayed maintenance and reduced power output and water production during cloudy and rainy periods. Despite these challenges, the SPWPS has some positive aspects, such as increased water production during sunny periods, lower operation and maintenance costs, and its environmentally friendly nature.

On the other hand, a questionnaire titled "Operational Challenges & Limitations Faced by the Community in Implementing and Managing the Installed SPWPS" was distributed by data collectors to 450 randomly selected individuals. This questionnaire contained six questions designed to identify operational challenges and limitations using a five-point Likert scale (1 for Strongly Disagree, 2 for Disagree, 3 for Neutral/Fair, 4 for Agree, and 5 for Strongly Agree). Thus, a reliability test of the questions and a normality test for the collected data were conducted, followed by a descriptive analysis of the frequency of the respondents' reactions.

Reliability testing was conducted for the six questions designed to identify the operational challenges and limitations the community faced during the administration and execution of the installed system. Thus, the Cronbach's alpha (α) result was 0.611, as shown in the annexed Table 3.4.1, indicating good reliability of the survey questions. This makes them a dependable tool for assessing the operational challenges and limitations the community experienced during the management and implementation of the installed system.

Likewise, the normality test was conducted for the operational challenges and limitations that the community experienced when managing and implementing the installed solar power-driven water pumping system, with a 95% confidence interval. The test results showed p-values lower than 0.05 for the tests, as indicated in the annexed table 3.4.2. This signifies a notable departure from a normal distribution, particularly in the case of the Shapiro-Wilk test, suggesting that the data are not normally distributed. Despite this deviation, the data remained statistically significant, and the frequency distribution analyses were considered valid.

Following this, descriptive analysis was conducted for this section, with results for the frequency of respondents' responses and the results offered in Table 4.12.

Table 4. 7: Frequency Analysis of Operational Challenges in Managing SPWPS

S/No	Variable Description	1 (SD) (%)	2 (DA) (%)	3 (N)(%)	4 (A) (%)	5 (SA) (%)
1	There is 24-hour access to water from the solar-powered water pumping system sourced from a borehole in my local government area, which benefits the community.	39 (8.7)	50 (11.1)	35 (7.8)	186 (41.3)	140 (31.1)
2	A channel is available locally to maintain and repair the damaged solar-powered water pumping system.	49 (10.9)	122 (27.1)	62 (13.8)	108 (24.0)	109 (24.2)
3	Maintaining and operating the solar-powered water pumping systems (SPWPS) is not a problem for the community.	109 (24.2)	184 (40.9)	64 (14.2)	65 (14.4)	28 (6.2)
4	The installed solar-powered water pumping systems (SPWPS) improved the community operational efficiency and managerial practices of water supply projects.	52 (11.6)	95 (21.1)	61 (13.6)	143 (31.8)	99 (22.0)
5	Regular maintenance and timely repair of solar-powered water pumping systems (SPWPS) components are essential for sustainability and optimal performance. However, accessing spare parts and qualified technicians for operation and repairs can be difficult in remote rural areas.	47 (10.4)	62 (13.8)	72 (16.0)	171 (38.0)	98 (21.8)
6	Capacity building, financial support, technological innovations, and collaboration between various stakeholders, including government agencies, NGOs, and stakeholders in the local community about solar-powered water pumping systems (SPWPS) considered operational challenges and limitations.	31 (6.9)	48 (10.7)	55 (12.2)	208 (46.2)	108 (24.0)

From the above analysis table, 186 respondents (41.3%) agreed that access to water for 24 hours, sourced from solar-driven groundwater, is beneficial to the community. However, 122 respondents (27.1%) disagreed with the availability of a proper channel in the locality for maintaining and repairing SPWPS damages. Additionally, 184 respondents (40.9%) disagreed that the operation and maintenance of SPWPS are not considered significant challenges for the community.

Moreover, 143 respondents (31.8%) agreed that the installed SPWPS has enhanced the community's operational efficiency and management practices for water supply projects. While regular maintenance and timely repairs are crucial for the sustainability and optimal performance of the systems, 171 respondents (38.0%) reported challenges in accessing spare parts and qualified technicians in remote rural areas. Lastly, 208 respondents (46.2%) emphasized that overcoming operational challenges requires capacity building, financial support, technological innovation, and collaboration among various stakeholders, including government agencies, NGOs, and the local community.

Field observations identified challenges such as a lack of knowledge in managing the system, low power output, and water service interruptions during cloudy days. Other issues include delays in recording daily water demand, problems with regular maintenance checklists, failure to pay for the service, dust covering the solar panels, shading, unavailability of spare parts in the local market, technological complexity—particularly in understanding RSI error reports—a lack of operation and maintenance experts, and the absence of collaboration among various stakeholders working with the technology to solve these problems.

In this regard from the scholars' point of view, Phiri et al. (2022) highlighted that enhanced access to drinking and irrigation water in rural areas was primarily achieved through strong financial and management frameworks, improved coordination, enforcement of product and installation standards, and greater community awareness and sensitization about solar water pumping (SWP) systems. Similarly, Salom and Khumalo (2022) stressed that the successful management of rural water supplies relies on critical factors such as governance, committee leadership, training and capacity building, community engagement, coordination, and ongoing support.

4.5. Community Engagement and Satisfaction

One of the research objectives was to evaluate the degree of community engagement and satisfaction with the installed solar-powered water pumping systems (SWPS). Hence, data collection tools were employed, including researcher-designed open-ended questions for technical staff and a survey questionnaire for the user community. Following data collection, the analysis, results, and discussion of the findings are offered below.

Primarily, to assess the level of community engagement with the SPWPS project cycles and satisfaction with the installed solar-powered water pumping systems (SWPS) in the study area, as stated open-ended questions with two queries were prepared for the technical staff from different representations and distributed to twenty (20) individuals. From the total, only sixteen (16) i.e. 80% questionnaires were addressed and returned to the researcher. Accordingly, the various responses were examined, and the following consolidated responses were disclosed.

Every response indicated that the community and local experts were involved directly and indirectly, in the entire operation of the SPWPS project cycle in their area, from site selection and security to the implementation of the solar-powered water supply system. As a result, the community provided valuable comments and feedback on the implementation and anticipated benefits. Additionally, awareness-raising initiatives were conducted to enhance the community's understanding of the SPWPS and to gather their input for improving project design.

Secondly, a researcher-made survey questionnaire called “The extent of the local community engagement in the project cycle and their satisfaction with the installed SPWPS” had six requests from the user community and was circulated to 450 randomly selected individuals through the data collectors. The inquiries were designed to evoke the community's thoughts on the level of engagement and satisfaction through a five-point Likert scale (1 for Strongly Disagree, 2 for Disagree, 3 for Neutral/Fair, 4 for Agree, and 5 for strongly Agree).

Thus, the Cronbach's alpha (α) result was 0.611, as shown in the annexed Table 3.5.1, indicating good reliability of the survey questions. The reliability tests of the requests were done, and the Cronbach’s alpha (α) result for the items constructed to measure consequences was 0.706, which showed that the predicted items had a good internal consistency, and normal correlation and were reliable for measuring the observation.

Next, a normality test was performed on the data with a 95% confidence interval. The results revealed p-values below 0.05, with a sample size of 450 (df=450), as shown in the annexed Table 3.5.2. This indicated a significant departure from normality, particularly in the Shapiro-Wilk test, suggesting the data are not normally distributed. Despite this deviation, the data remained statistically significant, and the frequency distribution test was considered valid.

The descriptive frequency analysis presented in Table 4.15 highlighted several key findings. Among the 450 respondents, 158 (35.1%) fully agreed that they were satisfied with their involvement in the entire solar-powered water pumping system (SPWPS) project, including the study, appraisal, site selection, implementation, operation, and management. Additionally, 145 respondents (32.2%) agreed on the importance of involving women, water technicians, and community leaders in the decision-making process for SPWPS implementation.

Furthermore,169 respondents (37.6%) highlighted the importance of local community involvement in site selection for SPWPS establishment. Additionally, 171 respondents (38.0%) expressed confidence in the long-term sustainability and reliability of the installed SPWPS. Of all respondents, 179 (39.9%) strongly agreed that they were satisfied with the SPWPS for community water supply. Lastly, 188 respondents (41.8%) strongly agreed that the installed solar-powered water supply system (SPWS) in their locality had significantly contributed to increased community satisfaction at the household level.

Overall, the local community's engagement in the project cycle, and their satisfaction with the installed SPWPS in the area were significant. They participated in various components of the SPWPS project cycle, from project initiation to system operation and management, to ensure the system's sustainability. The community raised questions about how to maintain an adequate water supply during the rainy season and how to operate the system locally. Generally, communities with functional water systems expressed satisfaction, while those with non-functional or broken systems did not. Additionally, most community members felt comfortable with their involvement in the project process and were satisfied with the solar-powered water supply projects.

Table 4. 8: Frequency Analysis of Community Engagement and Satisfaction with SPWPS

S/No	Variable Description	1 (SD) (%)	2 (DA) (%)	3 (N) (%)	4 (A) (%)	5 (SA) (%)
1	I am comfortable with my engagement in the process of the solar water pumping system (SPWPS) project study, appraisal, site selection, implementation, operation, and management process.	42 (9.3)	62 (13.8)	40 (8.9)	158 (35.1)	148 (32.9)
2	Women, water technicians, and community leaders are involved in the decision-making and execution of the solar-powered water supply (SPWPS) project.	37 (8.2)	95 (21.1)	60 (13.3)	145 (32.2)	113 (25.1)
3	The local community participated in the process of choosing a location for a solar-powered water supply (SPWS) project.	24 (5.3)	67 (14.9)	72 (16.0)	169 (37.6)	118 (26.2)
4	The installed solar-powered water supply (SPWPS) is perceived by the community members as sustainable and dependable, and they are sufficiently confident in this respect.	27 (6.0)	67 (14.9)	49 (10.9)	171 (38.0)	136 (30.2)
5	I am satisfied with the Solar Power Water Supply (SPWS) systems that have been put in place in my area.	16 (3.6)	51 (11.4)	44 (9.8)	159 (35.4)	179 (39.9)
6	With the presence of a solar-powered water supply system (SPWS) in our locality; my family and the community were satisfied with the project and service	28 (6.2)	58 (12.9)	27 (6.0)	149 (33.1)	188 (41.8)

According to Hanger et al. (2016), community acceptance of solar power is nearly universal, primarily because it is perceived as environmentally friendly. However, the perceived level of knowledge about the project is very low, which positively correlates with high acceptance. Additionally, Berg and Tempels (2022) identified that a key factor influencing community acceptance is the extent to which the benefits meet the community's needs. The success of solar farm developments in addressing these needs depends on the developers' motives, the local context, and the level of community involvement. Community acceptance increases when the benefits align with their needs. Conversely, if the compensation offered is insufficient, it undermines trust and fosters greater resistance.

Next, the Spearman correlation analysis assessed to evaluate the relationship between challenges in using solar-powered water pumping systems (SPWPS) for rural water supply, the social and environmental impacts of SPWPS installations, community engagement, and satisfaction, and the operational challenges faced during system implementation and management. The relationship strength and direction were evaluated using a coefficient range from -1 to 1, with a 95% confidence interval.

Thus, primarily, a non-parametric measure of the strength and direction of association between two variables was computed to examine the relationship between the challenges of solar-powered water pumping systems for rural community water supply and the social and environmental implications of the installed systems in the study area. The analysis revealed a statistically significant positive correlation ($\rho = 0.52$, the result is b/n 0.3 & 0.7), indicating challenges of SPWPS for rural water supply were moderately correlated to socio-environmental implications of SPWPS installations. The result suggests that the social and environmental consequences of the installed systems imposed an impact on the challenge for solar-powered water pumping systems in supplying water to the target area.

Secondly, an analysis was conducted to explore the relationship between the challenges of using solar-powered water pumping systems for rural water supply and the operational difficulties and limitations faced by the community in managing and implementing the system. The analysis resulted in a correlation coefficient of $\rho = 0.193$, which is lower than 0.3, indicating a weak correlation. This suggests that the operational challenges and constraints in implementing and managing the SPWPS have a limited impact on the overall challenges of using SPWPS for rural community water supply.

Thirdly, the relationship between the challenges of solar-powered water pumping systems for rural community water supply and the level of local community engagement in the project cycle and satisfaction with the installed systems was investigated. The analysis revealed a result of $\rho = 0.\ 3$, which is the same as 0.3, indicating that, they had a moderate correlation. Therefore, the level of local community engagement in the project cycle and satisfaction with the installed system influence the challenges of using SPWPS for rural community water supply.

Fourthly, an analysis was conducted to examine the relationship between the socio-environmental impacts of SPWPS installations and the operational challenges faced by the community during system management and implementation. The analysis yielded a value $\rho = 0.463$, indicating a moderate correlation (between 0.3 and 0.7). This suggests that the operational challenges and limitations encountered by the community during the system's management and implementation had a notable influence on the socio-environmental impacts of SPWPS components.

Fifthly, the same test was conducted on the socio-environmental implications of SPWPS feature installations, the level of local community engagement in the project cycle, and satisfaction with the installed systems. The analysis yielded a value $\rho = 0.596$, which falls between 0.3 and 0.7, indicating a moderate correlation. Therefore, the level of local community engagement in the project cycle and their satisfaction with the installed systems had a sensible effect on the socio-environmental implications of SPWPS component installations.

Lastly, the analysis examined the operational challenges and limitations experienced by the community during the management and implementation of the system, as well as the socio-environmental implications of the SPWPS component installations. The analysis produced a value of $\rho = 0.532$, which falls between 0.3 and 0.7, indicating a moderate correlation among the factors. As a result, the operational challenges and limitations faced by the community during management had a noteworthy effect on the level of local community engagement in the project cycle and their satisfaction with the installed systems.

Table 4. 9:Spearman Correlation Analysis Result

			Challenges of SPWPS	Implication SoEnv SPWPS	Operational Challenges of Using SPWPS	Comm. Engage. & Satisfaction with SPWPS
Spearman's rho, "ρ"	Challenges of solar-powered water Pumping Systems for rural community water supply	Correlation Coefficient	1	.514**	.193**	.262**
		Sig. (2-tailed)	.	0	0	0
		N	450	450	450	450
	Socio-environmental implications of SPWPS features installations	Correlation Coefficient	.514**	1	.463**	.596**
		Sig. (2-tailed)	0	.	0	0
		N	450	450	450	450
	Operational challenges and limitations the community experienced when managing and implementing the system	Correlation Coefficient	.193**	.463**	1	.532**
		Sig. (2-tailed)	0	0	.	0
		N	450	450	450	450
	Level of community engagement in the project cycle and satisfaction with the installed systems	Correlation Coefficient	.262**	.596**	.532**	1
		Sig. (2-tailed)	0	0	0	.
		N	450	450	450	450

**. Correlation is significant at the 0.01 level (2-tailed).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The research explored various aspects of solar-powered water supply systems in the target area, including technical challenges, design tool differences, socio-environmental impacts, operational issues, and the extent of community engagement and satisfaction with the installed systems. The findings provide valuable insights into addressing these challenges to enhance the performance and effectiveness of the systems for rural communities. Additionally, the results offer guidance for future implementations and improvements in rural water supply, both within the target area and in similar settings.

Key technical challenges identified in the study area, include a lack of expertise among local operators, misalignment with national sector guidelines (MoWE), and the unavailability of compatible spare parts. Additional issues such as extensive vegetation cover, substandard material quality, inconsistent installation practices, weak operation and maintenance, and scattered community settlements further exacerbated these challenges. Data analysis revealed disparities between SPWPS designs, with Grundfos ranking highest in efficiency, followed by MoWE, WM, and Lorentz. However, Lorentz systems were prone to component failures, leading to increased maintenance needs, particularly in adverse weather conditions. Problematic components included polycrystalline silicon PV solar panels, RSI, lightning arresters, DC connectors, breakers, and control boards.

Socio-environmentally, SPWPS installations posed challenges, such as non-functional solar arrays turning into waste, deforestation, and wildlife disruption. These issues, combined with poor management systems, threatened the long-term sustainability of the systems. Inspections of installed SPWPS revealed that several systems were non-operational. Nevertheless, the benefits of SPWPS were significant, including improved access to safe water, enhanced public health, time savings for women and children, cost savings compared to diesel systems, and environmental benefits like reduced carbon emissions.

The community encountered several challenges in operating and managing the system, such as inconsistent performance during adverse weather, reduced power output on cloudy days, delays in recording water demand, and complications with the payment process. Moreover, the technical complexity of understanding RSI error reports and the limited access to trained maintenance personnel further hindered the long-term functionality of the system. Despite strong community engagement throughout the project cycle, which fostered a sense of ownership, technical challenges and inconsistent system performance negatively affected user satisfaction.

The correlation analysis also highlighted a moderate link between technical challenges and socio-environmental impacts, suggesting that the environmental consequences of SPWPS installations affected the community's experience with the systems. Operational challenges were not strongly related to broader SPWPS challenges, indicating that these management issues had a limited effect on overall system performance. Community engagement and satisfaction were moderately linked to the technical challenges, operational difficulties, and socio-environmental outcomes, underscoring the importance of local involvement in overcoming these barriers.

In conclusion, while SPWPS installations provide numerous benefits for rural communities, addressing technical, operational, and socio-environmental challenges is essential to ensure the long-term success and sustainability of the projects. The study emphasizes that a holistic approach, which addresses these interrelated factors and fosters community involvement, is crucial for improving the performance and effectiveness of solar-powered water pumping systems in rural areas.

5.2. Recommendations

Based on the study's findings, the researcher respectfully recommends adopting a comprehensive approach to improve the efficiency, effectiveness, and sustainability of solar-powered water pumping systems (SPWPS) in rural communities. Key recommendations include timely addressing technical gaps, ensuring design compatibility, selecting appropriate tools, enhancing system management, promoting active community engagement, fostering stakeholder collaboration, establishing local spare part supply chains, and monitoring socio-environmental impacts. Furthermore, exploring the long-term effects of SPWPS and refining design tools is recommended to increase community benefits and system resilience. Sharing these findings widely will support the development of sustainable rural water supply solutions.

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ANNEXES

1. Research Data Collection Tools

Dear Responder,

This questionnaire aims to assess information and collect data for the research entitled "*Assessment of Solar Powered Water Pumping System Challenges for Rural Water Supply: A Case of Pinyudo town"* as part of the study in Master of Science (MSc) for Water Supply and Environmental Engineering at Adama Science and Technology University (ASTU). As a result, the information gathered in this procedure is kept safe and secure, and it will not be used for any other reason.

Therefore, please accept the researcher's heartfelt gratitude in advance for your willingness to respond to the questions and provide the information requested.

Thank you in advance for your time and good cooperation!

Bahiru Tefera Bezabih

April, 2024

Part 1: Research Questioners for Technical Personnel

Please fill out the following table with your personal information (እባክዎን በሚከተለው ሰንጠረዥ ዉስጥ ሥለእርስዎ ማንነት የሚጠይቁ መረጃዎችን ይሙሉ).

Name (ሥም)		Age (ዕድሜ)		Sex (ጾታ)	
Academic Status (የት/ት ደረጃ)		Occupation (ሥራ)		Service Year (የአገልግሎት ዘመን)	
Qualification (ክህሎት)		Position (ሃላፊነት)		Disability (አካል ጉዳኝነት) (Yes/No)	

Section 1: Multicriteria Analysis (MCA) of the SPWPS deployed in a rural community using various design techniques (tools): A case of Pinyudo community

(በገጠሩ አካባቢ በተለይም በፒኝዉዶ ማህበረሰብ ውስጥ በጸሀይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ በተለያዩ የዲዛይን ስርአቶችን (የንድፍ ዘዴዎችን) እና ሂደቶችን በመጠቀም ተገጥመዉ የሚሰሩ ፕሮጀክቶችን ለማነጻጸር የተዘጋጀ መጠይቅ፡፡)

Note፡ *Please give a comparative value from 1 to 5 as shown in the table: **"1"** for **"Very Poor"**, "2" for "**Poor",** for **"Neutral", "4"** for **"Good"** and **"5" for "Very Good"** to assess efficiency and performance results in the given space under each system concerning the technical aspect.*

*(**ማሳሰቢያ**- እባክዎን የቴክኖሎጂዎችን ቅልጥፍናን እንደዚሁም የተሻለ አፈፃፀምን ለመገምገም (ለማነጻጸር) ያስችል ዘንድ ቀጥሎ በቀረቡት መመዘኛዎች መሰረት ከቁጥር 1-5 ያሉትን መስፈርቶች በመመልከት፡- "1" ለ **"በጣም ዝቅተኛ"** ፤፤ "2" ለ **"ዝቅተኛ"** ፤ "3" ለ "**መካከለኛ (ፍትሃዊ)**" ፤ "4" ለ **"ጥሩ"** እና "5" ለ **"በጣም ጥሩ"** ከሚሉት ዉስጥ በእርስዎ አመለካከት በመገምግገም በእያንዳንዱ የቴክኖሎጂ ዲዛይን ስርዓት (ንድፍ ዘዴ) ስር በተዘጋጀው ክፍት ቦታ ላይ የቴክኖሎጂ ገጽታዉን በተመለከተ የእርስዎን ግምገማ የንጻሬ ዉጤት ይስጡ/ያስቀምጡ፡፡)*

S/No	Solar Powered Water Pumping System (SPWPS) Technical Aspect (አጠቃላይ በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ስርዓተ ሂደት የቴክኖሎጂ ገጽታ ቴክኒካዊ መስፈርት) (Parameter Description /Domain)	Design Tool-A	Design Tool-B	Design Tool-C	Design Tool-D
		Ministry of Water & Energy DT. የዉሃና ኢነርጂ ሀብት ሚኒስቴር የቴክኖሎጂ ዲዛይን ስርዓት	Water Mission DT/ የወተር ሚሽን የቴክኖሎጂ ዲዛይን ስርዓት	Grundfos DT/የግራንድ ፎስ ቴክኖሎጂ ዲዛይን ስርዓት	Lorentz DT/ የሎሬንዝ የቴክኖሎጂ ዲዛይን ስርዓት
1	**Technical Domains (Technical Aspect)**				
1.1	The designed solar panel energy and pump efficiency against the running (actual) efficiencies of the installed SPWPS. (በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት ዉስጥ በንድፈ ሐሳብ ደረጃ የነበረ የፀሐይ ሐይል ማሰባሰቢያ ፓነል የኃይል መሰብሰብ እና የፓምፕ ውጤታማነት በስራ ለይ ካለዉ (የትክክለኛነት) ጋር የዉጤታማነት ንጻሬ ተመሳሳይነት አለዉ፡፡)				
1.2	Communities' daily water demand versus supply concerning the national standard (water supply reliability). (ከብሔራዊ መለኪያ ደረጃ አንጻር የማህበረሰቡን የቀን የውሃ ፍላጎት መጠን ከአቅርቦት ሲመዘን (የውሃ አቅርቦት አስተማማኝነት) ተስማሚነት አለዉ፡፡)				
1.3	Storage Capacity and daily production rate with the national guidelines to satisfy the community's daily water demands.				
1.4	Ease of operation, maintenance, and system management with local knowledge. (ከብሔራዊ መለኪያ ደረጃ አንጻር የህብረተሰቡን የዕለት ተዕለት የውሃ ፍላጎት ለማሟላት የማከማቻ አቅም እና ዕለታዊ የምርት መጠን ተስማሚ ነዉ፡፡)				
1.5	SPWP System integration with the grid or diesel system (Hybridization compatibility).				
1.6	SPWP System installation complexity for the local experts. (በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት ለመትከል የሚጠይቀዉ ቴክኒካል ዕውቀት ለአካባቢው ባለሙያዎች የቴክኖሎጂ ውስብስብነት፤)				
	Total-1(ድምር-1)				
2	**Socio-Environmental Domain (Socio-Environmental Aspect)**				
2.1	SPWPS infrastructure installation requirements social &				

	environmental impacts (land, vegetation removal, waste material handling, etc.) (ከብሔራዊ ደረጃ መለኪያ አንጻር አጠቃላይ በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት ለመትከል የመሠረተ ልማት ዝርጋታ መስፈርቶች ማህበራዊና እና አካባቢያዊ ተፅዕኖዎች (የመሬት ጥያቄ፣ እፅዋትን ማስወገድ፣ ተረፈ ምርት ለአካባቢ ቆሻሻነት አስተዋጽዎ እና አያያዝ፣ ወዘተ.))				
2.2	*SPWPS end-users and other beneficiaries like technical personnel's satisfaction level, with the technology. (በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት የመጨረሻ ተጠቃሚዎችና የቴክኒካል ሰራተኞችና ሌሎች ተጠቃሚዎች በቴክኖሎጂው መርካት፤)*				
	Total-2(ድምር-2)				
3	***Economical Domain (Cost Aspect)***				
3.1	*The investment cost for the full installation package of the SPWPS system concerning the national standard. (ከብሔራዊ ደረጃ መለኪያ አንጻር አጠቃላይ በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት ለመገንባት የሚጠይቀዉ የኢንቨስትመንት ዋጋ ተስማሚ ነዉ፡፡)*				
3.2	*Yearly maintenance requirements and system-specific spare part availability in the local servicing market. (ዓመታዊ የጥገና ወጪ (ጥያቄ) እና በስርዓት-ተኮር የመለዋወጫ አቅርቦትና በአከባቢ የአገልግሎት ገበያ መገኘት መቻል፡፡)*				
	Total-3(ድምር-3)				
	Sub-Total (ንዑስ ድምር)				

Section 2: Comparative Analysis (CA) for Solar Powered Water Pumping System (SPWPS) Design Tool for Rural Community Water Supply: A Case of Pinyudo Community

Note—*As per the technical descriptions of the solar-powered water pumping system design tool presented, please give the Value "1" for **Absolutely Unacceptable**, "2" for **Unacceptable**, "3" for **Neutral**, "4" for **Acceptable**, and "**5**" for **Very Acceptable.***

*(**ማሳሰቢያ**- በሰንጠረዥ ዉስጥ በቀረቡት መመዘኛዎችን መሰረት በማድረግ የቴክኖሎጂዎችን ቅልጥፍናን እንደዚሁም አፈፃፀምን ለማነጻጸር ያስችል ዘንድ ቀጥሎ ከቁጥር 1-5 ያሉትን መስፈርቶች በመመልከት፡- "**1**" ለ "**በፍጹም ተቀባይነት የሌለዉ**" ፣ "2" ለ **ተቀባይነት የሌለዉ**" ፣ "3" ለ "**መካከለኛ**" ፣ "4" ለ **"ተቀባይነት ያለዉ ጥሩ"** እና "5" ለ **" በጣም ተቀባይነት ያለዉ"** ከሚሉት ዉስጥ በእርስዎ አመለካከት በመገምግገም በእያንዳንዱ የቴክኖሎጂ ዲዛይን /ንድፍ ዘዴ ስር በተዘጋጀው ክፍት ቦታ የእርስዎን የግምገማ የንጻሬ ዉጤትዎን ይስጡ/ያስቀምጡ፡፡)*

S/No	*Solar Powered Water Pumping System (SPWPS) Technical Aspect- **Key Performance metrics*** *(አጠቃላይ በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ስርዓተ ሂደት የቴክኖሎጂ ገጽታ ቴክኒካዊ መስፈርት)*	*Design Tool-A*	*Design Tool-B*	*Design Tool-C*	*Design Tool-D*
		Ministry of Water & Energy DT. የዉሃና ኢነርጂ ሀብት ሚኒስቴር የቴክኖሎጂ ዲዛይን ስርዓት	*Water Mission DT/ የወተር ሚሽን የቴክኖሎጂ ዲዛይን ስርዓት*	*Grundfos DT/የግራንድ ፎስ ቴክኖሎጂ ዲዛይን ስርዓት*	*Lorentz DT/ የሎሬንዝ የቴክኖሎጂ ዲዛይን ስርዓት*
C-1	The interface of the Solar Powered Water Pumping System (SPWPS) design tools is **easy to use (user-friendly interface).** *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት ሂደት ዲዛይን/ንድፍ ዘዴ በይነገጽ ለተጠቃሚዎች ምቹነት)*				
C-2	The Solar Powered Water Pumping System (SPWPS) **storage sizing, pump & solar module sizing tool components**. *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ዲዛይን ኢጋዥ መሳሪያ (ንድፍ ዘዴ) የዉሃ ማጠራቀሚያ መጠን ፣ የፓምፕ እና የፀሐይ ሞጁል የመመጠን (ዲዛይን የሚያደርግ) የሲስተም አካል)*				
C-3	The Solar Powered Water Pumping System design tools **interface availability for water points & mounting**				

	structure design interface. *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ዲዛይን አጋዥ መሳሪያ (ንድፍ ዘዴ) ለውሃ መከፋፈያ ቦኖዎች እና ፓነል ተሸካሚ ዉቅሮች ዲዛይን በይነገጽ ስርዓት ዉስጥ መገኘት/መካተት)*				
C-4	The Solar Powered Water Pumping System design tools **interface availability for solar irradiance & mounting direction determination**. *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ዲዛይን አጋዥ መሳሪያ (ንድፍ ዘዴ) ከአካባቢ ጂኦግራፊያዊ መረጃ ጋር የመሳሪያ ስርዓት ውህደት)*				
C-5	*The Solar Powered Water Pumping System (SPWPS)* ***compatibility and integration*** *between the various parts of the system. (በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት በእያንዳንዱ የዲዛይን የስርዓት ክፍሎች ውህደትና አንደኛዉ ከሌላኛዉ ያለዉ ተኳሃኝነት/ስምምነት)*				
C-6	The Solar Powered Water Pumping System (SPWPS) design tool **accuracy and Precision.** *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ዲዛይን/ንድፍ ዘዴ ትክክለኛነት እና ፍጹምነት)*				
C-7	The Solar Powered Water Pumping System design tool **modification or customization option & trends**. *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ዲዛይን አጋዥ መሳሪያ (ንድፍ ዘዴ) ማሻሻያ ወይም ማበልፀጊያ አማራጮች እና አዝማሚያዎች ወይም ልምምዶች)*				
C-8	In the Solar Powered Water Pumping System (SPWPS) project development, **the level of community participation in the entire process & Satisfaction using the technology**. *(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት የፕሮጀክት ልማት ሂደት ውስጥ ያለዉ የማህበረሰብ ተሳትፎ ደረጃ እና ቴክኖሎጂውን በመጠቀም ያለዉ የእርካታ መጠን)*::				
C-9	**Water Discharge Rate** (Volume of water flow over unit time in the system). *የውሃ መልቀቅ/መስጠት መጠን (በሲስተሙ ውስጥ ባለው የንጥል ጊዜ ውስጥ የውሃ ፍሰት መጠን) ።*				
C-10	**Availability/production of water** at the lowest irradiance of the day and the month with the expected quality to meet the daily demand. (*የእለት ተእለት ፍላጎትን ለማሟላት በሚጠበቀው የጥራት ደረጃ እና በወሩ ዝቅተኛ የጸሓይ ብርሃ ንባለበት ቀን የውሃ አቅርቦት/ምርታማነት።*				
C-11	**The system Yield Factor or Systems Panels Power Out Put** (The total energy generated by the solar plant over a specific period. This is the most fundamental Key performance Indicator indicating the plant's output). ((*በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ* .የሲስተሙ የምርት ውጤት ወይም የሲስተም ፓነሎች ሃይል አወጣጥ (በፀሐይ ፋብሪካ የሚመነጨው አጠቃላይ ሃይል በተወሰነ ጊዜ ውስጥ ነው። ይህ የፋብሪካውን ውጤት የሚያመለክት በጣም መሠረታዊው የቁልፍ አፈፃፀም አመላካች ነው)።				
C-12	**System Performance Availability Rate** (The percentage of time the plant is operational and producing energy. High availability is crucial for maximizing output)..የስርዓት አፈጻጸም ተገኝነት ደረጃ (ተክሉ የሚሰራበት እና ሃይል የሚያመነጭበት ጊዜ መቶኛ። ከፍተኛ ተገኝነት ከፍተኛ ውጤትን ለመጨመር ወሳኝ ነው)።				
C-13	**Inverter Availability and Performance Efficiency** (Availability & The efficiency with which inverters convert DC power from the PV panels to AC power. Inverter performance can significantly impact overall plant efficiency)				
C-14	**Solar Module Efficiency** (The efficiency of the solar modules in converting sunlight into electrical energy. Regular monitoring can indicate degradation or issues with specific modules). የፀሐይ ሓይል ማሰባቢያ ፓኔል ዉቴታማነት/ ቅልጥፍና (የፀሐይ ብርሃንን ወደ ኤሌክትሪክ ኃይል ለመለወጥ የፀሐይ ሞጁሎች ቅልጥፍና. መደበኛ ክትትል መበላሸትን ወይም ከተወሰኑ ሞጁሎች ጋር ያሉ ችግሮችን ሊያመለክት ይችላል).				
C-15	**Operation & Maintenance Frequency** (Total costs associated with running and maintaining the plant. Effective cost management is vital for financial sustainability). የክዋኔ እና የጥገና ድግግሞሽ (ሲስተሙን ለማካሄድ እና ከመጠበቅ ጋር የተያያዙ አጠቃላይ ወጪዎች. ውጤታማ የወጪ አስተዳደር ለፋይናንስ ዘላቂነት በጣም አስፈላጊ መሆን).				
	Total (ድምር)				

Section 3: Short Answer open-ended Questions for all members of the Community

(User community: Engineers, Operators technical personnel, Management Members)

Note- Please answer the questions below about the issues related to the installation and using the solar-powered water pumping system (SPWPS) for the rural community water supply system. (ማሳሰቢያ- እባክዎን ለገጠሩ ማህበረሰብ የውሃ አቅርቦት እንዲያገለግሉ ታስበዉ በተገነቡ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች አጠቃቀምን በሚመለከት ቀጥለዉ ለቀረቡ ጥያቄዎች ይመልሱ።

1) *a) In your experience, what are the top five expected causes of system component failure from the installed solar-powered pumping systems in your locality? (በአከባቢያችን ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ዉስጥ በተደጋጋሚ የሚያጋጥሙ ብልሽቶች ምንድናቸዉ? ለብልሽቶቹ ዋና ዋና ምክንያቶቻቸዉስ?*

From the installed solar-powered water supply (SPWPS) in your locality, which system causes continuous failure that you identified? (በአካባቢው ተገንብተዉ በጸሀይ ሐይል ከሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ዉስጥ በተደጋጋሚ የሚበላሸዉ በየትኛዉ የዲዛይን ዘዴ የተገነባዉ ነዉ?)

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b) What measures can be taken by the water technical experts and the user community to stop the failure? (በእርስዎ አመለካከት ይህንን አይነት ተደጋጋሚ ብልሽት ለማስወገድ በውሃ ቴክኒካል ባለሙያዎች እና ተጠቃሚው ማህበረሰብ ምን አይነት እርምጃዎችን ሊወስዱ ይችላሉ?)

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2) *Is there a government standard or policy to control the quality and ensure the system durability for different solar water pumping systems design and installation that you know about and/or recommend? (በአካባቢው ተገንብተዉ በጸሀይ ሐይል ለሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂን በተመለከተ እርስዎ የሚያዉቁት፣ የሚመክሩት፣ የቴክኖሎጂዉን ዘላቂነት ለማረጋገጥ የሚያግዝ ብሔራዊ መመሪያ ወይም ፖሊሲ አለ?)*

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3) *What are the operational challenges & limitations of the installed solar-powered water supply (SPWS) in implementing and managing in the rural community? (በአካባቢው ተገንብተዉ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎችን በተመለከተ በገጠሩ ማህበረሰብ ዘንድ በመተግበር እና በማስተዳደር ላይ ያለው የተግባር ተግዳሮቶች እና ዉስንነቶች ምንድናቸዉ?)*

4) *Is there any limiting component to the sustainability or lifetime of the existing solar-powered water supply (SPWPS) (e.g., the solar array, the inverter, electronic controls, motor, pump bearings, etc.)? (በአካባቢው ተገንብተዉ በጸሀይ ሐይል ከሚሰሩ ለመጠጥ አገልግሎት የዋሉ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች እድሚያቸዉን የሚያሳጥሩና ረዥም ጊዜ እንዳያገለግሉ የሚያደርጋቸዉ ክፍሎች የትኞቹ ናቸው? (ለምሳሌ የፀሐይ መሰብሰቢያ ፓኔል፣ ኢንቨርተር፣ የኤሌክትሪክ መቆጣጠሪያዎች፣ ሞተር፣ የፓምፕ ማፈኛዎች፣ ወዘተ?))*

5) *Is the limiting component (broken components) generally replaceable by the local technicians and system operators within the required time frame? (ከላይ የተገለጹት ብልሽቶች (የተበላሹ አካላት) በአጠቃላይ በአካባቢው ቴክኒሻኖች እና ስራዉን ዕለት ተዕለት በሚያከናዉኑ ኦፕሬተሮች በሚፈለገው የጊዜ ገደብ ውስጥ መተካትና ማስተካከል ይቻላል?)*

6) *How many different kinds of solar-powered water supply (SPWPS) are there in your area? What are some new, innovative designs for increasing the durability or robustness of SWPs from each system? (በአካባቢዎ ምን ያህል በጸሀይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ተገንብተዉ ይገኛሉ? በእርስዎ መረዳት ከእያንዳንዱ ስርዓት ዘላቂነትን ለማረጋገጥ ወይም ጥንካሬ ለመጨመር የተካተቱ አንዳንድ ነገሮች ወይም አዳዲስ ዲዛይኖች ምንድናቸዉ?)*

7) *Is there any cost concern regarding the installed solar-powered water pumping systems (SPWPS) in the locality? From your observation which system is cheap to install, operate and manage by the local community? (በአካባቢው ተገንብተዉ በጸሀይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂን በተመለከተ የአካባቢዉ ነዋሪዎች ወጪዉን ወይም ዋጋቸዉን በተመለከተ ቅሬታዎች ስጋት/ቅሬታ አለባቸዉ? ምንድን ናቸው? ከእርስዎ ምልከታ በአካባቢው ማህበረሰብ ለመገንባት፣ ስራዉን ለማከናወን እና ለማስተዳደር የትኛው የቴክኖሎጂ ስርዓት ይረክሳል?*

8) *What are the most common community complaints about solar-powered water pumping systems (SPWPS) operations? What is the most common positive feedback given? (በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂን የስራ ሂደት በተመለከተ የአካባቢዉ ነዋሪዎች ቅሬታዎች ምንድን ናቸው? በጣም የተለመዱት (በተደጋጋሚ የቀረቡ) አዎንታዊ ግብረመልሶች ምንድ ናቸው?)*

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9) *a) Do you have a direct engagement or an indirect engagement through the local leaders in designing and installing the solar water pumping systems? (በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርኣተ ሂደት ዲዛይን በማድረግና እና በግንባታ ወቅት ቀጥተኛ ተሳትፎ ወይም በአካባቢ መሪዎች (ተወካዮች) በኩል ቀጥተኛ ያልሆነ ተሳትፎ ያድርጉ ነበርን?)*

b) To what extent is the user community engaged in the solar-powered water supply (SPWS) design and establishment process? What issues were raised by the community and what is their feedback on the technology? (የተጠቃሚው ማህበረሰብ በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ የፕሮጀክቶች ዲዛይን እና የግንባታ ሂደት ውስጥ የተሳተፈው እስከ ምን ድረስ ነዉ? ከማህበረሰቡ የተነሱት ጉዳዮች እና በቴክኖሎጂው ላይ የሰጡት አስተያየቶች ምን ይመስላሉ?)

10) *a) What could be the most pressing challenges in using the solar-powered water supply (SPWS) and the system design tools? Which design tool is user-friendly?*

b) Why? (በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርኣተ ሂደት እና የስርዓተ- ንድፍ መሳሪያዎችን ለመጠቀም በጣም ከባድ የሆኑ ፈተናዎች ምን ሊሆኑ ይችላሉ? የትኛው የንድፍ መሳሪያ ለተጠቃሚዎች ምቹ ነው? ለምን?

Part 2: Research Questioners- Survey Data Collection Tools for the User Community

***Note**- Please thick (✓) for the Values “**1**” for “**Strongly Disagree (SD)**”, “**2**” for “**Disagree (DA)**”, “**3**” for “**Natural**”, “**4**” for “**Agree**” and “**5**” for “**Strongly Agree (SA)**” to collect data about the installation and using the solar powered water pumping system (SPWPS) for rural community water supply system issues mentioned from table 4.1- 4.4 in the description section.*

*(**ማሳሰቢያ**- እባክዎን በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ለገጠሩ ማህበረሰብ የመጠጥ ዉሃ አቅርቦት መግጠምና (መትከልና) መተግበር ጋር የተያያዙ ጉዳዮችን **ለመገምገምና** መረጃ ለማሰባሰብ ያስችል ዘንድ በሰንጠረዥ ቁጥር 4.1-4.4 የተገለጹትን መስፈርቶች በመመልከት፡- “1” ለ **“በጣም አልስማማም”** ፣ “2” ለ “**አልስማማም**” ፣ “2” ለ **“መካከለኛ (ፍትሃዊ)**” ፣ “3” ለ “**እስማማለሁ**” ፣ “4” ለ **“በጣም ጥሩ”** እና “5” ለ **“በጣም እስማማለሁ”** ከሚሉት ዉስጥ በእርስዎ ግምገማ መሰረት በቀረቡት መስፈረቶች በመመስረት የ (✓) ምልክት በዉጤቶቹ ለአንደኛዉ ብቻ ያድርጉ፡፡)*

Section 1: Challenges of the solar-powered water pumping systems (SPWPS) installation and implementation in rural communities.

(በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ለገጠሩ ማህበረሰብ መግጠምና/መትከልና መተግበር የሚያስከትላቸዉ ተግዳሮቶች (ፈተናዎች)

S/N	***Description***	***1***	***2***	***3***	***4***	***5***
1	The investment cost for purchasing and installing solar-powered water pumping systems (SPWPS) equipment can be difficult for rural communities. *(አጠቃላይ በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓት ለመትከል የሚጠይቀዉ የኢንቨስትመንት ዋጋ በቀላሉ በተመጣጣኝ ዋጋ ማግኘት ለገጠሩ ማህበረሰብ አዳጋች ነዉ፡፡)*					
2	Proper installation and maintenance of solar-powered water pumping systems (SPWPS) require technical expertise, and unavailability in rural areas might cause hindrances in the water supply system. *(በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎችን በትክክል ለመገጣጠምና ስራ ላይ ለማዋል እንደዚሁም ለመጠገን ቴክኒካል እውቀትን ይፈልጋል፡፡ ስለሆነም በገጠር አካባቢ የቴክኒክ ባለሙያና ክህሎት በቀላሉ አለመገኘት በውሃ አቅርቦት ስርዓት ላይ እንቅፋት ይፈጥራል።)*					
3	Lack of community engagement during project development and empowering ownership is a challenge in our locality and impacts the long-term sustainability of installed solar-powered water pumping systems (SPWPS). *(በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ትግበራ ወቅት፤ የማህበረሰብ ተሳትፎ በፕሮጀክት አፈጻጸም ወቅት አለመኖርና እና የባለቤትነት ስሜትን ማጎልበት አለመቻል በአከባቢያችን ፈታኝ እና የረጅም ጊዜ ዘላቂነት ላይ ተጽእኖ አሳድሯል)*					
4	Because of the poor quality and inaccessibility of the roads, transporting tools and supplies to isolated rural locations while installing and maintaining solar-powered water pumping systems (SPWPS) components can be difficult and expensive. *(በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች መግጠምና ስራ ላይ ለማዋል እንደዚሁም ሲጠገኑ መሳሪያዎች እና ቁሳቁሶችን ወደ ሩቅ ገጠራማ አካባቢዎች ማጓጓዝ ከመንገዶቹ አመቺ አለመሆንና አስቸጋሪነት የተነሳ ፈታኝ እና ውድ ሊሆን ይችላል፡፡)*					
5	The installed solar-powered water pumping systems (SPWPS) sometimes needed help to satisfy the daily water delivery service requirements due to inconsistent power generation & energy shortages during the wet season. *(በአከባቢያችን ተገጥመዉ አገልግሎት በመስጠት ላይ ያሉ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች (የፓምፖ ሲስተሞች) አንዳንድ ጊዜ በዝናባማና በደመና ወቅት ወጥ በሆነ የሃይል ማመንጫ እና የሐይል ምንጭ እጥረት ምክንያት የእለት ተእለት የውሃ ፍላጎትና አቅርቦት አገልግሎት መስፈርቶችን ማሟላት አልቻሉም።)*					

6	Identifying suitable water sources, and determining the optimal location, and space for Solar panel mounting for installing solar-powered water pumping systems (SPWPS) is a challenging issue in the rural community. *(በጸሐይ ሐይል የሚሰሩና የሚንቀሳቀሱ የጉድጓድ ዉሃ መሳቢያ የፓምፖች ቴክኖሎጂዎች ተስማሚ የውሃ ምንጮችን መለየት እና ተስማሚ የጸሐይ ማሰባሰቢያ ፓኔል መዘርጊያ ጥሩ ቦታ ማግኘትና መወሰን በገጠሩ ማህበረሰብ ውስጥ ፈታኝ ጉዳይ ነዉ፡፡)*					
7	The installed solar-powered water pumping systems (SPWP) could not satisfy the daily water delivery service requirements due to erratic power generation & energy Storage throughout the wet season. *(በአከባቢያችን ተገጥሞ አገልግሎት በመስጠት ላይ ያለ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች (የፓምፖ ሲስተሞች) ሁል ጊዜ በዝናባማና ወቅት (በክረምት ወቅትና በተሳለጠ የሃይል ማመንጫ እና ኢነርጂ ማከማቻ አለመኖር ምክንያት የእለት ተእለት የውሃ አቅርቦት አገልግሎት መስፈርቶችን ማሟላት አልቻለም።)*					
	Total (ድምር)					

Section 2: Implications of social and environmental features due to installed solar-powered <u>water pumping systems (SPWPS) infrastructures</u>.

(በጸሐይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂን ለመጠቀም በተተከሉ መሳሪያዎች ምክንያት የተፈጠሩትን ማህበራዊና አካባቢያዊ ተፅዕኖዎች)

S/N	***Description***	***1***	***2***	***3***	***4***	***5***
1	The availability of clean water from the installed solar-powered water pumping systems (SPWPS) enhanced the daily lives of the community. *(በአከባቢያችን የአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች በመኖራቸዉ በፕሮጀክቶቹ ጠቀሜታ እና ግልጋሎት ላይ እኔን ጨምሮ ቤተሰቦቼ እንደዚሁም የአካባቢዉ ማሕበረሰብ እርካታ አግኝተናል)*					
2	Concerns about land usage, cultural disruption, or other environmental issues are unrelated to the construction of solar-powered water pumping systems (SPWPS). *(ከመሬት አጠቃቀም፣ የባህል መጣረስ ወይም ሌሎች የአካባቢ ጉዳዮች አሳሳቢነት በፀሐይ ሃይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ፓምፕ ሲስተም በአከባቢያችን ከመገንባቱ ጋር ግንኙነት የላቸውም።)*					
3	The local communities can save money and invest in other necessities for household activities since the installed solar-powered water pumping systems (SPWPS) have decreased operational expenses for fuel and spare parts for daily water pumping. *(በፀሐይ ኃይል ሐይል የሚሰሩ የጉድጓድ ውኃ መሳቢያ ዘዴዎች ምክንያት ለነዳጅ እና ለተለያየ ዕለታዊ የውሃ ፓምፖችና ሌሎች መለዋወጫ ወጪዎችን በመቀነሱ የአካባቢው ማህበረሰቦች ገንዘብ መቆጠብ እና ለመደበኛ ኑሮ አስፈላጊ በሆኑ ነገሮች ላይ ማዋል ችለዋል፡፡)*					
4	In addition to ensuring rural communities' long-term social and environmental advantages, the solar-powered water pumping systems (SPWPS) successfully met the local water demand. *(የገጠሩን ማህበረሰብ የረዥም ጊዜ ማህበራዊ እና አካባቢያዊ ጥቅሞችን ከማረጋገጥ በተጨማሪ በፀሀይ ኃይል የሚንቀሳቀሱ የውሃ ፓምፖች አገልግሎት የአካባቢውን የውሃ ፍላጎት በተሳካ ሁኔታ ያሟላሉ።)*					
5	The installed solar-powered water supply (SPWS) projects influence the local community's quality of life, social integration, and well-being. *(በአከባቢያችን ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ አቅርቦት ፕሮጀክቶች የአካባቢውን ማህበረሰብ የኑሮ ጥራት፣ ማህበራዊ ውህደት እና ደህንነት ላይ በጎ ተጽእኖ አሳድረዋል።)*					
6	The presence of solar-powered water supply projects in my locality has improved the standard of living of the entire community. *(ለመጠጥ ዉኃ አገልግሎት እንዲዉሉ ታስበዉ በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ አቅርቦት ፕሮጀክቶች መኖራቸው የህብረተሰቡን የኑሮ ደረጃ አሻሽለዋል።)*					
7	Installation and operation of solar-powered water pumping systems (SPWPS) in the rural community can still have environmental impacts, such as habitat disruption, and afforestation which may be of concern in rural areas. *(በገጠሩ ማህበረሰብ አከባቢ ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ አቅርቦት ፕሮጀክቶች ግንባታ ወቅት የአካባቢ ተጽኖዎች እንደ መኖሪያ አካባቢ መረበሽ እንደዚሁም አሳሳቢ የሆኑ የደን መጨፍጨፍን ሊያስከትሉ ይችላሉ።)*					
	Total (ድምር)					

Section 3: Challenges of the solar-powered water pumping systems (SPWPS) installation and implementation in rural communities.

(በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ለገጠሩ ማህበረሰብ መግጠምና/መትከልና መተግበር የሚያስከትላቸዉ ተግዳሮቶች (ፈተናዎች)

S/N	Description	1	2	3	4	5
1	There is 24-hour access to water from the solar-powered water pumping system sourced from a borehole in my local government area, which benefits the community. *(በአከባቢያችን አስተዳደር ዉስጥ ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ማህበረሰቡ የ 24 ሰአታት ውሃ ማግኘት ይቻላል ይህ ደግሞ ህብረተሰቡን ተጠቃሚ አድርጓል፡፡)*					
2	A channel is available locally to maintain and repair the damaged solar-powered water pumping system. *(በአከባቢያችን የአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያና የውኃ ማስተላለፊያ ቢበላሽ ለመጠገን እና ለማስጠገን በአካባቢው ትክክለኛዉ አሰራርና ገቢያዉ አለ፡፡)*					
3	Maintaining and operating the solar-powered water pumping systems (SPWPS) is not a problem for the community. *(በአከባቢያችን የአገልግሎት በተገጠሙና በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎችን ማንቀሳቀስና በተበላሹ ሰአት መጠገን ለህብረተሰቡ ችግር አይደለም፡፡)*					
4	The installed solar-powered water pumping systems (SPWPS) improved the community operational efficiency and managerial practices of water supply projects. *(በአከባቢያችን ተገጥመዉ አገልግሎት የሚሰጡ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች በመኖራቸዉ የሕብረተሰቡን የዉኃ ተቋማት የመስተዳደር፣ የስራ ቅልጥፍናን ማዳበር ምክንት ከመሆን ባሻገር የተቋማት አስተዳደር ልምዶችን አሻሽሏል።)*					
5	Regular maintenance and timely repair of solar-powered water pumping systems (SPWPS) components are essential for sustainability and optimal performance. However, accessing spare parts and qualified technicians for operation and repairs can be difficult in remote rural areas. *በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች የተለያዩ አካላትን መደበኛና ወቅቱን የጠበቀ ጥገናና እድሳት የአገልግሎት ዘመናቸዉን ለማራዘም ምክንየት ቢሆንም ለስራ እና ለጥገና መለዋወጫ እና ብቁ ቴክኒሻኖችን በአከባቢያችን ራቅ ባሉ ገጠራማ አካባቢዎች ማግኘት አስቸጋሪ ነዉ።)*					
6	Capacity building, financial support, technological innovations, and collaboration between various stakeholders, including government agencies, NGOs, and stakeholders in the local community about solar-powered water pumping systems (SPWPS) considered operational challenges and limitations. *(በአከባቢያችን አገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች በተመለከተ የሚሰጡ የአቅም ግንባታ፣ የፋይናንስ ድጋፍ፣ የቴክኖሎጂ ፈጠራዎች እና የመንግስት ኤጀንሲዎች፣ መንግሥታዊ ያልሆኑ ድርጅቶች እና በአካባቢው ማህበረሰብ ውስጥ ያሉ ባለድርሻ አካላት መካከል ያለው ትብብርና ድጋፍ የቴክኖሎጂዉን የተግባር ፈተናዎችን እና ውስንነቶችን ከግምት ያስገባ ነዉ።)*					
	Total (ድምር)					

Section 4: Challenges of the solar-powered water pumping systems (SPWPS) installation and implementation in rural communities.

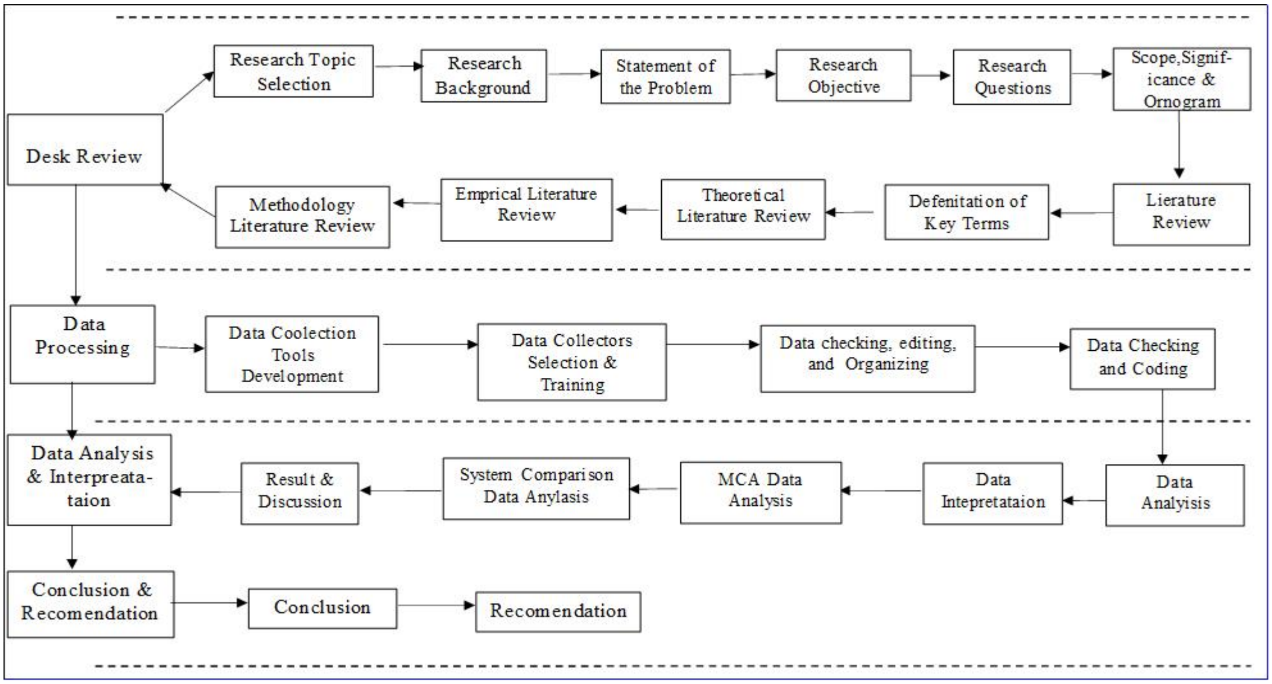
(በጸሀይ ሐይል የሚሰራ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂ ስርዓተ ሂደት ለገጠሩ ማህበረሰብ መግጠምና/መትከልና መተግበር የሚያስከትላቸዉ ተግዳሮቶች (ፈተናዎች)

S/N	*Description*	*1*	*2*	*3*	*4*	*5*
1	I am comfortable with my engagement in the process of the solar water pumping system (SPWPS) project study, appraisal, site selection, implementation, operation and management process. *(በአከባቢያችን ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች የፕሮጀክት ጥናት፣ ግምገማ፣ የቦታ ምርጫ፣ አተገባበር፣ አፕሬሽን እና የአስተዳደር ሂደት ውስጥ ተሳትፎዬ የተመዋላ ስለነበር ሂደቱ ተመችቶኛል።)*					
2	Women, water technicians, and community leaders are involved in the decision-making and execution of the solar-powered water supply (SPWPS) project. *(በአከባቢያችን ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች የህብረተሰቡ አመራሮች፣ የውሃ ቴክኒሻኖች እና ሴቶች በፀሃይ ሃይል የሚሰራ የውሃ አቅርቦት ፕሮጀክት ትግበራ እና ውሳኔ አሰጣጥ ሂደት ላይ ይሳተፋሉ።)*					
3	The local community participated in the process of choosing a location for a solar-powered water supply (SPWS) project. *(በአከባቢያችን በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ትግበራ ወቅት ቦታን በመምረጥ ሂደት የአካባቢው ማህበረሰብ ተሳትፏል።)*					
4	The installed solar-powered water supply (SPWPS) is perceived by the community members as sustainable and dependable, and they are sufficiently confident in this respect. *(በአከባቢያችን ለአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች አስተማማኝነት እና ዘላቂነት በተመለከተ የማህበረሰቡ አባላት ያላቸው ግንዛቤ በጣም አዎንታዊ እና በመተማመን ነው።)*					
5	The Solar Power Water Supply (SPWS) installations that have been implemented in my area have my satisfaction. *(በአከባቢያችን በተገነቡ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች ርካታና ደስታ ተሰምቶኛል፡፡)*					
6	With the presence of a solar-powered water supply system (SPWS) in our locality; my family and the community were satisfied with the project and service. *(በአከባቢያችን የአገልግሎት በተገጠሙ በጸሐይ ሐይል የሚሰሩ የጉድጓድ ዉሃ መሳቢያ ቴክኖሎጂዎች በመኖራቸዉ በፕሮጀክቶቹ ጠቀሜታ እና ግልጋሎት ለይ እኔን ጨምሮ ቤተሰቦቼ እንደዚሁም የአካባቢዉ ማሕበረሰብ በአገልግሎቱ እርካታ አግኝተናል)*					
	Total (ድምር)					

Part 3: Details of Collected Data from Field Observation

Pinyudo SPWPS Field Observation- A conso

3. The Research Process Schematic Representation



4. Data Analysis Results

4.1.Challenges associated with SPWPS Usage

Table 3.1.1: Reliability test result for the Challenges associated with SPWPS used for rural community water supply systems in the study area

Case Processing Summary			
		N	%
Cases	Valid	450	100
	Excluded[a]	0	0
	Total	450	100
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha		N of Items	
0.671		7	

Table 3.1.2: Normality test result for the Challenges associated with SPWPS used for rural community water supply systems in the study area

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Challenges of SPWPS	0.062	450	0	0.987	450	.000
a. Lilliefors Significance Correction						

4.2.Differences in Diverse Design Tools for SPWPS

3.2.1- Reliability Test Result for MCA tool data

Table3.2.1-1: Reliability test result for the MCA collected data about the MoWE design tool

Case Processing Summary			
		N	%
Cases	Valid	14	87.5
	Excluded[a]	2	12.5
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha	N of Items		
.883	10		

Table3.2.1-1: Reliability test result for the MCA collected data about the WM design tool

Case Processing Summary			
		N	%
Cases	Valid	15	93.8
	Excluded[a]	1	6.3
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha	N of Items		
.902	10		

Table 3.2.1-3: Reliability test result for the MCA collected data about the Grundfos design tool

Case Processing Summary			
		N	%
Cases	Valid	15	93.8
	Excluded[a]	1	6.3
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure			
Reliability Statistics			
Cronbach's Alpha	N of Items		
.909	10		

Table 3.2.1-4: Reliability test result for the MCA collected data about the Lorentz design tool

Case Processing Summary			
		N	%
Cases	Valid	13	81.3
	Excluded[a]	3	18.8
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha	N of Items		
.978	10		

3.2.2: Normality Test Result for MCA Tool Data

Table 3.2.2-1: Multi-Criteria Analysis data for MoWE SPWPS design tool-Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
MCA for MoWE DT	0	14	.200*	0.938	14	0.389
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 3.2.2-2: Multi-Criteria Analysis data for WM SPWPS design tool-Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
MCA for WM DT	.121	15	.200*	.933	15	.299
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 3.2.2-3: Multi-Criteria Analysis data for Grundfos SPWPS design tool-Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
MCA for Grundfos DT	.161	15	.200*	.966	15	.801
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 3.2.2-4: Multi-Criteria Analysis data for Lorentz SPWPS design tool-Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
MCA for Lorentz DT	.161	15	.200*	.966	15	.801
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

3.2.3- Reliability Test Result for Comparative Analysis (CA) Tool Data

Table 3.2.3-1: The reliability test result for the **MoWE design tool**

Case Processing Summary			
		N	%
Cases	Valid	14	87.5
	Excluded[a]	2	12.5
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure.			

Reliability Statistics	
Cronbach's Alpha	N of Items
.841	10

Table 3.2.3-2: The reliability test result for the CA collected data about the **WM design tool**

Case Processing Summary			
		N	%
Cases	Valid	15	93.8
	Excluded[a]	1	6.3
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha		N of Items	
.783		10	

Table 3.2.3-3: Reliability test result for the CA about the **Grundfos design tool**

Case Processing Summary			
		N	%
Cases	Valid	15	93.8
	Excluded[a]	1	6.3
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure			
Reliability Statistics			
Cronbach's Alpha		N of Items	
.927		10	

Table 3.2.3-4: Reliability test result for the CA collected data about the **Lorentz design tool**

Case Processing Summary			
		N	%
Cases	Valid	13	81.3
	Excluded[a]	3	18.8
	Total	16	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha		N of Items	
.934		10	

3.2.4- Normality Test Result for Comparative Analysis (CA)

Table 3.2.4-1: Comparative Analysis data for MoWE SPWPS design tool-Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CA for MoWE DT	.106	15	.200*	.969	15	.838
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 3.2.4-2: Comparative Analysis data for WM SPWPS design tool-Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CA for WM DT	.106	15	.200*	.969	15	.838
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 3.2.4-3: Comparative Analysis data for Grundfos SPWPS design tool-Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CA for Grundfos DT	.165	15	.200*	.940	15	.384
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 3.2.4-4: Comparative Analysis data for Lorentz SPWPS design tool-Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CA for Lorentz DT	.216	13	.100	.856	13	.035
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

4.3. Social and Environmental Implications of SPWPS Components

Table 3.3.1: Reliability test result for the implications of social and environmental features due to installed solar-powered water pumping systems (SPWPS) components

Case Processing Summary			
		N	%
Cases	Valid	450	100
	Excluded[a]	0	0
	Total	450	100
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha		N of Items	
0.631		7	

Table 3.3.2: Normality test result for the implications of social and environmental features due to installed solar-powered water pumping systems (SPWPS) components

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Implication _ SoEnv _SPWPS	.092	450	.000	.979	450	.000
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

4.4.Operational challenges and limitations in managing SPWPS

Table 3.4.1: Table Reliability test result for the data concerning operational challenges & limitations faced in implementing, and managing the installed SPWPS by the local community

Case Processing Summary			
		N	%
Cases	Valid	450	100
	Excluded[a]	0	0
	Total	450	100
a. Listwise deletion based on all variables in the procedure.			

Reliability Statistics	
Cronbach's Alpha	N of Items
0.611	6

Table 3.4.2: Normality test result for the operational challenges and limitations that the community experienced when managing and implementing the installed SPWPS

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Operational Challenges of Using SPWPS	.076	450	.000	.987	450	.001
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

4.5. Community Engagement and Satisfaction

Table 3.5.1: Reliability test result for the extent of community engagement in the project cycle and their satisfaction with the installed SPWPS

Case Processing Summary			
		N	%
Cases	Valid	450	100
	Excluded[a]	0	0
	Total	450	100
a. Listwise deletion based on all variables in the procedure.			

Reliability Statistics	
Cronbach's Alpha	N of Items
0.706	6

Table 3.5.2: Normality test result for the level of community engagement and satisfaction with the installed SPWPS

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Comm _ Engagement _ Satisfaction_ SPWPS	.085	450	.000	.967	450	.000
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

3.6- Weighted Sum Method (WSM) Test Result for MCA tool data

Multicriteria Analysis (MCA) of the SPWPS deployed in a rural community using various design techniques (tools)

The SPWPS Design Tools performance table presents a Multicriteria Analysis (MCA) result based on a simple additive weighting model.

Table 3.6.1: FDRE Ministry of Water and Energy (MoWE) SPWPS Design Tool

S/No	Variable Description (Domain)	First Level weights (R)	Second Level Weights (w)	Average Scored Result of the Subdomain (x)	Weighted average Score of the subdomain at the Second Level	Weighted average Score of the subdomain at the First Level
1	**Technical Domains (Technical Aspect)**	**0.50**				
1.1	Designed solar panel energy and pump efficiency against the running (actual) efficiencies of the installed SPWPS.		0.35	3.64	1.28	0.64
1.2	Communities' daily water demand versus supply concerning the national standard (water supply reliability).		0.25	2.93	0.73	0.37
1.3	Storage Capacity and daily production rate with the national guidelines to satisfy the community's daily water demands.		0.12	3.64	0.44	0.22
1.4	Ease of operation, maintenance, and system management with local knowledge.		0.08	2.93	0.23	0.12
1.5	SPWP System integration with the grid or diesel system (Hybridization compatibility).		0.10	2.93	0.29	0.15
1.6	SPWP System installation complexity for the local experts.		0.10	2.93	0.29	0.15
	Total Result of the Design Tool at Domain-1					**1.63**
2	**Socio-Environmental Domain (Socio-Economic Aspect)**	**0.25**				
2.1	SPWPS infrastructure installation requirements social & environmental impacts (land, vegetation removal, waste material handling, etc.)		0.30	3.21	0.96	0.24
2.2	SPWPS end-users and other beneficiaries like technical personnel's satisfaction with the technology.		0.70	3.43	2.40	0.60
	Total Result of the Design Tool at Domain-2					**0.84**
3	**Economical Domain (Cost Aspect)**	**0.25**				
3.1	The SPWPS system full package installation investment cost concerning the national standard.		0.65	3.21	2.09	0.52
3.2	Yearly maintenance requirements and system-specific spare part availability in the local servicing market.		0.35	2.71	0.95	0.24
	Total Result of the Design Tool at Domain-3					**0.76**
	Total Result for the 3 domains from 5	**1.00**			**-**	**3.23**
	Total Result for the 3 domains from 100 %	**100.00**			**-**	**64.67**

Multicriteria Analysis (MCA) of the SPWPS deployed in a rural community using various design techniques (tools)						
The SPWPS Design Tools performance table presents a Multicriteria Analysis (MCA) result based on a simple additive weighting model.						
Table 3.6.2: Water Mission (WM) SPWPS Design Tool						
S/No	**Variable Description (Domain)**	**First Level weights (R)**	**Second Level Weights (w)**	**Average Scored Result of the Subdomain (x)**	**Weighted average Score of the subdomain at the Second Level**	**Weighted average Score of the subdomain at the First Level**
1	**<u>Technical Domains (Technical Aspect)</u>**	**0.50**				
1.1	Designed solar panel energy and pump efficiency against the running (actual) efficiencies of the installed SPWPS.		0.35	2.93	1.03	0.51
1.2	Communities' daily water demand versus supply concerning the national standard (water supply reliability).		0.25	3.07	0.77	0.38
1.3	Storage Capacity and daily production rate with the national guidelines to satisfy the community's daily water demands.		0.12	3.60	0.43	0.22
1.4	Ease of operation, maintenance, and system management with local knowledge.		0.08	2.40	0.19	0.10
1.5	SPWP System integration with the grid or diesel system (Hybridization compatibility).		0.10	3.40	0.34	0.17
1.6	SPWP System installation complexity for the local experts.		0.10	2.93	0.29	0.15
	Total Result of the Design Tool at Domain-1					**1.53**
2	**<u>Socio-Environmental Domain (Socio-Economic Aspect)</u>**	**0.25**				
2.1	SPWPS infrastructure installation requirements social & environmental impacts (land, vegetation removal, waste material handling, etc.)		0.30	3.53	1.06	0.27
2.2	SPWPS end-users and other beneficiaries like technical personnel's satisfaction with the technology.		0.70	3.67	2.57	0.64
	Total Result of the Design Tool at Domain-2					0.91
3	**<u>Economical Domain (Cost Aspect)</u>**	**0.25**				
3.1	The SPWPS system full package installation investment cost concerning the national standard.		0.65	2.60	1.69	0.42
3.2	Yearly maintenance requirements and system-specific spare part availability in the local servicing market.		0.35	2.47	0.86	0.22
	Total Result of the Design Tool at Domain-3					**0.64**
	Total Result for the 3 domains from 5	**1.00**			**-**	**3.07**
	Total Result for the 3 domains from 100 %	**100.00**			**-**	**61.41**

Multicriteria Analysis (MCA) of the SPWPS deployed in a rural community using various design techniques (tools)						
The SPWPS Design Tools performance table presents a Multicriteria Analysis (MCA) result based on a simple additive weighting model.						
Table 3.6.3: Grundfos SPWPS Design Tool						
S/No	**Variable Description (Domain)**	**First Level weights (R)**	**Second Level Weights (w)**	**Average Scored Result of the Subdomain (x)**	**Weighted average Score of the subdomain at the Second Level**	**Weighted average Score of the subdomain at the First Level**
1	**Technical Domains (Technical Aspect)**	**0.50**				
1.1	Designed solar panel energy and pump efficiency against the running (actual) efficiencies of the installed SPWPS.		0.35	3.67	1.28	0.64
1.2	Communities' daily water demand versus supply concerning the national standard (water supply reliability).		0.25	3.07	0.77	0.38
1.3	Storage Capacity and daily production rate with the national guidelines to satisfy the community's daily water demands.		0.12	3.87	0.46	0.23
1.4	Ease of operation, maintenance, and system management with local knowledge.		0.08	3.00	0.24	0.12
1.5	SPWP System integration with the grid or diesel system (Hybridization compatibility).		0.10	3.53	0.35	0.18
1.6	SPWP System installation complexity for the local experts.		0.10	3.07	0.31	0.15
	Total Result of the Design Tool at Domain-1					**1.71**
2	**Socio-Environmental Domain (Socio-Economic Aspect)**	**0.25**				
2.1	SPWPS infrastructure installation requirements social & environmental impacts (land, vegetation removal, waste material handling, etc.)		0.30	3.53	1.06	0.27
2.2	SPWPS end-users and other beneficiaries like technical personnel's satisfaction with the technology.		0.70	3.87	2.71	0.68
	Total Result of the Design Tool at Domain-2					**0.94**
3	**Economical Domain (Cost Aspect)**	**0.25**				
3.1	The SPWPS system full package installation investment cost concerning the national standard.		0.65	3.47	2.25	0.56
3.2	Yearly maintenance requirements and system-specific spare part availability in the local servicing market.		0.35	2.93	1.03	0.26
	Total Result of the Design Tool at Domain-3					**0.82**
	Total Result for the 3 domains from 5	**1.00**			-	**3.47**
	Total Result for the 3 domains from 100 %	**100.00**			-	**69.37**

Multicriteria Analysis (MCA) of the SPWPS deployed in a rural community using various design techniques (tools)						
The SPWPS Design Tools performance table presents a Multicriteria Analysis (MCA) result based on a simple additive weighting model.						
Table 3.6.4: Lorentz SPWPS Design Tool						
S/No	**Variable Description (Domain)**	**First Level weights (R)**	**Second Level Weights (w)**	**Average Scored Result of the Subdomain (x)**	**Weighted average Score of the subdomain at the Second Level**	**Weighted average Score of the subdomain at the First Level**
1	**Technical Domains (Technical Aspect)**	**0.50**				
1.1	Designed solar panel energy and pump efficiency against the running (actual) efficiencies of the installed SPWPS.		0.35	2.54	0.89	0.44
1.2	Communities' daily water demand versus supply concerning the national standard (water supply reliability).		0.25	2.54	0.63	0.32
1.3	Storage Capacity and daily production rate with the national guidelines to satisfy the community's daily water demands.		0.12	2.54	0.30	0.15
1.4	Ease of operation, maintenance, and system management with local knowledge.		0.08	2.54	0.20	0.10
1.5	SPWP System integration with the grid or diesel system (Hybridization compatibility).		0.10	2.54	0.25	0.13
1.6	SPWP System installation complexity for the local experts.		0.10	2.85	0.28	0.14
	Total Result of the Design Tool at Domain-1					**1.28**
2	**Socio-Environmental Domain (Socio-Economic Aspect)**	**0.25**				
2.1	SPWPS infrastructure installation requirements social & environmental impacts (land, vegetation removal, waste material handling, etc.)		0.30	2.69	0.81	0.20
2.2	SPWPS end-users and other beneficiaries like technical personnel's satisfaction with the technology.		0.70	3.08	2.15	0.54
	Total Result of the Design Tool at Domain-2					**0.74**
3	**Economical Domain (Cost Aspect)**	**0.25**				
3.1	The SPWPS system full package installation investment cost concerning the national standard.		0.65	2.62	1.70	0.43
3.2	Yearly maintenance requirements and system-specific spare part availability in the local servicing market.		0.35	2.38	0.83	0.21
	Total Result of the Design Tool at Domain-3					**0.63**
	Total Result for the 3 domains from 5	**1.00**			**-**	**2.66**
	Total Result for the 3 domains from 100 %	**100.00**			**-**	**53.17**

4. Design Tools employed in the study area

4.1. FDRE Ministry of Water and Energy SPWPS Design Tool

MWE-SW-RWS-Solar Pump-Deisgn Tool-21

RWSSSM Guideline final.pdf

4.2. Water Mission (WM) SPWPS Design Too

1-Water Mission Pump Design Tool (PI

2-Solar Rack Design Tool.xlsx

3-Financial Sustainability Worksh

4.3. Grundfos SPWPS Design Tool

Grundfos SOLAR-POWERED-61

4.4. Lorentz SPWPS Design Tool

Loretz SPWPS design Tool.pdf