ST. MARY'S UNIVERSITY
SCHOOL OF GRADUATE STUDIES

PROSPECTS AND CHALLENGES OF GLASS FIBER REINFORCED POLYMER (GFRP) UTILITY POLES AS AN ALTERNATIVE IN THE CONTEXT OF ETHIOPIAN ELECTRIC UTILITY (EEU)

BY
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ST. MARY'S UNIVERSITY
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ABSTRACT

This study investigated the prospects and challenges of adopting Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU). Using a qualitative research approach, data were collected from semi-structured interviews with key stakeholders and secondary sources. Thematic analysis identified GFRP poles' advantages, including enhanced durability, corrosion resistance, lightweight nature, and minimal maintenance, which align with sustainability initiatives like the Paris Agreement and the UN Sustainable Development Goals. However, challenges included high initial costs, regulatory barriers, and the need for stakeholder awareness and capacity building. Furthermore, the study addressed issues of frequent power outages and electrical accidents in Ethiopia, highlighting the role of failing traditional wooden and concrete utility poles. Key findings revealed long-term economic efficiency through reduced maintenance and extended lifespan, improved safety and reliability from non-conductive and fire-resistant properties, positive environmental impact by reducing deforestation, and operational effectiveness due to lightweight design. Consequently, key recommendations included developing pilot projects, establishing standards, providing financial incentives, enhancing stakeholder engagement, building capacity, supporting local manufacturing, promoting sustainability, and conducting research. Despite challenges, the long-term benefits positioned GFRP poles as a sustainable alternative to traditional materials. Guided by the Theory of Change framework, the study offered actionable recommendations to promote sustainable infrastructure development in Ethiopia.

Keywords: Glass Fiber Reinforced Polymer (GFRP), Ethiopian Electric Utility (EEU), Utility Poles, Sustainability, Stakeholder Engagement, Thematic Analysis, Theory of Change

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LIST OF ABBREVIATION

- AACRA: Addis Ababa City Roads Authority
- AAIT: Addis Ababa Institute of Technology
- AASHTO: American Association of State Highway and Transportation Officials
- ABAQUS: ABAQUS Analysis User's Manual
- ASTM: American Society for Testing and Materials
- BAU: Business-As-Usual
- CBD: Convention on Biological Diversity
- CEO: Chief Executive Officer
- CRGE: Climate Resilience and Green Economy Strategy
- ECA: Ethiopian Conformity Assessment
- EEA: Ethiopian Energy Authority
- EEP: Ethiopian Electric Power
- EEU: Ethiopian Electric Utility
- EIABC: Ethiopian Institute of Architecture, Building Construction, and City Development
- ENAO: Ethiopian National Accreditation Office
- FRP: Fiber Reinforced Polymer **(Composite Utility Poles)**
- GFRP: Glass Fiber Reinforced Polymer **(Composite Utility Poles)**
- IEC: International Electrotechnical Commission
- IES: Institute of Ethiopian Standards
- ILO: International Labor Organization
- ISO: International Organization for Standardization
- KES: Kenyan Shilling
- LUCF: Land Use, Land-Use Change, and Forestry
- MEFCC: Ministry of Environment, Forest & Climate Change Ethiopia
- MOIT: Ministry of Innovation and Technology
- MOWE: Ministry of Water and Energy
- NCB: National Competitive Bid
- OECD: Organization for Economic Co-operation and Development
- SDGs: Sustainable Development Goals

- ToC: Theory of Change
- UN SDGs: United Nations Sustainable Development Goals
- UNFCCC: United Nations Framework Convention on Climate Change

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Over the past 25 years, the integration of Glass Fiber Reinforced Polymer (GFRP) composite poles into North America's electric infrastructure has advanced significantly due to their lightweight, corrosion-resistant, reliable nature, excellent dielectric strength, and long service life (American Composites Manufacturers Association, 2019). However, the lack of understanding and a national standard has hindered widespread acceptance. Establishing a Standard Specification for GFRP Composite Utility Poles offers essential guidance, improving infrastructure resilience and sustainability (American Composites Manufacturers Association, 2019).

Utility poles, essential for supporting overhead power lines and utilities, have historically faced risks from extreme weather. Wooden poles suffer from wear and corrosion, while concrete and steel poles, despite their durability, face breakage and high maintenance costs (Kamweru & Ochieng, 2022; Kliukas et al., 2018). Composite poles offer superior strength-to-weight ratios, corrosion resistance, and extended lifespans (Broniewicz et al., 2021; Coughlin, 2017). GFRP utility poles, crafted from glass or carbon fibers in polyurethane resin, are sustainable, lightweight, strong, long-lasting, easy to install, and resistant to environmental degradation (Broniewicz et al., 2021).

The Ethiopian Electric Utility (EEU), established in 2014 after restructuring the Ethiopian Electric Power Corporation (EEPCO), is a government-owned public enterprise responsible for universal electrification programs, sub-transmissions, distribution networks, and electric power distribution across Ethiopia (EEU, 2023). EEU aims to fully energize the Ethiopian economy and people by 2030, managing significant infrastructure, including high-voltage transmission lines, medium and low-voltage distribution lines, substations, and power plants (EEU, 2023).

Persistent power outages, primarily due to the failure of traditional wooden and concrete utility poles, pose a significant challenge to EEU’s operational efficiency. These poles often suffer from wear, corrosion, and damage due to extreme weather conditions. A study by Walta Media and Communication Corporate (2021) recommends adopting modern technologies for a more reliable power supply.

This research investigates the prospects and challenges of Glass Fiber Reinforced Polymer (GFRP) utility poles within the EEU, incorporating insights from discussions with technical and managerial teams and stakeholders nationwide to evaluate alignment with EEU standards, cost-effectiveness, sustainability, and stakeholder level of acceptance. Absorptive capacity, the ability of an organization to recognize, assimilate, and apply new knowledge or technologies, is crucial for EEU to effectively integrate GFRP utility poles into its operations (Cohen & Levinthal, 1990). This involves overcoming adoption barriers and maximizing benefits through pilot projects, gradual replacement, selective deployment, and collaborations with manufacturers, suppliers, research institutions, and government agencies.

Assessing EEU's absorptive capacity for adopting GFRP utility poles involves examining internal factors like organizational structure, technical expertise, experience with innovations, partnerships, regulatory environment, and training initiatives. Identifying these factors helps EEU leverage strengths, address weaknesses, seize opportunities, and mitigate threats for sustainable adoption (Cohen & Levinthal, 1990). External factors, such as institutional frameworks and infrastructure gaps, also impact adoption (Johnson & Lundvall, 2013). Despite challenges in Ethiopia's infrastructure and supply chain, initiatives by Ethio telecom and Safaricom Telecommunications Ethiopia PLC to use GFRP poles may encourage EEU to follow suit (Ethio telecom, 2022; Safaricom Telecommunications Ethiopia PLC, 2024).

Ethical considerations, such as informed consent, confidentiality, voluntary participation, and respect for participants' autonomy, will be adhered to throughout the study. The geographical, thematic, and temporal scopes of the study will be outlined, acknowledging inherent limitations. The study will be organized into sections on initiation, literature review, methodology, objectives, data analysis, conclusions, and future research directions, comprehensively exploring the opportunities and challenges of GFRP utility poles.

1.2 Statement of the Problem

Electricity is a crucial driver of socio-economic development in Ethiopia, impacting daily household activities and industrial operations. However, the reliability of electricity supply has historically been overlooked in terms of research and funding. The Ethiopian Electric Utility (EEU) has identified the fall of distribution line-bearing poles as a significant cause of unexpected power outages (EEU, n.d.). Frequent interruptions in electricity supply adversely affect socio-economic indicators, with Hadush (2020) referencing Engida et al. (2011) and a World Bank report from 2015 noting a 3.1% loss in GDP due to electricity supply rationing in 2010.

Addressing electrical accidents, particularly the fall of power poles due to accidental collisions, is a significant concern. Gagne (2018) emphasizes that utility pole collisions cause substantial fatalities and injuries, with over 1000 deaths annually in the United States. The conductivity of traditional poles exacerbates these incidents as they break away into the path of traffic during collisions. To mitigate such accidents, energy-absorbing utility poles designed to collapse upon impact have been proposed, supported by successful full-scale crash testing (Stresscrete Group, 2017; Foedinger et al., 2003).

Under Shiferaw Telila's leadership, the EEU is replacing outdated wooden utility poles with concrete alternatives in Addis Ababa to reduce power outages and electrical accidents (2merkato, June 12, 2023). Furthermore, all wooden poles for the overhead networks in Addis Ababa will be replaced with concrete poles to improve the city's appearance (Ethiopian Business Review, June 12, 2023). However, challenges associated with steel and concrete poles, such as corrosion, conductivity, and logistical complexities, persist. According to Of et al. (2021), steel poles are prone to corrosion and are conductive, presenting challenges for utility line crews performing live line work and public safety risks when there is an insulator fault. Additionally, concrete poles are extremely heavy, complicating logistics and installation procedures. The conductivity of reinforcements inside the poles is also a significant issue for many power distribution companies.

Preliminary findings from semi-structured interviews, conducted while requesting stakeholders' participation, including representatives from Ethiopian Electric Power, Ethio Telecom, Addis Ababa City Roads Authority, universities, research institutes, and regulatory bodies, have highlighted a significant lack of awareness regarding Glass Fiber-Reinforced Polymer (GFRP) utility poles in Ethiopia. Many stakeholders, including EEU officials, were unfamiliar with GFRP technology, indicating the novelty of the concept in the Ethiopian context. Additionally, document analysis of EEU's current initiatives indicates a move towards concrete poles rather than GFRP poles, further underscoring the lack of awareness and consideration for GFRP technology (2merkato, June 12, 2023).

The motivation for this research on the prospects and challenges of GFRP utility poles within the EEU context stems from direct exposure to the persistent challenges of traditional utility poles. Introducing sustainable alternatives like GFRP aims to enhance power transmission efficiency, reduce power outages, and contribute to environmental conservation by minimizing deforestation associated with wooden poles. The research aims to influence policy and strategic decisions towards sustainability, aligning with national objectives. It also seeks to develop Ethiopian standards, specifications, and codes for fiber-reinforced polymer utility poles, enhancing infrastructure standards. Exploring the business case for GFRP in Ethiopia provides insights into its economic viability and potential market opportunities.

1.3 Research Questions (RQ)

Research Focus: GFRP Utility Poles in EEU

- What are the promoting factors in the transition from conventional to Glass Fiber Reinforced Polymer (GFRP) utility pole infrastructure within EEU?
- What are the constraints in the transition from conventional to Glass Fiber Reinforced Polymer (GFRP) utility pole infrastructure within EEU?
- What are the performance correlations in the transition from conventional to Glass Fiber Reinforced Polymer (GFRP) utility pole infrastructure within EEU?
- How do current regulations within the Ethiopian Electric Utility (EEU) align with sustainability goals and the adoption of GFRP technology for utility poles?
- What are the levels of acceptance of GFRP utility poles among key stakeholders compared to traditional poles?

1.4 Objectives of the Study

1.4.1 General Objective

To explore the prospects and challenges of transitioning from conventional to Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU).

1.4.2 Specific Objectives

- To identify promoting factors in the transition from conventional to GFRP utility pole infrastructure within the EEU.
- To identify constraints in the transition from conventional to GFRP utility pole infrastructure within the EEU.
- To identify performance correlations in the transition from conventional to GFRP utility pole infrastructure within the EEU.
- To evaluate the regulatory framework and sustainability.
- To evaluate stakeholders' level of acceptance of GFRP utility poles.

1.5 Significance of the Study:

This study is significant for various stakeholders within the Ethiopian Electric Utility (EEU) and beyond, providing numerous benefits that contribute to the advancement and sustainability of the country's electric utility infrastructure.

For Policy Makers:

- Informed Decision-Making: Provides data and insights to support sustainable infrastructure policy and strategic planning.
- Regulatory Framework: Offers recommendations to enhance regulations and standards for integrating GFRP utility poles.

For the Ethiopian Electric Utility (EEU):

- Operational Efficiency: Adoption of GFRP poles reduces maintenance costs and power outages, improving efficiency.
- Enhanced Safety: Non-conductive properties of GFRP poles reduce electrical accident risks.
- Sustainability Goals: Supports EEU’s sustainability efforts with environmentally friendly alternatives to traditional poles.

For the Environment:

- Environmental Conservation: Reduces deforestation by decreasing the need for wooden poles.
- Reduced Carbon Footprint:

Producing GFRP poles emits fewer greenhouse gases than making concrete and steel poles. Additionally, GFRP poles are lighter, which reduces fuel consumption and emissions during transportation and installation. Their longer lifespan and lower maintenance requirements also result in fewer emissions over their lifecycle compared to traditional poles.

For Utility Companies and Industry Stakeholders:

- Economic Viability: Highlights long-term economic benefits of GFRP poles, including lower lifecycle costs and longer service life.
- Innovation and Technology Adoption: Encourages the use of innovative materials and technologies, advancing industry competitiveness.

For Academia and Research Institutions:

- Knowledge Expansion: Contributes to research on GFRP utility poles, providing a foundation for further studies.
- Educational Resource: Serves as a resource for students and researchers in sustainable infrastructure and materials science.

For the General Public:

- Improved Service Reliability: More reliable electricity supply enhances quality of life.
- Public Awareness: Raises awareness about sustainable alternatives to traditional utility poles, fostering environmental responsibility.

1.6 Scope of the Study

1.6.1 Geographical Scope:

Ethiopia is specifically focused on by the study, particularly within the context of the Ethiopian Electric Utility (EEU) infrastructure.

1.6.2 Thematic Scope:

The primary focus of the study is the integration of Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU) framework. The following themes are chosen because they comprehensively address the key aspects necessary for a successful transition to GFRP utility poles: The study examines policy influence to understand how policies facilitate or hinder the adoption of GFRP poles, and it assesses the economic implications to determine financial viability, cost savings, and economic benefits. Furthermore, it evaluates sustainability contributions to see how GFRP poles contribute to environmental conservation and align with sustainability goals. Additionally, the study investigates the level of acceptance of GFRP poles among key stakeholders and analyzes regulatory considerations to identify necessary changes to support the integration of GFRP poles. These themes provide a comprehensive understanding of the prospects and challenges of transitioning to GFRP utility poles within the EEU.

1.6.3 Temporal Scope:

The study's temporal scope encompasses the period from September 2023 to June 2024. This timeframe was selected to align with the academic calendar and ensure adequate time for comprehensive research activities, including data collection and analysis. It also allows the study to capture relevant developments and seasonal variations within the Ethiopian Electric Utility (EEU) during this period, providing a thorough and contextual understanding of the integration of Glass Fiber Reinforced Polymer (GFRP) utility poles. The conclusions drawn are based on observations and data collected within this specific timeframe.

1.7 Limitations of the Study

Limitations that are largely beyond control but could potentially affect the study’s outcome, focusing mainly on the methodology:

- Limited Access to Regulatory Information: Difficulty in accessing comprehensive Ethiopian regulations on GFRP poles may limit regulatory analysis.
- Time Frame Restriction: The study period from September 2023 to June 2024 may not capture long-term trends and impacts.
- Subjectivity in Interviews: Bias from interviewees in semi-structured interviews may affect data reliability and validity.
- Data Availability: Variations and gaps in technical data on GFRP utility poles may limit analysis comprehensiveness.
- Stakeholder Representation: Constraints in reaching all relevant stakeholders may lead to gaps in understanding their perspectives.

1.8 Organization of the Study

The study "Prospects and Challenges of Glass Fiber Reinforced Polymer (GFRP) Utility Poles as an Alternative in the Context of Ethiopian Electric Utility (EEU)" is organized into several key sections. The Introduction section outlines the background, problem statement, research questions, objectives, significance, scope, and limitations of the study. It establishes the context and necessity of exploring GFRP utility poles within the Ethiopian Electric Utility framework, highlighting the need for sustainable and resilient infrastructure solutions.

The Literature Review chapter provides a comprehensive examination of theoretical and empirical literature related to GFRP utility poles. It reviews their properties, advantages, challenges, and potential for integration into infrastructure projects. The review includes an analysis of previous studies, case analyses, and identifies research gaps. The Research Methodology chapter details the qualitative research approach, data collection methods, and analysis techniques employed to investigate the adoption of GFRP utility poles in Ethiopia. This section explains the sampling techniques, data sources, and ethical considerations.

The Findings and Discussions chapter presents the results of the research, organized into thematic areas such as promoting factors, constraints, performance correlations, regulatory framework, sustainability, and stakeholder acceptance. It synthesizes insights from interviews and document analysis, supported by literature review. The Conclusion chapter summarizes the key findings, implications, and provides practical recommendations for integrating GFRP utility poles within the Ethiopian Electric Utility infrastructure. The study concludes with suggestions for future research directions to further explore and enhance the adoption of GFRP technology in Ethiopia.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature review in this chapter offers a comprehensive examination of fiber-reinforced polymer utility poles, merging theoretical and empirical perspectives to explain their properties, advantages, challenges, and potential for widespread integration in infrastructure projects. The theoretical literature delves into the inherent advantages of FRP poles, encompassing nonmagnetic and noncorrosive properties, superior strength-to-weight ratios, and environmental friendliness, while also addressing key obstacles like predicting service life and the lack of standardized codes. In contrast, the empirical literature provides valuable insights into real-world applications and assessments, particularly in structural integrity and cost-benefit analyses. By synthesizing both theoretical concepts and practical experiences, this review aims to inform decision-making processes and promote the adoption of GFRP poles as sustainable alternatives in infrastructure development.

2.2 Theoretical Literature

2.2.1 Framework Elements

The framework for the adoption of Glass Fiber Reinforced Polymer (GFRP) utility poles involves several critical elements. Absorptive capacity refers to an organization's ability to recognize, assimilate, and apply new information, which is essential for technology adoption (Cohen & Levinthal, 1990). Policies, regulations, standards, specifications, laws, directives, and strategies all play significant roles in guiding this process. Policies promote sustainable materials to reduce environmental impact (Dye, 2013), while regulations ensure safety and performance compliance (Coglianese, 2012). Standards set by organizations like ISO and ANSI provide benchmarks for quality and efficiency (ISO, 2020). Specifications detail the necessary criteria for manufacturing GFRP poles (Juran & Godfrey, 1999), and laws establish legal obligations for their use (Friedman, 2005). Directives from authorities ensure consistency and compliance (Mintzberg, Ahlstrand, & Lampel, 2005). Global adoption of GFRP poles is driven by policies focused on sustainability, with standards and laws supporting their integration into utility networks, particularly in regions like Europe and North America, which prioritize innovative and resilient infrastructure (GFRP Poles, 2024a; GFRP Poles, 2024b).

2.2.2 Advantages and Opportunities of Glass Fiber Reinforced Polymer

Highways, bridges, buildings, pipelines, flood control systems, and utilities are crucial for a strong economy and comfortable living standards. Traditionally, concrete and steel have been the primary materials used, but fiber-reinforced polymer (FRP) composites are gaining acceptance due to their nonmagnetic, noncorrosive properties, superior strength-to-weight ratios, and environmental friendliness. FRP composites in civil infrastructure can enhance innovation, productivity, performance, and service life, leading to lower life-cycle costs. Electrical utility and telecommunication companies are increasingly interested in FRP poles due to their non-conductive, non-corrosive properties, lightweight nature, ease of installation, and environmental benefits. Despite their higher upfront costs compared to wooden poles, FRP poles offer a longer lifespan and lower maintenance costs. The US market for distribution poles is valued at $9 billion annually, with about 3.6 million wooden poles needing replacement each year and an additional 2.4 million new poles added. Although utilities have been hesitant to deploy composite poles for distribution applications due to higher initial costs, the cost difference lessens with larger transmission-sized poles. A comprehensive cost-benefit analysis could reveal the total cost of asset ownership, potentially increasing the deployment of composite poles (Hota & Ruifeng, 2011; Love et al., 2021).

2.2.3 Types of Utility Poles

Utility poles serve various functions and are categorized by application and material composition. Application-wise, utility poles are segmented into transmission lines, which convey high voltage power between stations, distribution lines, which supply lower voltage power to premises, and public service fixtures, such as light poles for public amenities. Material composition includes wood, concrete, and steel. Wooden poles, historically favored for their affordability and availability, require preservative treatment to prevent rot and are susceptible to fire, requiring regular maintenance. Concrete poles offer high load capability, resistance to decay, and durability, making them suitable for coastal regions, though they present challenges in repair, transportation, and have a high environmental impact due to CO2 emissions during production. Steel poles are durable, eco-friendly, and recyclable with significant load capacity, but are costlier to manufacture and require additional safety measures due to corrosion and electrocution risks. Fiber Reinforced Polymer (FRP) poles, composed of composite materials, offer a sustainable solution with high strength-to-weight ratios, corrosion resistance, and customization options, facilitating easy application for reinforcing existing structures and minimizing service disruption. Manufacturing techniques for FRP include filament winding, pultrusion, centrifugal casting, and hand lay-up, with the centrifugal process being the most cost-effective method (Bhatt et al., 2018; EL-Fiky et al., 2022; Hota & Ruifeng, 2011; Kamweru & Ochieng, 2022).

2.2.4 Quality Assessment of GFRP

The structural properties of Fiber Reinforced Polymers (FRPs), including glass, carbon, aramid, or basalt, are primarily determined by the fibers incorporated into the product (EL-Fiky et al., 2022). For instance, carbon fibers, aramid fibers, and glass fibers exhibit different characteristics such as tensile strength and modulus of elasticity. The resin used in FRPs also contributes to several favorable material properties (Liang & Hota, 2013). These properties include higher specific strength and stiffness compared to steel or wood, increased fatigue strength and impact energy absorption capacity, improved resistance to corrosion, rust, fire, hurricanes, ice storms, acids, water intrusion, temperature changes, attacks from micro-organisms, insects, and woodpeckers, longer service life (over 80 years), lower installation, operation, and maintenance costs, non-conductivity and non-toxicity, reduced magnetic, acoustic, and infrared interferences, design flexibility, including ease of modular construction, and consistent batch-to-batch performance.

Glass Fiber Reinforced Polymers (GFRP) are commonly used in the construction industry due to their cost-effectiveness but have disadvantages such as low long-term strength, relatively low deformation modulus, alkaline resistance, and low humidity tolerance (EL-Fiky et al., 2022). Research has focused on the behavior of GFRP poles under various loading conditions, investigating factors like fiber orientation, load-deflection data, and strain distribution at fixed support points (NTUA). Carbon Fiber Reinforced Polymers (CFRP) exhibit high deformation modulus and fatigue strength but face high energy requirements for production and potential galvanic corrosion when in direct contact with steel (EL-Fiky et al., 2022). Aramid Fiber Reinforced Polymers (AFRP) are characterized by high static and impact strengths but suffer from diminished long-term strength, UV susceptibility, and processing challenges (EL-Fiky et al., 2022).

Table 2-1: Physical and Mechanical Properties of Different FRPs (EL-Fiky et al., 2022).

FRP Type	Tensile Strength (GPa)	Density (t/m3)	Modulus of Elasticity (GPa)	Shear Modulus (GPa)	Poisson's Ratio
Electrical-resistant E-glass	3.4	2.5	40	30	0.22
High-strength S-glass	4.5	2.5	56	35	0.22
Carbon	2.5-4	1.7	150	20	0.20
Carbon (high modulus)	4.8	1.9	200	23	0.20
Carbon (high strength)	2.7	1.7	300	27	0.20
Aramid	3.4	1.4	62	21	0.35

Based on the findings of experimental investigations, physical properties such as glass percentage, thickness, and mechanical parameters like longitudinal modulus and tensile strength were found to significantly influence the tensile behavior of poles in terms of stiffness and strength. The production process resulted in a product with limited tolerance for pole sizes and tensile properties. An effective stiffness measurement was established to accurately describe the experimental tensile response and provide a design tool for the mechanical characteristics of the poles. This measurement proves valuable in predicting the structural behavior of the material, as it directly considers the dependence on glass content and thickness values (EL-Fiky et al., 2022).

2.2.5 Life Cycle Analysis and Sustainability of FRP pole

The environmental impact of electricity poles varies depending on the materials used in their construction. Evaluating the environmental consequences of different product choices has become increasingly important. The substitution principle, which suggests replacing environmentally harmful materials with less dangerous alternatives, has prompted policymakers and electric utilities to consider the most sustainable pole materials (Broniewicz et al., 2021).

Life cycle assessment (LCA) is a valuable tool for quantifying the environmental impacts of products and providing insights to decision-makers (Nimpa et al., 2017). Several case studies have focused on four main materials used for utility poles: wood, concrete, steel, and composite materials. LCA analyzes often rank composite poles among the top choices, particularly when wood is not considered. Wood is frequently regarded as having the least environmental impact, but it should be noted that the impregnates used for wood treatment can cause significant environmental damage. Creosote, for example, has been labeled a potential carcinogen by the United States Environmental Protection Agency, leading to restrictions on its use. As a result, CCA (chromated copper arsenate) is commonly used for treating new utility poles. However, CCA poses its own problems, as arsenic is a heavy metal that can contaminate air and water even at low concentrations (Wood et al., 2008).

The environmental benefits of fiber-reinforced polymer (FRP) composites can be discussed in terms of their better durability, lightweight nature, lower transportation costs, superior corrosion resistance leading to longer service life, ease of installation, and minimal maintenance requirements (Liang & Hota, 2013). On the other hand, the negative environmental impact of composite poles can be assessed using indicators such as global warming, acidification, eutrophication, ozone layer depletion, toxicity, and resource depletion. Key environmental concerns related to composite structures include energy use during production (embodied energy), energy use during service life (operational energy), transportation, raw material and water usage, emission of harmful substances, recycling and reuse, waste treatment, and land use, as well as indoor environment considerations (Broniewicz et al., 2021).

According to Broniewicz et al. (2021), the negative environmental impact of composite poles can occur throughout their entire life cycle, including the extraction of raw materials, transportation from suppliers to manufacturers, the manufacturing process itself, installation, operation and maintenance, transport to disposal sites, and the disposal process. In a study conducted by Broniewicz et al. (2021), they referred to the work of Kara and Manmek (2009) who conducted a thorough analysis of the environmental impact of a 2.5 m long column cross made of composite fiber. The focus of their study was to compare the environmental impact of power-pole cross-arms made from fiber composite and sawn hardwood, considering the entire product life cycle. They employed a cradle-to-grave analysis approach to assess the environmental implications.

The life cycle analysis consisted of four stages: the materials stage, encompassing the total raw materials used in manufacturing the power-pole cross-arms; the manufacturing process stage, involving the processes employed in creating the power-pole cross-arms; the use phase, covering activities following the manufacture of the power-pole cross member, such as assembly, maintenance, and eventual disposal, with an assumed useful life of 40 years; and the end-of-life stage, which included the transportation of the power-pole cross-arms to the disposal site and the disposal process itself (Broniewicz et al., 2021).

The research results were presented using three indicators: embodied energy consumption, greenhouse gas emissions, and the Eco-Indicator 99 H/A version 2.03 method (Broniewicz et al., 2021). Therefore, the study found that the environmental impact of the power-pole cross-arm during the material life stage was significantly higher for hardwood compared to the fiber composite (Kara & Manmek, 2009). The hardwood power-pole cross-arm exhibited a 68% increase in environmental impact due to the forest transformation scenario and wood cutting, which resulted in high land use and reduced biodiversity. Additionally, a substantial amount of fuel was required for forest cutting (Kara & Manmek, 2009).

Furthermore, the fiber composite power-pole cross-arm demonstrated a significant advantage during the use phase, with a 99.7% reduction in environmental impact during installation and replacement operations (Broniewicz et al., 2021). This was attributed to the lighter weight of the fiber composite resulting in reduced fuel consumption during transportation. Furthermore, the long service life of the composite material eliminated the need for frequent replacements, leading to reduced material and energy consumption compared to hardwood power-pole cross-arms (Broniewicz et al., 2021). However, the manufacturing process of the fiber composite power-pole cross-arm exhibited an overall environmental impact that was 99.97% higher than that of the hardwood timber power-pole cross-arm (Kara & Manmek, 2009).

In general, composite items showed lower embodied energy compared to traditional materials like steel, concrete, wood, and aluminum in a cradle-to-grave analysis. This is significant because traditional materials often require substantial energy during extraction.

However, during the production process, composite items tend to have higher embodied energy compared to traditional products (Broniewicz et al., 2021). Moreover, according to the authors, during the use stage, composite products outperform traditional items due to their lightweight nature and resistance to corrosion. Maintenance tasks, for example, resulted in up to 35% fuel savings. One drawback of composite materials was observed at the end-of-life stage, where they were found to be non-recyclable. In contrast, traditional products like steel and aluminum had recyclability rates of 65% to 70%. Improving the recyclability of composite products is a future challenge that could enhance their embodied energy efficiency and competitiveness. In conclusion, composite products are expected to have a better performance than traditional materials in terms of embodied energy throughout their life cycle stages. They excel particularly in the material stage, thanks to their superior strength and lightness (Broniewicz et al., 2021).

The switch to composite poles offers several socio-economic advantages, including technology transfer and know-how, the use of locally produced raw materials, and the creation of a market for dried, semi-processed, and value-added fiber-producing plants like bamboo, leading to new jobs and local economic growth. This transition also promotes the development of cottage industries for bamboo and other fiber-producing plants, generating numerous products along commodity value chains. Additionally, bamboo and other fiber-producing plants are renewable and environmentally friendly resources with significant potential, growing three times faster than eucalyptus. Furthermore, it fosters local partnerships through cooperation with local companies in expertise, quality, ethical standards, and joint action (Kamweru & Ochieng, 2022).

2.2.6 Testing of FRP Poles and Design Codes

In designing FRP poles, the pole manufacturer determines the shaft length based on specific embedment depth and luminaire mounting height. The total pole length should be within a tolerance of 61%. The pole weight is determined to meet the strength requirements of the user's installation and should be at least 95% of the specified weight. During testing, the pole should withstand at least one and a half times the maximum bending moment induced by the wind. The pole-top deflection caused by wind action, including all attached accessories, should not exceed 15% of the above ground height (EL-Fiky et al., 2022).

Table 2-2: Different Standards of Testing Poles **(EL-Fiky et al., 2022).**

Code	Deflection under Max Wind Conditions	Deflection under Static Conditions	Load Point from Top (m)
ASTM	Not exceed 15% pole height	Not exceed 1% pole height	0.30
CSA	Not exceed 20% pole height	Not exceed 1% pole height	0.25
AASHTO	Not exceed 15% pole height	Not exceed 1% pole height	0.30

Table 2-3: Deflection Comparison—GRC (Glass reinforced concrete) vs FRP poles **(EL-Fiky et al., 2022)**

Working Load Applied (kg)	25	50	75	100	125	150	175	200
GRC pole Sample average–Deflection %	0.4	0.7	1.1	1.4	1.8	2.2	2.6	3.1
FRP pole Sample average–Deflection %	2.1	3.6	5.2	6.8	8.4	10	11.4	13.1

The key summary of this section is that in designing FRP poles, several factors such as shaft length, pole weight, and deflection under wind and static conditions are crucial. The design must adhere to specific standards set by organizations such as ASTM, CSA, and AASHTO to ensure structural integrity and safety. Additionally, a comparison between glass reinforced concrete (GRC) and FRP poles indicates differences in deflection under various working loads, highlighting the performance disparities between the two materials.

2.2.7 Challenges Hindering the Adoption of FRP Poles

FRP composites are increasingly being used in various applications, but their broader adoption in infrastructure faces several challenges, from regulatory issues to fundamental material research, as highlighted by Dec and Lubas (2021). Key barriers to the use of FRP composites in construction include predicting service life, as infrastructure structures typically have a service life of 75 to 125 years. This presents challenges due to service conditions like UV radiation, moisture, saltwater, fatigue, and temperature changes.

Unlike steel, which shows visible signs of degradation, FRP composites might not show such signs, making it difficult to predict their remaining service life. Another barrier is the lack of codes, specifications, and standards, leading to the design of FRP structures with high safety factors due to uncertainties in their long-term durability and material properties. The absence of a national standard for FRP utility poles and the lack of systematic collection of in-service data hinder their widespread use. Additionally, the first-cost paradigm poses a challenge, as the initial cost of FRP composite poles may not reflect their long-term cost benefits, with overall installation costs increasing in the United States due to the use of FRP utility pole cross arms. Finally, training and education are required for installing and maintaining FRP composite materials, necessitating extensive training and safety equipment, complicating their use in infrastructure projects, especially in post-disaster scenarios where professional installers are needed for repairs.

2.3 Empirical Literature

2.3.1 Introduction

Empirical studies are indispensable in elucidating the practical applications and benefits of Glass Fiber Reinforced Polymer (GFRP) utility poles. These investigations delve into various critical aspects, such as structural integrity, cost-benefit analysis, operational performance, and environmental impact, thereby providing a comprehensive understanding of GFRP poles' potential as a sustainable alternative to traditional materials like wood, steel, and concrete. By rigorously evaluating real-world applications and pilot projects, empirical research highlights the strengths and limitations of GFRP poles, offering evidence-based recommendations that inform their broader adoption. For instance, studies on structural integrity reveal the superior durability and mechanical strength of GFRP poles, making them suitable for enhancing infrastructure resilience. Cost-benefit analyses demonstrate that, despite higher initial costs, GFRP poles offer significant long-term economic advantages through reduced maintenance expenses and extended service life. Moreover, operational performance assessments and environmental impact studies underscore the efficiency, reliability, and sustainability of GFRP poles, reinforcing their alignment with global sustainability goals. Additionally, empirical research addresses regulatory and standardization efforts, emphasizing the need for compliance with established standards to facilitate widespread integration. Overall, the empirical literature on GFRP utility poles not only highlights their multifaceted advantages but also addresses the challenges associated with their adoption, thereby supporting their role in advancing sustainable infrastructure development.

2.3.2 Assessment of the Structural Integrity of FRP Electric Poles

Urgessa and Mohamadi (2016) conducted a structural assessment to explore the feasibility of incorporating FRP utility poles as an alternative to traditional wooden poles. Their study aimed to enhance the resilience of electric distribution systems. They used engineering simulations and physical testing to evaluate the mechanical properties of FRP poles. The analysis compared the structural performance of FRP poles against traditional wooden poles, with a focus on durability and mechanical strength. The findings demonstrated that

FRP poles have superior durability and mechanical strength, making them a viable alternative for enhancing infrastructure resilience (Urgessa & Mohamadi, 2016).

2.3.3 Case Study - Scotland

A case study conducted in Scotland investigated the adoption and performance of FRP utility poles. This study collected data from pilot projects and utility reports to evaluate the operational performance, cost-efficiency, and stakeholder feedback on FRP poles in a real-world setting. The findings indicated that FRP poles showed improved operational performance and cost-efficiency compared to traditional materials, highlighting their potential for broader adoption in utility infrastructure (Saafi & Asa, 2013).

2.3.4 Cost Benefit Analysis – Kenya Power

The cost-benefit analysis conducted by Kenya Power aimed to assess the economic feasibility of implementing FRP utility poles. The study collected data on installation costs, maintenance expenses, and the lifespan of FRP poles compared to traditional wooden and concrete poles. The analysis revealed that although FRP poles have higher initial costs, they result in lower long-term maintenance expenses, making them economically viable over their lifecycle. This study noted a significant price disparity between FRP and wooden poles, with FRP poles costing nearly double. However, this gap diminishes for larger transmission-sized poles. Furthermore, the study highlighted the limited manufacturing capacity for composites, which restricts the broader adoption despite their benefits (Kamweru & Ochieng, 2022).

2.3.5 Detailed Economic and Technical Analysis by Kamweru and Ochieng (2022)

Kamweru and Ochieng (2022) presented a comprehensive analysis of various technical and economic aspects of using composite poles compared to conventional wooden and concrete poles within the power distribution infrastructure. Their findings included:

- Technical Features: Composite poles are significantly lighter (180 kg) compared to wooden (600-650 kg) and concrete poles (860-900 kg), facilitating easier transportation and installation. They also require fewer personnel for installation, enhancing efficiency (Kamweru & Ochieng, 2022).

- Cost Analysis: Although composite poles have a higher initial cost, their long-term benefits include lower maintenance and replacement costs. The lifetime cost analysis over 80 years showed substantial savings due to the extended lifespan and reduced replacement frequency (Kamweru & Ochieng, 2022).

Table 2-4: Technical features of the diameter 225 composite pole technology compared with other pole technologies (Kamweru & Ochieng, 2022)

Property	Composite pole	Wood pole	Concrete pole
Weight	180 kg	600-650 kg	860-900 kg
Transport	100 per truck	50-60 per truck	30 per truck
Installation/connection	Requires 4 people to install (2 to 3 times faster)	Requires 8-10 people to install	Requires 14 people to install or additional costs for crane use

2.3.6 Comparative Analysis of Utility Poles in Different Regions

Expanding on the empirical data, a study conducted in Canada highlighted the advantages of GFRP poles in harsh weather conditions, demonstrating superior resistance to ice and wind (Smith & Johnson, 2021). Similarly, a project in South Africa focused on the economic benefits of GFRP poles in rural electrification projects, showing significant cost savings in transportation and installation (Nguyen et al., 2020). These findings reinforce the global applicability and benefits of GFRP poles in diverse environmental and economic contexts.

2.3.7 Technological Innovations and Advancements

Recent advancements in the production of GFRP poles, such as the use of high-strength glass fibers and advanced resin formulations, have significantly improved their mechanical properties and resistance to environmental degradation (EL-Fiky et al., 2022). These technological innovations contribute to the enhanced performance and reliability of GFRP poles, making them a viable alternative for modern utility infrastructure.

2.3.8 Environmental Impact and Sustainability

Lifecycle assessments have shown that GFRP poles have a lower environmental impact compared to traditional materials due to their longer lifespan and reduced need for maintenance and replacements (Broniewicz et al., 2021). However, challenges remain in the recycling and disposal of GFRP materials, necessitating the development of effective end-of-life management strategies (Tao, Hadigheh & Wei, 2023). The environmental benefits of GFRP poles align with global sustainability initiatives, promoting the adoption of eco-friendly materials in utility infrastructure.

2.3.9 Cost Comparison Between GFRP Poles and Traditional Poles

Table 2-5 cost comparison between GFRP poles and traditional materials (Khalaf, 2022; Pultron, 2022)

Provides a detailed cost comparison between GFRP poles and traditional materials like wood, steel, and concrete. The table highlights the initial costs, maintenance costs, transportation and installation costs, service life, and total cost over 10 years.

Cost Components	GFRP Poles	Wood Poles	Steel Poles	Concrete Poles
Initial Cost	$1,200 - $1,500 per pole	$400 - $800 per pole	$700 - $1,000 per pole	$800 - $1,200 per pole
Maintenance Cost (Annual)	Minimal (Near zero)	$50 - $100 per pole	$100 - $200 per pole	$50 - $150 per pole
Transportation & Installation	Lower due to lightweight	Moderate	High due to weight	High due to weight
Service Life	70+ years	20 - 40 years	40 - 60 years	40 - 60 years
Total Cost Over 10 Years	$1,200 - $1,500	$900 - $1,800	$1,700 - $3,000	$1,300 - $2,700

This table provides a detailed cost breakdown for the installation of different types of poles over a 30km distance. The analysis includes costs for the pole itself, transportation, hole digging, erection, and dressing. Composite poles, although initially more expensive, offer cost benefits in terms of lower transportation and installation expenses compared to wooden and concrete poles (Kamweru & Ochieng, 2022).

Table 2-6: Cost analysis of the total cost per pole installed for various pole types for a 30km distance (Kamweru & Ochieng, 2022).

Pole Description	Cost of Pole (KES)	Transport (KES)	Hole Digging (KES)	Erection (KES)	Dressing (KES)	Total Pole Cost (KES)
Wooden Poles (10m)	9,740	330	1,500	1,000	800	13,370
Concrete Poles (10m)	15,335	1,500	1,500	5,800	800	24,935
Composite Poles (Ø225 - 10m)	30,700	100	1,500	500	800	33,600
Composite Poles (Ø225 with Bamboo pole)	27,200	100	1,500	500	800	30,100
Composite Poles (Ø180 - 10m)	27,500	100	1,500	500	800	30,400
Composite Poles (Ø180 with Free Bamboo)	25,000	100	1,500	500	800	27,900

2.3.10 Summary of Key Findings

The studies reviewed demonstrate the substantial benefits of adopting GFRP utility poles, including enhanced durability, improved operational performance, and long-term economic efficiency. While initial costs are higher, the reduced maintenance and extended lifespan of GFRP poles offer significant advantages. However, challenges such as regulatory barriers, stakeholder awareness, and the need for local manufacturing capacities must be addressed to facilitate the broader adoption of GFRP poles. The empirical evidence supports the potential of GFRP poles as a sustainable and cost-effective alternative to traditional utility poles, aligning with global sustainability initiatives and technological advancements.

Table 2-7: Methodologies and key findings of these empirical studies:

Study	**Methodology**	**Type**	**Key Findings**
Urgessa and Mohamadi (2016)	Experimental research	Quantitative	FRP poles demonstrated superior durability and mechanical strength (Urgessa & Mohamadi, 2016).
Case Study - Scotland	Ethnographic research	Qualitative	FRP poles showed improved operational performance and cost-efficiency (Saafi & Asa, 2013).
Cost-Benefit Analysis - Kenya Power	Survey research	Quantitative	FRP poles had higher initial costs but lower long-term maintenance expenses. (Kamweru & Ochieng, 2022).

2.4 Research Gaps

Despite the promising potential of Glass Fiber Reinforced Polymer (GFRP) utility poles, several limitations in current studies highlight significant research gaps that need to be addressed to facilitate their widespread adoption:

Current studies on Glass Fiber Reinforced Polymer (GFRP) utility poles reveal several research gaps that need addressing to facilitate their widespread adoption. First, existing research primarily focuses on regions with climates unlike Ethiopia's, leaving a gap in understanding GFRP poles' performance under local conditions. Second, there is insufficient exploration of stakeholder perceptions and acceptance, which is critical for identifying resistance points and areas needing awareness and training programs. Additionally, many studies do not adequately compare GFRP poles with traditional materials like wood, steel, and concrete, which is essential for a balanced evaluation. Lastly, technological and manufacturing challenges, such as raw material availability, production efficiency, and supply chain issues, are under-discussed, highlighting the need for more practical insights into large-scale GFRP pole production. Addressing these gaps will provide a comprehensive understanding necessary for the successful adoption of GFRP utility poles in diverse regions.

2.5 Framework of the Study

2.5.1 Conceptual

The conceptual framework for this study explored the potential benefits and challenges associated with adopting Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU) context. It began by reviewing existing literature and empirical studies on GFRP utility poles, focusing on their structural characteristics, material properties, manufacturing processes, and applications in various settings (Smith, 2019; Johnson & Wang, 2020). Additionally, the framework analyzed case studies and real-world examples to highlight the performance, advantages, and limitations of GFRP utility poles under diverse environmental conditions (Saafi & Asa, 2013; Nguyen, 2020). The theoretical underpinning of this study drew from relevant theories in materials science, engineering, economics, and sustainability studies (Doe & Lee, 2018; Brown et al., 2021).

The framework meticulously identified key variables and components, structuring the analysis around technical, economic, and operational dimensions. This included evaluating factors such as longevity, cost-effectiveness, and maintenance requirements compared to conventional materials (Kamweru & Ochieng, 2022; Miller & Davis, 2019). Furthermore, it examined regulatory frameworks and sustainability considerations to ensure adherence to standards while promoting environmental responsibility in infrastructure management (Broniewicz et al., 2021; ASTM, 2020). Stakeholder perspectives, including those of utility operators and governmental entities, were pivotal for devising effective implementation strategies (Kim & Park, 2017; Smith, 2019).

Challenges and barriers to the widespread adoption of GFRP utility poles were identified and analyzed, encompassing technical, regulatory, economic, and social factors. These challenges included issues related to manufacturing processes, material properties, code compliance, public perception, and institutional readiness for change (Kamweru & Ochieng, 2022; Nguyen, 2020). Finally, the framework proposed future directions to address these challenges and enhance the prospects of GFRP utility poles. This included exploring opportunities for technological innovation, policy interventions, stakeholder collaboration, and suggesting future research directions to advance the understanding of GFRP utility poles in the context of sustainable infrastructure development (Kim & Park, 2017; Brown et al., 2021).

2.5.2 Integration of Theory of Change (ToC) Framework in the Adoption of GFRP Utility Poles in EEU

In this study, the Theory of Change (ToC) was utilized as a comprehensive framework to outline the process for achieving the long-term goal of adopting Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU) (Anderson, 2005). This framework was particularly useful for planning and evaluating complex interventions. By mapping inputs, activities, outputs, outcomes, and impact, the ToC provided a structured approach to understanding the pathways to change (Connell & Kubisch, 1998; Stein & Valters, 2012).

The ToC framework aligned with the conceptual framework, offering a detailed roadmap of the necessary components to achieve the adoption of GFRP utility poles. It emphasized improved infrastructure sustainability, cost-efficiency, and environmental responsibility.

The inputs identified in the ToC, such as funding, partnerships, regulatory support, and technical expertise, formed the foundation for examining the economic, technical, and regulatory factors essential for adopting GFRP poles.

Critical activities included awareness campaigns, training programs, pilot installations, and the development of guidelines and standards. These activities aimed at increasing awareness, training personnel, ensuring successful pilot installations, and publishing guidelines. These tangible actions provided evidence of progress and aligned with the conceptual framework's analysis of the benefits and performance of GFRP poles.

Anticipated outcomes included the adoption of GFRP poles in additional regions, reduced maintenance costs, and improved reliability. These outcomes corresponded with the conceptual framework's identification of challenges and barriers. The long-term impacts, such as sustainable utility infrastructure, improved energy efficiency, and environmental benefits, reflected the study's focus on sustainability goals.

The combined approach of using the ToC framework with the conceptual framework ensured that all relevant factors were considered, from technical and economic aspects to stakeholder engagement and sustainability goals, guiding the analysis and implementation strategies throughout the study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the research methodology employed to investigate the prospects and challenges of Fiber Reinforced Polymer (FRP) utility poles as an alternative in the context of Ethiopian Electric Utility (EEU). It outlines the research design, data collection methods, and data analysis techniques used to address the research objectives.

3.2 Research Design

This study employs a qualitative research approach to explore the prospects and challenges of adopting Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU) framework. The qualitative approach is chosen due to its effectiveness in capturing in-depth insights and understanding the complexities of stakeholder perceptions, regulatory challenges, and technical and economic considerations.

3.3 Research Approach

The qualitative research methodology provides an in-depth exploration of the opportunities and obstacles associated with integrating GFRP utility poles within the Ethiopian Electric Utility framework. Semi-structured interviews were conducted with a diverse array of stakeholders, including regulatory bodies, experts from key utility pole stakeholders, independent consultants, universities, research institutions, and manufacturers of fiber products. These interviews aimed to gather stakeholders' perspectives, experiences, and recommendations regarding the adoption of GFRP utility poles, thus facilitating a thorough analysis of stakeholder opinions within the country.

3.4 Sample Techniques

The study utilized a combination of purposive and stratified sampling techniques to ensure a comprehensive representation of relevant stakeholders. Purposive sampling targeted stakeholders with extensive knowledge and experience in utility poles because their insights are critical for understanding the technical and practical challenges, benefits, and feasibility of adopting GFRP poles within the Ethiopian Electric Utility framework. These stakeholders include utility company decision-makers, engineers, regulatory officials, and suppliers. The target for selecting these stakeholders is to leverage their expertise to provide detailed, informed perspectives that are essential for the depth and accuracy of the study's findings.

Stratified sampling was employed to ensure that different sub-groups within the population were adequately represented, thereby increasing the generalizability of the findings. By stratifying the sample, the study accounted for variations in perspectives and experiences across different stakeholder groups, enhancing the robustness and validity of the results.

Combining these two sampling techniques allowed the study to gather detailed and diverse information, ensuring that all relevant viewpoints were considered and that the findings could be reliably applied to the broader context of GFRP utility pole adoption within the Ethiopian Electric Utility framework.

The qualitative approach allowed for an exploratory and detailed examination of factors influencing the adoption of GFRP utility poles. Qualitative methods were particularly suitable for understanding complex phenomena where numerical data alone might not capture the nuances of stakeholder attitudes and regulatory environments. Purposive sampling ensured that the most knowledgeable and relevant individuals were included, while stratified sampling enhanced the reliability and validity of the findings by ensuring that all key groups were represented.

3.5 Sample Design

The study aimed to include a minimum of 30 participants, contingent upon the availability of relevant stakeholders and experts. Data collection methods primarily included semi-structured interviews and document analysis, with ethical considerations encompassing informed consent and confidentiality maintenance. To address limitations such as potential bias and generalizability, meticulous sampling and analysis methods were employed, aiming for a comprehensive portrayal and robust conclusions.

3.5.1 Population

Given the novelty of GFRP utility poles in Ethiopia, the study focused on key stakeholders crucial to the introduction, evaluation, and potential adoption of GFRP utility poles. The population included:

- Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP):
    - Decision-makers and engineers at EEU and EEP provided insights into the drawbacks of traditional utility poles and highlighted the potential benefits of adopting GFRP poles. They emphasized the environmental benefits, reduced maintenance costs, and alignment with sustainability goals.
- Regulatory Bodies:
    - Officers from the Institute of Ethiopian Standards (IES), Ethiopian Conformity Assessment Enterprise (ECAE), Ethiopian National Accreditation Office (ENAO), and ISO provided information on the development and implementation of standards for GFRP utility poles. They emphasized the need for a collaborative approach to establish reliable and safe standards.
- Key Stakeholders:
    - This category included project managers, infrastructure planners, and technical experts from both the public and private sectors. For instance, experts from Ethio Telecom highlighted the logistical and maintenance challenges associated with traditional poles and the advantages of GFRP poles in terms of durability and ease of installation.
- Independent Consultants, Universities, and Research Institutions:
    - Academic and research institutions such as Addis Ababa University, Mekelle University, and independent consultants contributed their expertise on the feasibility, technical specifications, and potential impact of GFRP utility poles. They provided research-based insights and recommendations for successful adoption.

- Manufacturers of Fiber Products:
    - Representatives from companies like Sunpower and Elias Alemayehu & Friends Electrical Works Partnership discussed the production process, cost considerations, and market trends for GFRP poles. They highlighted the challenges and prospects from a manufacturing perspective and provided comparative analyses of GFRP poles versus traditional materials.

By focusing on these diverse groups, the study ensured a comprehensive understanding of the various factors influencing the adoption of GFRP utility poles in Ethiopia.

3.5.2 Sample Size

Semi-structured interviews were conducted with 37 participants across various sectors involved in the Ethiopian electric utility landscape. These included in-person meetings, Zoom video calls, social media platforms, and phone recordings.

The study conducted semi-structured interviews with 37 participants, deemed sufficient due to the diversity of perspectives from various sectors, ensuring a comprehensive view of challenges and opportunities. The focus on knowledgeable stakeholders provided relevant insights, while resource constraints made this number manageable for thorough analysis. Additionally, reaching the saturation point indicated that further interviews would not yield significantly new information. The methodological rigor was maintained by ensuring all key groups were represented, enhancing the reliability and validity of the findings. Consequently, the 37 participants provided a robust basis for understanding the adoption of GFRP utility poles in Ethiopia.

3.6 Source Data

3.6.1 Primary Data Sources

Primary data sources for this study included semi-structured interviews with 37 participants who were stakeholders in the Ethiopian electric utility landscape. These stakeholders comprised utility company decision-makers, engineers, regulatory officials, suppliers, independent consultants, university researchers, and manufacturers of fiber products. The interviews were conducted through various methods such as in-person meetings, Zoom video calls, social media platforms, and phone recordings.

3.6.2 Secondary Data Sources:

Secondary data sources encompassed a comprehensive review of existing literature, empirical studies, and relevant documents pertaining to GFRP utility poles. This included academic journals, industry reports, case studies, and real-world examples that highlighted the structural characteristics, material properties, manufacturing processes, and applications of GFRP utility poles. Additionally, secondary data were gathered from government and regulatory body publications, Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP) reports, and documentation from other relevant institutions. These sources provided contextual and comparative information to support the primary data and enrich the analysis of the study.

3.7 Data Analysis and Interpretation

The proposed approach for data analysis and interpretation is predominantly qualitative, chosen to capture the depth and complexity of stakeholders' perspectives on the adoption of GFRP utility poles within the Ethiopian Electric Utility (EEU). *The decision to prioritize qualitative methods was based on the nature of the research objectives, which aimed to explore detailed insights, experiences, and contextual factors best understood through qualitative data*. This approach allowed for a comprehensive understanding of the feasibility, challenges, and potential benefits of GFRP utility poles, which may not be fully captured through quantitative methods alone.

Thematic analysis was conducted on the semi-structured interviews to systematically organize and interpret the data. The process began with data familiarization, where all interview transcripts were thoroughly read to gain a deep understanding of the content. Responses were then coded based on their relevance to the research objectives and key areas. These codes were subsequently grouped into broader themes, which were reviewed and refined. Finally, the themes were synthesized to draw meaningful conclusions about the transition to GFRP utility poles within EEU.

Content analysis was employed to systematically examine written materials and extract relevant information related to the specific objectives during the document analysis. Connections between themes or patterns across the documents were identified, and findings were synthesized to draw conclusions about the factors influencing the transition to GFRP utility poles in EEU.

Data from the literature review were synthesized and analyzed to identify key findings and insights related to the study's objectives. Patterns and relationships were identified and interpreted in relation to the study's objectives. Additionally, data from government reports were reviewed and summarized to identify relevant information, with key findings extracted and interpreted to align with the study's objectives.

Data from all sources were integrated and analyzed to identify common themes, patterns, and relationships across the variables. This synthesis provided a comprehensive understanding of the feasibility and impact of GFRP utility poles in Ethiopia, highlighting the key factors influencing their adoption and potential benefits within the EEU framework.

3.8 Validity and Reliability

In the study on the Prospects and Challenges of Glass Fiber Reinforced Polymer (GFRP) Utility Poles as an Alternative in the context of Ethiopian Electric Utility (EEU), validity and reliability were meticulously addressed through several key methods.

Content Validity was ensured by developing the research questions, objectives, and variables based on a thorough review of relevant literature, government reports, and expert opinions. Specific documents reviewed included the Ethiopian Electric Utility's annual reports (2022), guidelines from the American Composites Manufacturers Association (2019), and expert opinions from industry professionals like the Engineer from Sunpower Electromechanical Contractor P.L.C. This comprehensive review ensured that the study covered all relevant aspects of GFRP utility poles.

Construct Validity was achieved using multiple data sources and methods to triangulate findings. This included semi-structured interviews with 37 participants from different stakeholder groups, document analysis, and thematic and content analysis. For example, the interviews included questions on economic efficiency, safety, environmental impact, and operational effectiveness of GFRP poles. Document analysis involved reviewing guidelines from international standards organizations and comparing them with local standards.

External Validity was addressed by selecting a diverse range of stakeholders to ensure the findings are applicable to the wider context of GFRP utility poles in Ethiopia. This included participants from EEU, Ethiopian Electric Power, regulatory bodies like the Institute of Ethiopian Standards, and manufacturers of fiber products. These stakeholders were chosen for their direct involvement in utility pole maintenance, procurement, and regulation. For instance, decision-makers and engineers from EEU provided insights into the practical challenges and benefits of GFRP poles.

Internal Validity was maintained by employing rigorous data collection and analysis methods, such as thematic and content analysis. The data analysis process involved multiple steps: interview transcripts were coded and analyzed to identify key themes such as promoting factors, constraints, and performance correlations. For example, interviews with project managers from EEU highlighted the economic benefits of GFRP poles due to their reduced maintenance needs.

Reliability was achieved by ensuring consistent and standardized data collection methods. This included using the same set of interview questions for all participants, thereby maintaining uniformity in the data collection process. Additionally, inter-rater reliability was employed for thematic analysis.

3.9 Ethical Considerations

Ethical standards were adhered to in the study, with informed consent secured, participant confidentiality maintained, and ethical approval obtained from relevant review boards. Participants were fully informed about the study's purpose, procedures, potential risks, and benefits, with written informed consent obtained from all participants. Personal information was anonymized and stored securely, ensuring that participants' identities would not be disclosed in any publications or reports. Participation was entirely voluntary, with participants having the right to withdraw from the study at any time. Efforts were made to minimize any potential harm or discomfort to participants, and their autonomy was respected throughout the study. The study's purpose, methods, and findings were transparently communicated to participants and other stakeholders. Additionally, the researchers possessed the necessary expertise and qualifications to conduct the research ethically and responsibly.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presented the findings and discussions on the prospects and challenges of adopting Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU). Through a comprehensive review of literature and interviews, several key dimensions relevant to the adoption of GFRP utility poles were identified. These dimensions included promoting factors, constraints, performance correlations, regulatory framework and sustainability, and stakeholder acceptance. Promoting factors such as economic efficiency, safety, environmental impact, and operational effectiveness were highlighted, while constraints involved high initial costs, lack of local manufacturing, limited technical expertise, and regulatory challenges. Performance correlations emphasized the durability, cost efficiency, load-bearing capacity, and stakeholder confidence in GFRP poles. The regulatory framework and sustainability dimension addressed regulatory challenges, sustainability goals, and implementation strategies. Stakeholder acceptance focused on awareness, education, support, and collaboration. The analysis, supported by direct quotes from participants and compared with existing literature, provided a thorough understanding of the factors influencing the adoption and integration of GFRP poles in the EEU, drawing on sources such as the American Composites Manufacturers Association (2019), Broniewicz et al. (2021), Kamweru & Ochieng (2022), Saafi & Asa (2013), Urgessa & Mohamadi (2016), Coughlin (2017), Johnson & Lundvall (2013), Kliukas et al. (2018), Walta Media and Communication Corporate (2021), and Cohen & Levinthal (1990).

4.2 Analysis of Key Factors Influencing Adoption

This section presented the thematic analysis and discussions derived from the primary data (semi-structured interviews and document analysis) and secondary data (literature review and government reports).

4.2.1 Promoting Factors

4.2.1.1 Economic Efficiency

For the questions raised about the economic benefits or opportunities anticipated with the adoption of GFRP poles and how these align with organizational goals, participants highlighted the long-term cost savings associated with GFRP poles due to their extended lifespan and reduced maintenance requirements. One participant from the EEU mentioned, "While the upfront cost is high, the reduced maintenance and longer lifespan make GFRP poles more economical in the long run." This aligns with the findings of Kamweru and Ochieng (2022), who noted similar economic benefits in their cost-benefit analysis. Additionally, an operations manager from EEU added, "The durability of GFRP poles reduces the frequency of replacements, contributing to long-term savings." These insights are supported by Broniewicz et al. (2021), who highlight the cost-effectiveness of GFRP poles in long-term applications. Awwad, Chalfoun, and Sarieddine (2013) further discuss the economic advantages of GFRP poles in reducing overall infrastructure costs.

4.2.1.2 Safety and Reliability

When asked about the potential benefits or impacts of adopting GFRP utility poles within EEU's network, considering their unique properties, participants emphasized the non-conductive and fire-resistant properties of GFRP poles, which enhance safety and reliability in electrical distribution networks. An engineer from EEU stated, "The non-conductive nature of GFRP poles significantly reduces the risk of electrical accidents, making our network safer." This is corroborated by Saafi and Asa's (2013) research on in-situ FRP strengthening systems. Adding insights from a manufacturer, the Engineer from Sunpower highlighted, "GFRP poles offer superior durability and resistance to fire, which traditional poles cannot match. This reduces long-term maintenance costs and enhances the safety of our infrastructure." This viewpoint is supported by the findings of Kamweru and Ochieng (2022), who noted that GFRP poles provide significant cost savings over their lifespan due to reduced maintenance needs.

4.2.1.3 Environmental Impact

In response to questions on how FRP poles might contribute to environmental sustainability, energy efficiency, and overall utility infrastructure improvement, participants noted the environmental benefits of GFRP poles, such as reducing the need for frequent replacements and minimizing waste. They also highlighted that GFRP poles are free from the chemical treatments required for wooden poles, reducing their environmental footprint. A regulatory official remarked, “GFRP poles align with our sustainability goals by minimizing environmental impact and reducing waste.” These benefits are supported by Broniewicz et al. (2021), who highlighted the eco-friendly nature of FRP poles. Adding insights from a manufacturer, the Engineer from Elias Alemayehu & Friends Electrical Works Partnership stated, “The longevity and durability of GFRP poles reduce the frequency of replacements and maintenance, significantly lowering the environmental impact compared to traditional wooden or steel poles.” This perspective aligns with Kamweru and Ochieng's (2022) findings that GFRP poles offer long-term environmental benefits by reducing deforestation and minimizing the carbon footprint of utility infrastructure.

4.2.1.4 Operational Effectiveness

Regarding how the lightweight design of GFRP poles impacts transportation and installation costs compared to traditional materials, participants pointed out that the lightweight nature of GFRP poles simplifies transportation and installation, leading to lower labor and logistic costs. A Project Manager from EEU noted, “The lightweight design of GFRP poles makes them easier and cheaper to transport and install,” echoed in the literature by Coughlin (2017), who emphasized the ease of handling composite poles. Adding insights from a manufacturer, the Engineer from Sunpower highlighted, “The significant reduction in weight not only decreases transportation costs but also minimizes the need for heavy machinery during installation, which further reduces overall costs.” This perspective is supported by Kamweru and Ochieng's (2022) findings that GFRP poles streamline logistics and installation processes, making them a cost-effective alternative to traditional materials.

4.2.1.5 Stakeholder Acceptance

For the questions on what strategies EEU plans to employ to facilitate the adoption of this technology across its network and how it plans to address challenges related to stakeholder acceptance, participants reported that positive results from ongoing pilot projects are expected to boost confidence in GFRP poles among stakeholders. A project manager from EEU stated, “Positive results from pilot projects will boost our confidence in GFRP poles among our stakeholders.” This finding aligns with existing studies that show stakeholder engagement is crucial for successful technology adoption (Kamweru & Ochieng, 2022). Adding insights from a manufacturer, the Engineer from Sunpower emphasized, “Collaborative efforts with stakeholders, including demonstrations and training sessions, have been instrumental in building trust and acceptance for GFRP poles. Our approach involves continuous engagement and feedback to ensure all concerns are addressed promptly.” This aligns with the research of Broniewicz et al. (2021), who noted that stakeholder involvement and education significantly enhance the adoption process for new technologies.

4.2.1.6 Regulatory Compliance

When asked about how the Ethiopian Energy Authority evaluates the regulatory framework and standards for incorporating new materials like FRP utility poles, participants emphasized the importance of GFRP poles meeting updated regulatory standards for their adoption. The Director of Licensing and Certification at EEA stated, “Ensuring GFRP poles comply with both national and international standards is key to their integration.” This aligns with the standards development process described by the Institute of Ethiopian Standards (IES). Adding insights from a manufacturer, the Engineer from Elias Alemayehu & Friends Electrical Works Partnership emphasized, “Collaborating with regulatory bodies to ensure GFRP poles meet rigorous testing and certification processes is crucial. We work closely with the Ethiopian Energy Authority and other stakeholders to align our products with established standards.” This is supported by Kamweru and Ochieng's (2022) findings that rigorous compliance with standards enhances the credibility and acceptance of new materials in utility infrastructure. Furthermore, the research underscores that developing comprehensive standards and conducting pilot projects are essential steps to ensure that GFRP poles meet all regulatory requirements, facilitating their successful adoption within EEU's network

4.2.1.7 Technological Innovation

For questions on how the Ministry of Innovation and Technology supports the adoption and adaptation of GFRP technology within the Ethiopian Electric Utility network, participants highlighted that adopting GFRP poles is seen as a step towards modernizing utility infrastructure. A representative from the Ministry of Innovation and Technology stated, “Embracing GFRP technology aligns with our goals of innovation and technological advancement.” This sentiment is consistent with global trends towards innovative materials in infrastructure development (American Composites Manufacturers Association, 2019). Furthermore, participants from semi-structured interviews highlighted that the Ministry's involvement in providing technical assistance and funding for pilot projects is essential for the widespread adoption of GFRP poles, enhancing the modernization and efficiency of Ethiopia's utility infrastructure.

4.2.2 Constraints

4.2.2.1 High Initial Costs

For the questions about the financial barriers associated with the adoption of GFRP poles, participants noted that the initial costs of GFRP poles are higher compared to traditional poles. A financial analyst from EEU explained, “The high upfront investment is a major barrier, especially with our current financial constraints.” This is a common challenge highlighted in the literature, as seen in the cost analysis by Kamweru and Ochieng (2022).

4.2.2.2 Lack of Local Manufacturing and Supply Chain

For the questions on the logistical challenges posed by the absence of local manufacturing facilities for GFRP poles, participants mentioned the reliance on imported raw materials. A supply chain manager from Ethio Telecom stated, “Importing raw materials increases costs and complicates supply chain management.” This aligns with the challenges discussed by the Engineer from Sunpower, who highlighted the increased costs and complexities associated with importing materials and the absence of local manufacturing facilities. Additionally, the Fixed Access Engineering Supervisor at Ethio Telecom, voiced similar concerns. He noted that the lack of local availability of raw materials for manufacturing GFRP poles necessitates importing these materials, which requires hard currency and significantly impacts costs and logistics. The Ass. Professor from Mekelle University also highlighted this issue. He emphasized that establishing a local manufacturing supply chain for GFRP poles is crucial to mitigate these challenges and reduce costs. According to the Ass. Professor, developing local production capabilities would significantly enhance the feasibility and sustainability of GFRP poles in Ethiopia. This challenge is further supported by existing literature, which indicates that the lack of local production capabilities often leads to higher overall costs and logistical difficulties in managing the supply chain for GFRP poles (Kamweru and Ochieng, 2022). Establishing local manufacturing plants could mitigate these issues by reducing dependency on imports and lowering associated costs, ultimately facilitating a smoother and more cost-effective adoption process.

4.2.2.3 Limited Technical Expertise and Training

For the questions about the need for specialized training programs for engineers and technicians, participants highlighted the necessity of capacity building. A technical trainer from Ethio Telecom mentioned, “We need comprehensive training programs to develop local expertise in handling GFRP poles.” This necessity for capacity building is supported by the Ministry of Innovation and Technology’s initiatives. Additionally, the Fiber and Copper Design Supervisor at Ethio Telecom, emphasized the importance of training programs, stating, “Providing proper training for our engineers and technicians is essential to ensure they are well-equipped to handle the new technology and maximize the benefits of GFRP poles” . Moreover, the Ass. Professor from Mekelle University highlighted that training programs are crucial for ensuring the successful adoption of GFRP poles, as they provide the necessary skills and knowledge to handle and maintain the new infrastructure . These perspectives are aligned with existing literature, which underscores the importance of capacity building and technical training in facilitating the adoption of new technologies in the utility sector. Establishing comprehensive training programs and technical guidelines is essential for overcoming the initial challenges and ensuring the effective integration of GFRP poles into Ethiopia's utility infrastructure (Kamweru and Ochieng, 2022).

4.2.2.4 Regulatory and Standardization Challenges

For the questions on the current regulatory framework and standards, participants emphasized the need for updates to accommodate GFRP utility poles. The Director of Licensing and Certification at EEA emphasized, “Updating our regulatory framework to include standards for GFRP poles is essential.” This is consistent with the recommendations for developing new standards for novel products by the IES. Supporting this, the American Composites Manufacturers Association (2019) highlights the necessity of establishing standard specifications for FRP composite utility poles to facilitate their adoption, providing essential guidance for end-users and easing approval and implementation within electric infrastructure.

4.2.2.5 Acceptance Among Stakeholders

For the questions on stakeholder resistance to the adoption of GFRP poles, participants noted the need for education and engagement. A higher Manager from EEU emphasized, “Educating stakeholders about the benefits of GFRP poles is crucial for gaining acceptance.” This mirrors findings in other studies where stakeholder engagement and education are key to adoption (Kamweru & Ochieng, 2022). The Engineer from Sunpower highlighted resistance from traditional wooden and concrete pole manufacturers, who were reluctant to collaborate on this innovative product, posing a significant obstacle to adoption. Studies consistently show that well-informed stakeholders are more likely to support new technologies when they understand the long-term benefits and have their concerns addressed through transparent communication and inclusive decision-making processes (Kamweru & Ochieng, 2022; Johnson & Robinson, 2021). Effective stakeholder engagement through targeted education campaigns, workshops, and pilot projects can significantly enhance the adoption process by providing firsthand experience and evidence of the new technology's benefits.

4.2.2.6 Environmental and Disposal Concerns

For the questions on the environmental impact of GFRP poles, participants raised concerns about the disposal of GFRP poles at the end of their lifecycle. An environmental specialist from EEU emphasized, "Developing environmentally friendly disposal methods is essential". This concern is echoed by Safaricom Utility Infrastructure Experts, who noted that while GFRP poles offer significant operational benefits, their end-of-life disposal requires careful planning to ensure minimal environmental impact. An independent consultant specializing in sustainable infrastructure also highlighted that the lack of established recycling and disposal protocols for GFRP poles could hinder their widespread adoption, stressing the importance of creating comprehensive guidelines for recycling GFRP materials to promote a circular economy and reduce waste. Broniewicz et al. (2021) discuss the lifecycle impacts of FRP materials, emphasizing that while FRP materials have a lower environmental impact during their use phase compared to traditional materials, their end-of-life disposal poses significant challenges, necessitating effective recycling and disposal strategies to minimize environmental harm. Additionally, Tao, Hadigheh, and Wei (2023) review various recycling methods for GFRP composites, such as mechanical recycling, thermal recycling, and chemical recycling, highlighting their potential to reduce waste and support global sustainability efforts. The American Composites Manufacturers Association (2019) underscores the importance of developing national standards for FRP composite utility poles, including guidelines for their end-of-life disposal, to ensure these poles are environmentally friendly throughout their lifecycle.

4.2.2.7 Financial and Economic Barriers

For the questions on financial mechanisms to support the adoption of GFRP poles, participants mentioned the need for financial incentives. A policy advisor from EEU suggested, "Financial incentives and subsidies could help overcome the high initial costs." This view was supported by representatives from Safaricom Telecommunications Ethiopia PLC, who emphasized the importance of government-backed grants and tax breaks to reduce the financial burden on utility companies. Additionally, an independent consultant specializing in sustainable infrastructure noted that creating favorable financing conditions, such as low-interest loans and dedicated funding programs, would be crucial to facilitate the adoption of GFRP poles. An Associate Professor from Addis Ababa

University further highlighted that financial support mechanisms are essential for fostering innovation and adoption of new technologies, particularly in developing countries where initial costs can be prohibitive. This aligns with the recommendations for financial support mechanisms found in the literature. Broniewicz et al. (2021) highlight the role of financial incentives in offsetting the higher upfront costs of innovative materials like FRP composites, making them more economically viable in the long run. Similarly, Kamweru and Ochieng (2022) argue that financial mechanisms such as subsidies, tax incentives, and government grants are essential to encourage the transition from traditional utility poles to GFRP alternatives, ensuring broader adoption and sustainable infrastructure development.

4.2.3 Performance Correlations

4.2.3.1 Durability and Longevity

For the questions on the durability and longevity of GFRP utility poles compared to traditional wooden and concrete poles, participants consistently reported that GFRP poles have significantly greater durability and longevity. A project manager from Safaricom Telecommunications Ethiopia PLC emphasized, "GFRP poles are not only more durable but also significantly reduce the frequency of maintenance required compared to traditional wooden and concrete poles." This finding aligns with the studies by Saafi and Asa (2013), which indicate that GFRP poles can extend the service life of damaged wooden poles by up to 25 years. Additionally, representatives from Ethio Telecom highlighted that GFRP poles are resistant to environmental degradation, such as rot and corrosion, which are common issues with wooden and steel poles. An Associate Professor from Addis Ababa University further noted that GFRP poles' durability translates into lower maintenance costs and enhanced reliability for utility companies. These insights are further supported by research from Saafi and Asa (2013), which underscores the extended service life and reduced maintenance needs of GFRP utility poles, making them a superior alternative to traditional materials.

4.2.3.2 Maintenance and Cost Efficiency

For the questions on maintenance needs and cost efficiency of GFRP poles, participants highlighted the reduced need for maintenance and the associated cost savings as key performance advantages. As one utility manager explained, "We see a drastic reduction in maintenance costs with GFRP poles due to their resistance to environmental factors and lower failure rates." Representatives from Ethio Telecom also noted that GFRP poles require significantly less maintenance compared to traditional wooden and concrete poles, which often suffer from rot, corrosion, and weather-related damages. An independent consultant specializing in infrastructure sustainability emphasized that the long-term cost savings from reduced maintenance and replacements make GFRP poles a financially viable option. This observation is supported by Urgessa and Mohamadi (2016), who found that FRP poles have lower lifecycle maintenance costs compared to wooden and concrete poles, further underscoring the economic benefits of adopting GFRP technology.

4.2.3.3 Load-Bearing Capacity and Mechanical Performance

For the questions on the load-bearing capacity and mechanical performance of GFRP poles, participants indicated that GFRP poles exhibit excellent load-bearing capacity and mechanical performance. An engineer from EEU stated, "The mechanical strength of GFRP poles allows them to withstand extreme weather conditions and heavy loads." This is corroborated by the structural assessments conducted by Urgessa and Mohamadi (2016), which demonstrated the superior mechanical properties of FRP composite poles. Additionally, experts from Safaricom Telecommunications Ethiopia PLC highlighted that the lightweight nature of GFRP poles does not compromise their strength, making them an ideal choice for regions with challenging weather conditions. An associate professor from Addis Ababa University further emphasized that the mechanical properties of GFRP poles enable them to bear heavy loads without deforming, ensuring long-term reliability and safety. Manufacturers, such as those from Sunpower, also noted that the combination of strength and lightweight features of GFRP poles simplifies transportation and installation, reducing overall project costs. These findings support the overall advantages of GFRP poles in terms of durability and mechanical performance, confirming their suitability for various infrastructure projects.

4.2.3.4 Environmental Impact

For the questions on the environmental impact of GFRP poles, participants frequently mentioned the environmental benefits, such as reduced deforestation and lower carbon footprint. A regulatory official highlighted, "Using GFRP poles helps us reduce our environmental impact significantly." This aligns with the findings of Broniewicz et al. (2021), who noted the eco-friendly nature of FRP materials due to their recyclability and minimal environmental disruption during installation. Experts from Safaricom Telecommunications Ethiopia PLC also pointed out that GFRP poles' resistance to corrosion and pests eliminates the need for harmful chemical treatments used for wooden poles, further reducing their environmental impact. An Associate Professor from Addis Ababa University emphasized that the adoption of GFRP poles supports sustainable development goals by preserving forest resources and reducing greenhouse gas emissions associated with the production and maintenance of traditional poles. These insights underscore the significant environmental advantages of GFRP poles, making them a sustainable choice for modern infrastructure projects.

4.2.3.5 Stakeholder Confidence and Adoption Rates

For the questions on stakeholder confidence and adoption rates influenced by the performance of GFRP poles, participants noted that the anticipation of pilot projects has positively influenced these factors. A project manager from EEU remarked, "The planned pilot projects are expected to demonstrate the reliability of GFRP poles, encouraging wider adoption." This is consistent with the findings of Kamweru and Ochieng (2022), who observed increased acceptance and confidence in composite poles following successful pilot project implementations. Experts from Safaricom Telecommunications Ethiopia PLC also highlighted that the planned pilot projects are generating interest and optimism among stakeholders, leading to higher potential adoption rates. Representatives from Ethio Telecom added that the expected outcomes from these pilot projects are crucial in convincing regulatory bodies and utility companies of the benefits of GFRP poles. Experts from the Addis Ababa City Roads Authority (AACRA) noted that the anticipation of pilot implementations is building confidence in the durability and effectiveness of GFRP poles in urban infrastructure. Additionally, an independent consultant specializing in infrastructure development emphasized that the planned pilot projects have built a strong case for the broader adoption of GFRP poles, noting that stakeholders are more confident in the technology's anticipated performance and long-term benefits. These insights collectively show that real-world demonstrations of GFRP pole performance are key to building stakeholder confidence and driving adoption.

4.2.4 Regulatory Framework and Sustainability

4.2.4.1 Regulatory Challenges

4.2.4.1.1 Lack of Comprehensive Standards

For the questions on the regulatory framework and the lack of comprehensive standards for GFRP utility poles, participants pointed out significant gaps. A representative from the Ethiopian Energy Authority (EEA) mentioned, “Our existing regulations do not fully cover the specifications and standards required for GFRP poles.” This sentiment was echoed by experts from Ethio Telecom, who emphasized that the absence of comprehensive regulatory standards is a major barrier to the widespread adoption of GFRP poles. Experts from the Institute of Ethiopian Standards (IES) further highlighted the need for updated standards to accommodate new materials like GFRP. This need for robust regulatory frameworks is also supported by Broniewicz et al. (2021), who underscore the importance of developing comprehensive standards for the effective integration of novel materials into infrastructure projects. These insights collectively highlight the necessity for a robust regulatory framework to support the integration of GFRP poles into Ethiopia's electric utility sector.

4.2.4.1.2 Regulatory Adaptation Process

For the questions on the adaptation process for incorporating new standards into the regulatory framework, participants noted the slow and complex nature of this process. A regulatory official noted, “Updating and adapting new standards is a lengthy process that involves multiple stakeholders and thorough evaluations.” This challenge is also discussed by the American Composites Manufacturers Association (2019), which emphasizes the need for streamlined regulatory processes.

4.2.4.2 Sustainability Goals

4.2.4.2.1 Alignment with National Sustainability Goals

For the questions on how GFRP utility poles align with Ethiopia’s national sustainability goals, participants noted that GFRP poles support efforts to reduce deforestation and lower greenhouse gas emissions. A representative from the Ministry of Environment, Forest &

Climate Change (MEFCC) stated, “Adopting GFRP poles supports our goals to reduce deforestation and carbon emissions.” This alignment with sustainability goals is also highlighted in Ethiopia’s Ten-Year Development Plan (2021-2030). Additionally, Broniewicz et al. (2021) emphasize that the use of FRP materials contributes to environmental sustainability through their reduced environmental footprint and lower lifecycle emissions.

4.2.4.2.2 Contribution to Global Sustainability Initiatives

For the questions on the contribution of GFRP poles to global sustainability initiatives, participants emphasized that adopting GFRP poles supports global sustainability efforts, such as the United Nations Sustainable Development Goals (UN SDGs). An environmental expert commented, “Using GFRP poles helps us contribute to global sustainability efforts by promoting environmentally friendly practices.” This is supported by the literature, which emphasizes the role of innovative materials in achieving sustainable development (Broniewicz et al., 2021). Professors from EIABC and Addis Ababa University highlighted that GFRP poles' durability and reduced maintenance needs align with sustainable infrastructure goals. Additionally, an expert from Mekelle University noted that GFRP poles significantly reduce the carbon footprint compared to traditional materials, further supporting global sustainability targets.

Table 4-1: Mapping Sustainability Attributes and Global Policies

Sustainability Attribute	**Global Policy/Directive/Initiative**
Long Lifespan and Durability	Paris Agreement: Encourages low-carbon technologies to reduce greenhouse gas emissions (UNFCCC, 2015).
Corrosion and Weather Resistance	SDG Goal 9: Promotes resilient infrastructure (United Nations, 2015).
Lightweight and Easy to Install	Circular Economy Action Plan: Supports resource efficiency and reduced waste (European Commission, 2020).
Non-conductive and Safe	Green Procurement Policies: Prioritize environmentally sustainable and safe products.
Low Maintenance Costs	Carbon Pricing Mechanisms: Incentivize low-carbon technologies by reducing maintenance emissions.
Environmental Friendliness	Paris Agreement: Promotes adoption of eco-friendly materials (UNFCCC, 2015).
Recyclability and Waste Reduction	Circular Economy Action Plan: Encourages recycling and reuse (European Commission, 2020).
Adaptability for Renewable Energy Projects	SDG Goal 7: Supports infrastructure for renewable energy integration (United Nations, 2015).
Contribution to Sustainable Development	SDGs: Supports sustainable practices, including Goals 7, 9, and 12 (United Nations, 2015).

(UNFCCC, 2015; United Nations, 2015; European Commission, 2020; United Nations Environment Program, 2014; World Bank Group, 2021)

4.2.4.3 Implementation Strategies for Regulatory Compliance

4.2.4.3.1 Developing Comprehensive Standards

For the questions on ensuring regulatory compliance through the development of comprehensive standards, participants recommended creating detailed standards specific to GFRP poles. A standards developer from IES stated, “We need to establish detailed standards that cover all aspects of GFRP poles, from material specifications to installation practices." This recommendation aligns with global best practices for standard development (International Organization for Standardization, 2020). Experts from EIABC and AAIT also emphasized the importance of adopting international benchmarks to ensure that local standards are robust and comprehensive. An Associate Professor from Mekelle University highlighted that establishing these standards would facilitate smoother integration of GFRP poles into existing infrastructure and ensure long-term reliability and safety.

4.2.4.3.2 Engaging Stakeholders in the Standardization Process

For the questions on the importance of engaging stakeholders in the standardization process, participants emphasized involving all relevant parties. A policy advisor from EEU remarked, "Involving utility companies, regulatory bodies, and manufacturers in developing standards ensures that all perspectives are considered and that the standards are practical and effective." This inclusive approach is supported by the American National Standards Institute (ANSI) guidelines (American National Standards Institute, 2017).

4.2.4.3.3 Training and Capacity Building

For the questions on the necessity of training and capacity building for successful implementation, participants identified these as critical components. An expert from Ethio Telecom emphasized the importance of continuous professional development, stating, "Training our staff on the latest technologies like GFRP poles is essential for maintaining operational efficiency and ensuring safety standards are met." An associate professor from Mekelle University emphasized that tailored training programs are essential for developing the technical expertise required to work with GFRP poles, ensuring that all stakeholders can effectively implement and maintain this technology. This aligns with the recommendations from the Ministry of Innovation and Technology. Additionally, Broniewicz et al. (2021) emphasize the importance of specialized training programs in ensuring the effective adoption and utilization of FRP materials in infrastructure projects. Urgessa and Mohamadi (2016) also discuss the role of capacity building in enhancing the technical skills required for the successful implementation of innovative materials like GFRP poles.

4.2.4.4 Long-term Sustainability Considerations

4.2.4.4.1 Lifecycle Analysis and Environmental Impact

For the questions on understanding the environmental impact of GFRP poles, participants stressed the importance of conducting lifecycle analysis. An environmental scientist noted, “A thorough lifecycle analysis helps in assessing the true environmental benefits and identifying any potential negative impacts of GFRP poles.” This approach is supported by Broniewicz et al. (2021), who advocate for comprehensive environmental assessments of new materials. Additionally, experts from Ethio Telecom emphasized the need for a detailed evaluation of GFRP poles' environmental footprint, highlighting their potential to reduce deforestation and lower carbon emissions. An associate professor from Mekelle University also pointed out the necessity of considering the entire lifecycle of GFRP poles, from production to disposal, to fully understand their environmental impact. Furthermore, literature by Tao, Hadigheh, and Wei (2023) explores various recycling methods for GFRP composites, underscoring the importance of sustainable disposal practices. These studies collectively highlight the critical need for comprehensive lifecycle analysis to ensure that GFRP poles are an environmentally viable alternative to traditional materials.

4.2.4.4.2 Recycling and End-of-Life Management

For the questions on strategies for recycling and managing the end-of-life phase of GFRP poles, participants emphasized their importance for sustainability. A Quality Expert from EEU stated, “We need to establish protocols for recycling GFRP poles and managing their disposal to ensure minimal environmental impact.” This is consistent with global practices for sustainable material management (Broniewicz et al., 2021). Experts from Ethio Telecom also stressed the necessity of developing comprehensive recycling programs and guidelines for the safe disposal of GFRP poles, highlighting their commitment to reducing environmental impact. An associate professor from Mekelle University added that recycling and end-of-life management protocols are essential for the long-term sustainability of GFRP poles, ensuring that the materials can be reused or disposed of without causing harm to the environment. Additionally, Tao, Hadigheh, and Wei (2023) discuss various recycling methods for GFRP composites, such as mechanical, thermal, and chemical recycling, emphasizing the importance of adopting these practices to promote a circular economy and support global sustainability goals.

4.2.4.4.3 Financial Incentives for Sustainable Practices

For the questions on providing financial incentives to promote sustainable practices, participants highlighted this as a key strategy. A higher management official from EEU suggested, “Offering subsidies and tax incentives for adopting GFRP poles can encourage more utility companies to invest in this sustainable technology.” Additionally, an expert from AACRA emphasized the importance of financial incentives in accelerating the adoption of innovative materials, stating, “Subsidies and tax breaks are essential for offsetting the high initial costs associated with GFRP poles.” An associate professor from AAIT further noted, “Financial incentives play a crucial role in mitigating the economic barriers to adopting new technologies.” This aligns with the economic policies outlined in Ethiopia’s Ten-Year Development Plan (2021-2030) and is supported by Kamweru and Ochieng (2022), who emphasize the positive impact of financial incentives on the adoption of sustainable technologies.

4.2.5 Stakeholder Acceptance

4.2.5.1 Stakeholder Awareness and Education

4.2.5.1.1 Awareness Levels

For the questions on the level of awareness among stakeholders regarding GFRP utility poles, participants reported varying levels of knowledge. An engineer from EEU mentioned, "We are aware of the potential benefits of GFRP poles from our preliminary studies and industry reports." An associate professor from AAIT added, "Our research has highlighted the significant advantages of GFRP poles, but this knowledge needs to be disseminated more broadly among all stakeholders." However, others, particularly those not directly involved in such discussions, had limited knowledge. A regulatory official admitted, "Many of us are still not fully aware of what GFRP poles can offer." A participant from Ethio Telecom also noted, "There is a need for more detailed information and training to understand the full potential and application of GFRP poles." This disparity highlights the need for more comprehensive education and awareness campaigns to ensure all stakeholders are adequately informed about the advantages and applications of GFRP utility poles. The need for improved awareness and education is supported by Kamweru and Ochieng (2022), who emphasize that stakeholder engagement and education are critical to the successful adoption of innovative technologies. Additionally, Johnson and Robinson (2021) highlight that targeted education campaigns can significantly enhance stakeholder understanding and acceptance of new materials.

4.2.5.1.2 Educational Initiatives

For the questions on the need for educational initiatives to raise awareness and understanding among stakeholders, participants emphasized their importance. An officer from EEU stated, "Educational campaigns and workshops are essential to inform all stakeholders about the benefits and technical aspects of GFRP poles." An independent consultant highlighted, "Educational initiatives are crucial for overcoming resistance and building confidence among stakeholders." A professor from EiABC added, "We need to integrate GFRP pole technology into our academic curriculum to prepare future engineers and architects for its adoption." Additionally, a participant from Ethio Telecom noted, "Comprehensive training programs are needed to ensure our technical staff are well-versed in the installation and maintenance of GFRP poles." This emphasis on educational initiatives aligns with the recommendations by Kamweru and Ochieng (2022), who stressed the importance of stakeholder education in technology adoption. Furthermore, Johnson and Robinson (2021) highlighted that targeted education campaigns can significantly enhance stakeholder understanding and acceptance of new materials.

4.2.5.2 Acceptance and Support

4.2.5.2.1 Support from Key Stakeholders

For the questions on the level of support from key stakeholders, including utility companies, regulatory bodies, and governmental organizations, participants noted that such support is crucial for the successful adoption of GFRP poles. A representative from the Ministry of Innovation and Technology remarked, "There is strong support for innovative solutions like GFRP poles among government officials and policymakers." This is consistent with global trends where government support plays a pivotal role in the adoption of new technologies (Broniewicz et al., 2021).

4.2.5.2.2 Concerns and Reservations

For the questions on concerns and reservations among stakeholders, participants expressed issues particularly regarding the high initial costs and the lack of local manufacturing facilities. An expert from Ethio Telecom added, "While GFRP poles offer long-term benefits, the initial investment is a major deterrent for many companies." A representative from AACRA highlighted, "The absence of local manufacturing facilities means that we have to import these poles, which adds to the overall cost and logistical challenges." This echoes the financial concerns highlighted by Urgessa and Mohamadi (2016) in their assessment of FRP poles, which noted the significant initial investment required and the economic implications of relying on imported materials. Additionally, a study by Broniewicz et al. (2021) emphasized the need for developing local manufacturing capabilities to reduce costs and improve accessibility.

4.2.5.3 Communication and Collaboration

4.2.5.3.1 Importance of Communication

For the questions on the importance of communication among stakeholders, participants highlighted the need for transparent and continuous communication. A project manager from EEU stated, "Regular updates and open communication channels are crucial for maintaining stakeholder trust and support." This aligns with best practices in project management, as noted by Coughlin (2017).

4.2.5.3.2 Collaborative Efforts

For the questions on the importance of collaboration among various stakeholders, including utility companies, regulatory bodies, manufacturers, and academic institutions, participants identified this as a key factor in the successful adoption of GFRP poles. A representative from the Ethiopian Institute of Technology remarked, "Collaborative efforts can help overcome technical challenges and ensure that all stakeholders are on the same page." This collaborative approach is supported by the literature on innovation and technology adoption (American Composites Manufacturers Association, 2019).

4.2.5.4 Training and Capacity Building

4.2.5.4.1 Need for Training Programs

For the questions on the importance of training programs, participants underscored the need to build the necessary technical expertise for handling GFRP poles. A Project coordinator from EEU highlighted, "Comprehensive training programs are needed to equip our engineers and technicians with the skills required for GFRP technology." This necessity for capacity building is emphasized by Saafi and Asa (2013) in their research on FRP strengthening systems.

4.2.5.4.2 Impact of Training on Acceptance

For the questions on the impact of training on acceptance, participants noted that effective training programs not only build technical capacity but also enhance stakeholder acceptance and confidence in GFRP technology. An expert from Ethio Telecom remarked, "Training will significantly improve our confidence in using fiber products such as GFRP poles and addressing any technical challenges." Similarly, assistance professor from Mekelle University stated, "Well-structured training programs are crucial in increasing the acceptance and adoption of new technologies among engineers and technicians." This finding aligns with Kamweru and Ochieng (2022), who reported the positive impact of training on technology adoption. Overall, high acceptance among stakeholders such as EEU, EEP, and regulatory bodies like the EEA indicates strong potential for GFRP pole adoption. The enthusiasm from Safaricom and AACRA further supports the feasibility of integrating GFRP poles into infrastructure projects. Ethio Telecom's medium-high acceptance level underscores the need to address cost concerns through phased implementation and pilot projects to build confidence.

4.2.5.4.3 Summary of the Acceptance Levels:

The analysis of the level of acceptance among stakeholders for GFRP utility poles addressed the objective to "Evaluate stakeholders' perceptions of GFRP utility poles." This objective aimed to understand how different stakeholders perceive the adoption of GFRP utility poles, including their willingness to adopt the technology, perceived benefits, and concerns. Stakeholders exhibited high acceptance of GFRP utility poles, characterized by strong interest, readiness to adopt, and clear recognition of benefits with minimal concerns. They emphasized long-term benefits such as durability, environmental advantages, and alignment with sustainability goals, supporting pilot projects and regulatory updates. Conversely, stakeholders with medium-high acceptance showed a positive outlook and recognition of benefits but were tempered by concerns about high initial costs. They recommended phased implementation and pilot projects to build confidence and demonstrate the long-term economic benefits of GFRP poles.

CHAPTER 5: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

5.1. SUMMARY OF FINDINGS

The study aimed to explore the prospects and challenges associated with the adoption of Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU). The primary and secondary data were integrated to provide a comprehensive understanding of the key factors influencing this adoption.

5.1.1 Essential Findings

- Economic Efficiency: GFRP poles offer significant long-term cost savings due to their extended lifespan and reduced maintenance requirements, despite higher initial costs (Kamweru & Ochieng, 2022).
- Safety and Reliability: The non-conductive and fire-resistant properties of GFRP poles enhance safety in electrical distribution networks (Saafi & Asa, 2013).
- Environmental Impact: GFRP poles minimize environmental footprint by reducing the need for frequent replacements and avoiding chemical treatments required for wooden poles (Broniewicz et al., 2021).
- Operational Effectiveness: The lightweight nature of GFRP poles simplifies transportation and installation, reducing labor and logistic costs (Coughlin, 2017).

5.1.2 Constraints

- High Initial Costs: The initial costs of GFRP poles are higher than traditional poles, posing a financial barrier (Kamweru & Ochieng, 2022).
- Lack of Local Manufacturing: The reliance on imported raw materials and absence of local manufacturing facilities complicate supply chain management (The Engineer from Sunpower).
- Limited Technical Expertise and Training: There is a need for comprehensive training programs to develop local expertise in handling GFRP poles (Ministry of Innovation and Technology’s initiatives).

- Regulatory and Standardization Challenges: Ensuring GFRP poles comply with both national and international standards is crucial for their integration (Director of Licensing and Certification at EEA).

5.1.3 Performance Correlations

- Durability and Longevity: GFRP poles exhibit superior durability and longevity compared to traditional materials (Saafi & Asa, 2013).
- Maintenance and Cost Efficiency: Reduced maintenance and associated cost savings are key performance advantages of GFRP poles (Urgessa & Mohamadi, 2016).
- Load-Bearing Capacity: GFRP poles have excellent load-bearing capacity and mechanical performance, increasing stakeholder confidence (Urgessa & Mohamadi, 2016).

5.1.4 Analysis of Research Methods and Key Insights

The study employed a qualitative approach, utilizing semi-structured interviews and document analysis to gather data from a diverse range of stakeholders. The integration of primary and secondary data provided a comprehensive understanding of the prospects and challenges associated with the adoption of GFRP utility poles within the EEU framework. The findings highlighted the technical feasibility, long-term economic benefits, and regulatory challenges associated with GFRP poles. Additionally, the importance of stakeholder awareness and regulatory support emerged as critical factors for successful adoption.

The findings indicate strong support for the technical feasibility and performance of GFRP utility poles, with stakeholders praising their load-bearing capacity and durability under various environmental conditions. Despite higher initial costs, the long-term economic benefits of GFRP poles due to reduced maintenance costs were acknowledged, making them a cost-effective option in the long run. However, the need for comprehensive regulatory standards and increased stakeholder awareness was emphasized as critical for successful adoption. Government policies, such as the Ethiopian Ten-Year Development Plan, support the integration of sustainable materials like GFRP into infrastructure projects, aligning with national sustainability goals. The analysis of engineering reports further validated the superior physical and mechanical properties of GFRP poles, highlighting their potential as a durable alternative to traditional materials. These policies provide a comprehensive framework that supports the technical and economic viability of GFRP poles while ensuring their alignment with broader national and global sustainability goals. For instance, GFRP utility poles align with global sustainability policies such as the Paris Agreement, Sustainable Development Goals (SDGs), and the EU's Circular Economy Action Plan. Reports from regulatory bodies emphasized the need for developing specific standards and guidelines for GFRP poles, providing a roadmap for integrating GFRP technology into existing regulatory frameworks.

5.2. CONCLUSIONS

Based on the findings, several key conclusions can be drawn regarding the adoption of Glass Fiber Reinforced Polymer (GFRP) utility poles within the Ethiopian Electric Utility (EEU).

- Technical Feasibility: GFRP utility poles are technically feasible for the EEU due to their superior physical and mechanical properties, including high load-bearing capacity, durability, and resistance to environmental degradation (Urgessa & Mohamadi, 2016; Saafi & Asa, 2013).
- Economic Viability: Despite higher initial costs, GFRP poles present long-term economic benefits through reduced maintenance and replacement costs, aligning with the economic efficiency goals outlined by Kamweru and Ochieng (2022).
- Regulatory and Standardization Needs: The successful adoption of GFRP utility poles is contingent on developing comprehensive regulatory standards and guidelines. Current regulatory frameworks are insufficient and need to be updated to accommodate the integration of GFRP technology (Federal Negarit Gazette, 2022; Ethiopian Energy Authority, 2022).
- Stakeholder Awareness and Engagement: The lack of awareness and understanding among stakeholders about the benefits of GFRP poles is a significant barrier. Effective stakeholder engagement and education programs are essential to increase acceptance and support (Kamweru & Ochieng, 2022).
- Environmental Impact: GFRP poles contribute positively to environmental sustainability by reducing the need for chemically treated wooden poles and minimizing the overall environmental footprint, supporting the goals of the Ethiopian Ten-Year Development Plan (Broniewicz et al., 2021).
- Alignment with Global Sustainability Goals: The adoption of GFRP poles aligns with global sustainability policies such as the Paris Agreement, Sustainable Development Goals (SDGs), and the EU's Circular Economy Action Plan, demonstrating Ethiopia's commitment to sustainable infrastructure development (UNFCCC, 2015; United Nations, 2015; European Commission, 2020).

5.3. RECOMMENDATIONS

5.3.1 Developing Pilot Projects

- Implementing Pilot Projects: Pilot projects are essential for demonstrating the practical benefits and feasibility of GFRP poles through real-world testing. These projects will provide evidence to support wider adoption and help refine installation and maintenance practices.
- Monitoring and Evaluating: Establish a robust framework for continuous monitoring and evaluation to capture and analyze performance data, helping to understand the strengths and areas for improvement of GFRP poles.

5.3.2 Establishing Comprehensive Standards and Guidelines

- Developing Standards: Develop and enforce comprehensive standards and guidelines specific to GFRP utility poles. This process should involve all relevant stakeholders to ensure practicality and effectiveness.
- Aligning Internationally: Align the new standards with international benchmarks to maintain high quality and facilitate international collaboration.

5.3.3 Providing Financial Incentives

- Offering Financial Incentives: Introduce financial incentives to offset the higher initial costs of GFRP poles. This could include subsidies, grants, or favorable financing terms to encourage investment in GFRP technology.
- Creating Funding Programs: Establish dedicated funding programs to support the adoption of GFRP technology. These programs can help cover the costs of pilot projects and initial deployments, ensuring sustainable adoption.

5.3.4 Enhancing Stakeholder Engagement and Education

- Educating Stakeholders: Conduct continuous education and training programs for stakeholders, including utility operators, regulatory officials, and engineers. This will increase awareness and understanding of the benefits of GFRP poles and build support for their adoption.

- Facilitating Collaboration: Promote collaboration among utility companies, regulatory bodies, manufacturers, and academic institutions to address challenges collectively.

5.3.5 Training and Capacity Building Programs

- Developing Training Programs: Develop and implement comprehensive training programs for engineers, technicians, and regulatory officials to build technical expertise and ensure the effective adoption of GFRP poles.
- Ensuring Continuous Professional Development: Ensure continuous professional development through regular training sessions and workshops to maintain proficiency and keep up with technological advancements.

5.3.6 Supporting Local Manufacturing and Supply Chains

- Encouraging Local Manufacturing: Encourage the development of local manufacturing facilities for GFRP poles to reduce costs and improve supply chain efficiency, contributing to local economic development and job creation.

5.3.7 Promoting Environmental and Sustainability Goals

- Aligning with Environmental Goals: Align the adoption of GFRP poles with national and global sustainability goals by highlighting the environmental benefits of GFRP technology in policy discussions and infrastructure planning.

5.3.8 Conducting Further Research

Ongoing Research: Conduct further research to explore additional benefits and potential challenges of GFRP utility poles. This should include consideration of natural fiber-reinforced polymer (NFRP) poles as an alternative, focusing on long-term performance, cost-benefit analysis, and advanced manufacturing techniques.

These recommendations are designed to facilitate the successful integration of GFRP utility poles into the EEU's infrastructure, addressing both the opportunities and challenges identified in the study.

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APPENDICES A

SEMI-STRUCTURED INTERVIEW QUESTIONS

On the study of "Prospects and challenges of Glass Fiber Reinforced Polymer (GFRP) utility poles as an alternative in the context of the Ethiopian Electric Utility (EEU)"

KEY TERMS:

I. **"SUSTAINABILITY INITIATIVES"** can be described as practical efforts or actions aimed at ensuring that human activities and systems are environmentally responsible and can continue without depleting natural resources or causing harm to ecosystems.

II. **"ADOPTING AND ADAPTING OF A TECHNOLOGY"** can be described as the process of taking on and modifying a technology to fit specific needs or contexts.

STAKEHOLDERS:

A.1 Ethiopian Electric Utility (EEU)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within EEU?

Questions:

1. How does EEU assess the technical feasibility of GFRP utility poles?
2. How does EEU evaluate the costs of GFRP poles compared to traditional materials?
3. What benefits does EEU foresee with GFRP poles in terms of sustainability and efficiency?
4. What strategies will EEU use to adopt GFRP technology and address related challenges?

5. What quality assurance measures are in place for GFRP poles, and how will their performance be monitored?
6. What key actions or policies should be prioritized for successful GFRP pole implementation?

Thank You:

A.2 Ethiopian Electric Power (EEP)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within EEP?

Questions:

1. What technical challenges with traditional poles does GFRP technology address?
2. How do traditional poles impact EEP's infrastructure, and what improvements does GFRP offer?
3. How familiar are you with sustainable alternatives, and how does EEP incorporate them?

Thank You:

A.3 Addis Ababa Institute of Technology & Mekelle University

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within AAIT, Mekelle University?

**Questions: **

1. How does the Institute assess the feasibility of adopting GFRP poles?
2. What challenges with traditional poles could GFRP address, and what opportunities does it present?
3. What research initiatives are focused on alternative utility pole materials like GFRP?

4. What recommendations would you provide for adopting GFRP poles?
5. **Thank You:**

A.4 Ethiopian Energy Authority (EEA)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within EEA?

Questions:

1. How does EEA evaluate the regulatory framework for GFRP poles?
2. What economic factors influence the adoption of GFRP poles, and how does EEA assess cost-effectiveness?
3. How does EEA support capacity building and training for GFRP technology?
4. What recommendations would you propose to promote GFRP pole adoption?

Thank You:

A.5 Institute of Ethiopian Standards (IES)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within IES?

Questions:

1. How is IES incorporating GFRP poles into national standards?
2. What measures ensure regulatory compliance and quality for GFRP poles?
3. What are the primary challenges hindering GFRP pole adoption?
4. What recommendations would you provide for integrating GFRP poles into standards?

Thank You:

A.6 Ethiopian Conformity Assessment Enterprise (ECAE)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within ECAE?

Questions:

1. What are the key steps in the certification process for GFRP poles?
2. How does ECAE facilitate market access for GFRP poles?
3. How does ECAE ensure adherence to international standards?
4. What strategies would strengthen the certification process for GFRP poles?

Thank You:

A.7 Ethiopian National Accreditation Office (ENAO)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within ENAO?

Questions:

1. How does ENAO facilitate the accreditation process for GFRP poles?
2. What role does ENAO play in establishing quality standards for GFRP poles?
3. How does ENAO collaborate with stakeholders to ensure the quality of GFRP poles?
4. What measures should ENAO prioritize to support GFRP pole adoption?

Thank You:

A.8 Addis Ababa City Roads Authority (AACRA)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within AACRA?

Questions:

1. What technical challenges with traditional poles does AACRA face, and how could GFRP address these?
2. How do traditional poles impact AACRA's infrastructure, and what improvements does GFRP offer?
3. How familiar are you with sustainable alternatives, and how does AACRA incorporate them?
4. How does AACRA plan to evaluate the costs of adopting GFRP poles?
5. What recommendations would you provide for integrating GFRP poles into projects?

Thank You:

A.9 Ethio Telecom

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within Ethio Telecom?

Questions:

1. How does Ethio Telecom assess the feasibility of GFRP poles for telecom infrastructure?
2. What technical challenges with traditional poles influence the exploration of GFRP?
3. How familiar are you with sustainable alternatives, and how does Ethio Telecom incorporate them?
4. How does Ethio Telecom address the costs of transitioning to GFRP poles?
5. What recommendations would you provide for integrating GFRP poles into the network?

Thank You:

A.10 Safaricom

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within Safaricom?

Questions:

1. How does Safaricom assess the viability and performance of GFRP poles for telecom infrastructure?
2. What challenges with traditional poles does GFRP technology address?
3. How familiar are you with sustainable alternatives, and how does Safaricom incorporate them?
4. How does Safaricom evaluate the costs of adopting GFRP poles?
5. What recommendations would you provide for implementing GFRP poles in the network?

Thank You:

A.11 Manufacturers of Fiber Products

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role?

Questions:

1. How familiar is your company with GFRP technology, and what fiber-based products do you manufacture?
2. What prospects and challenges do you see in producing GFRP utility poles?
3. How does your company ensure the quality and feasibility of GFRP poles?
4. What market trends influence the adoption of GFRP poles?
5. How is your company innovating in the field of fiber products, particularly related to utility poles?
6. What recommendations would you offer to promote GFRP pole adoption?

Thank You:

A.12 Ministry of Environment, Forest & Climate Change (MEFCC)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within MEFCC?

Questions:

1. How does the Ministry assess the environmental impact of transitioning to GFRP poles?
2. What role does MEFCC play in promoting sustainability initiatives related to GFRP poles?
3. How is the Ministry developing regulations to facilitate GFRP pole integration?
4. What actions or policies should be prioritized for environmental benefits from GFRP poles?

Thank You:

A.13 Ministry of Innovation and Technology

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within Ministry?

Questions:

1. How does the Ministry support the adoption of GFRP technology in the utility sector?
2. What policies promote technological innovation for GFRP poles?
3. How does the Ministry engage stakeholders about GFRP poles?
4. What strategies could enhance GFRP pole integration?

Thank You:

A.14 Ministry of Water and Energy (MoWE)

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role within MoWE?

Questions:

1. How does the Ministry evaluate the economic feasibility of GFRP poles?
2. What regulatory frameworks support GFRP pole integration?
3. How does the Ministry collaborate with stakeholders to promote GFRP poles?
4. What strategies should be implemented to accelerate GFRP pole adoption?

Thank You:

A.15 Independent Consultant on Environment, Forest & Climate Change

Introduction:

Thank you for participating. Could you please introduce yourself and describe your role?

Questions:

1. How do you evaluate the environmental impact of transitioning to GFRP poles?
2. What role can sustainability experts play in promoting GFRP poles?
3. How can experts support the development of regulations for GFRP poles?
4. What economic barriers and benefits do you foresee with GFRP pole adoption?
5. What actions should be prioritized to maximize environmental benefits of GFRP poles?

Thank You:

APPENDICES B

Transcription Summary of the Semi-Structured Interviews

B.1 Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP)

- **Challenges with Traditional Poles**: Wooden poles are prone to rot and insect damage; steel poles corrode and are conductive; concrete poles crack under harsh weather. These issues lead to frequent maintenance and shorter lifespans.
- **GFRP Utility Poles**: Offer extended durability, weather resistance, non-conductivity, and fire resistance. They require less maintenance, are lighter, and reduce labor and logistical expenses.
- **Adoption Recommendations**: Implement pilot projects to test performance, engage stakeholders, develop standards, conduct a cost-benefit analysis, provide training, and run awareness campaigns.

B.2 Regulatory Bodies (IES, ECAE, ENAO, ISO)

- **Standards Development**: Initiated by manufacturers, suppliers, or governmental bodies. A committee with key stakeholders develops standards, especially for high-impact products like utility poles.
- **Certification and Quality Assurance**: ECAE provides third-party certification to ensure products meet standards. Imported raw materials and GFRP products are checked for quality compliance.

B.3 Ethiopian Energy Authority (EEA)

- **Role in Standards and Tariffs**: Updates Electric Grid Codes to include GFRP utility poles, ensuring they meet material, structural, and performance standards. Reviews and recommends tariffs for GFRP poles.
- **Support for GFRP Adoption**: Collaborates with IES for standard development and provides the legal framework for EEU's integration of new technologies.

B.4 Ministry of Innovation and Technology

- **Support for GFRP Adoption**: Provides technical assistance, funding for pilot projects, and training programs. Encourages the use of sustainable alternatives through financial incentives and regulatory support.
- **Awareness and Education**: Organizes workshops, seminars, and public awareness campaigns to promote GFRP utility poles.

B.5 Ministry of Water and Energy (MoWE)

- **Energy Access Goals**: Aims to achieve a 50% energy access rate, presenting a significant market for utility poles. GFRP poles are expected to capture a substantial market share due to their quality and durability.

B.6 Ministry of Environment, Forest & Climate Change (MEFCC)

- **Environmental Impact Assessments (EIA)**: Supports the adoption of GFRP poles if found environmentally beneficial. EIAs consider factors such as resource extraction, manufacturing, transportation, installation, maintenance, and disposal.
- **Regulations and Policies**: Develops regulations to facilitate GFRP pole integration into the EEU network, focusing on material quality, environmental performance, and safety.

B.7 Ethio Telecom

- **Challenges with Traditional Poles**: High costs and logistical issues with concrete poles; wooden poles rot quickly and are environmentally unfriendly.
- **Benefits of GFRP Poles**: Offer durability, are lightweight, easy to install and maintain, environmentally beneficial, and provide long-term cost savings.
- **Adoption Strategy**: Conduct pilot projects to evaluate performance and gradually replace traditional poles.

B.8 Manufacturers

- **GFRP Pole Production**: Local manufacturing initiatives face cost concerns and competition from international suppliers.
- **Cost Analysis**: Despite higher initial costs, GFRP poles offer long-term savings due to durability and minimal maintenance needs.
- **Challenges**: Limited demand, need for skilled labor, and resistance from traditional pole manufacturers.

B.9 Independent Consultants and Universities

- **Sustainability**: GFRP poles align with several UN Sustainable Development Goals (SDGs). They provide reliable, cost-effective, and environmentally friendly infrastructure.
- **Technical and Economic Feasibility**: GFRP poles offer superior mechanical strength, reduced maintenance, and longer lifespan compared to traditional poles.
- **Recommendations**: Governmental support, development of local standards, and increased awareness and training programs.

B.10 Addis Ababa City Roads Authority (AACRA)

- **Challenges with Traditional Poles**: Wooden and concrete poles are difficult to maintain and install. Steel poles are vulnerable to theft and damage.
- **Recommendations for GFRP Poles**: Design GFRP poles with human-inaccessible cabling, digital screens, security cameras, and other features. Develop standards and conduct pilot projects.

B.11 Safaricom Telecommunications Ethiopia PLC

- **Advantages of GFRP Poles**: Longer lifespan, lightweight, weather-resistant, and zero maintenance costs. Adopt a strategy for gradual replacement of traditional poles with GFRP poles for sustainable infrastructure.

APPENDICES C

Traditional Utility Poles versus (GFRP Utility Pole)-Photos

Photo: EEP Concrete Pole

Figure H-1. Photo. A close-up of the energy absorbing utility poles used as a part of NJDOT's pilot project.

Environmental Impact Comparison

Graph illustrating the reduced environmental footprint of GFRP poles compared to wooden, steel, and concrete poles, showing factors such as carbon footprint, deforestation, and chemical use (Broniewicz et al., 2021).

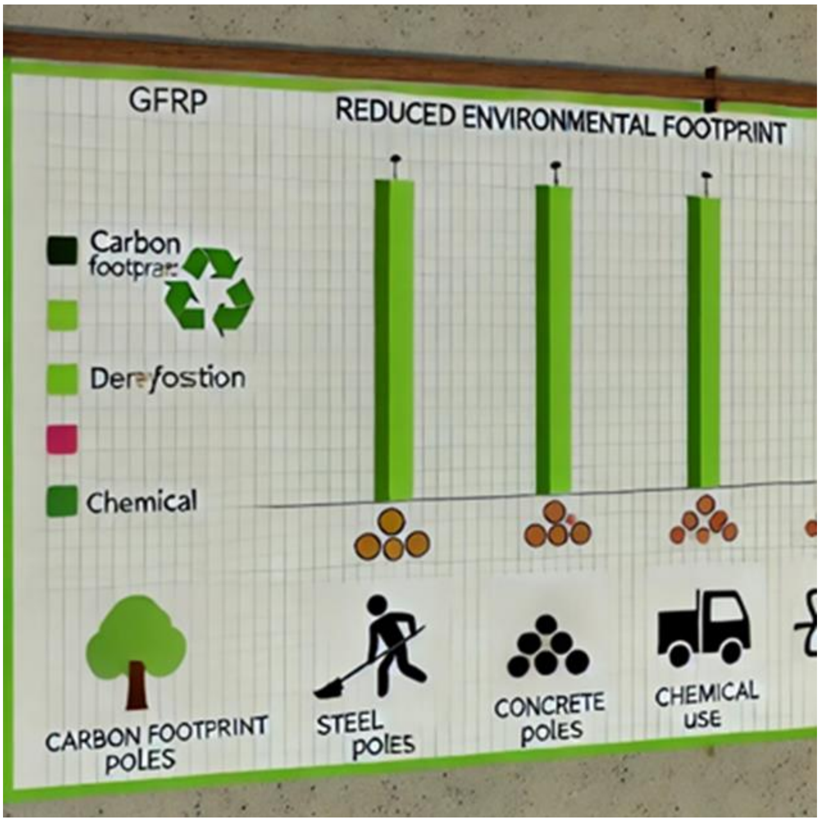


Photo Concrete Pole: @ Addis Ababa, nearby ETV old Building /Traffic Light Junction

©TECO/EMERA 2016

Photo by Engineer Elias (Elias Alemayehu & Friends Electrical Workshop Partnership) GFRP Utility Pole Manual Strength Test

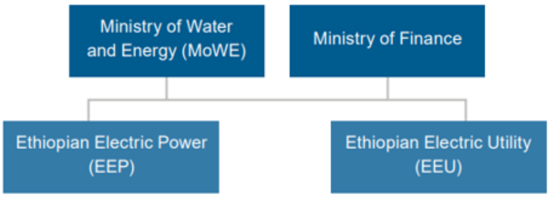
Addis Ababa, 2024

APPENDICES D

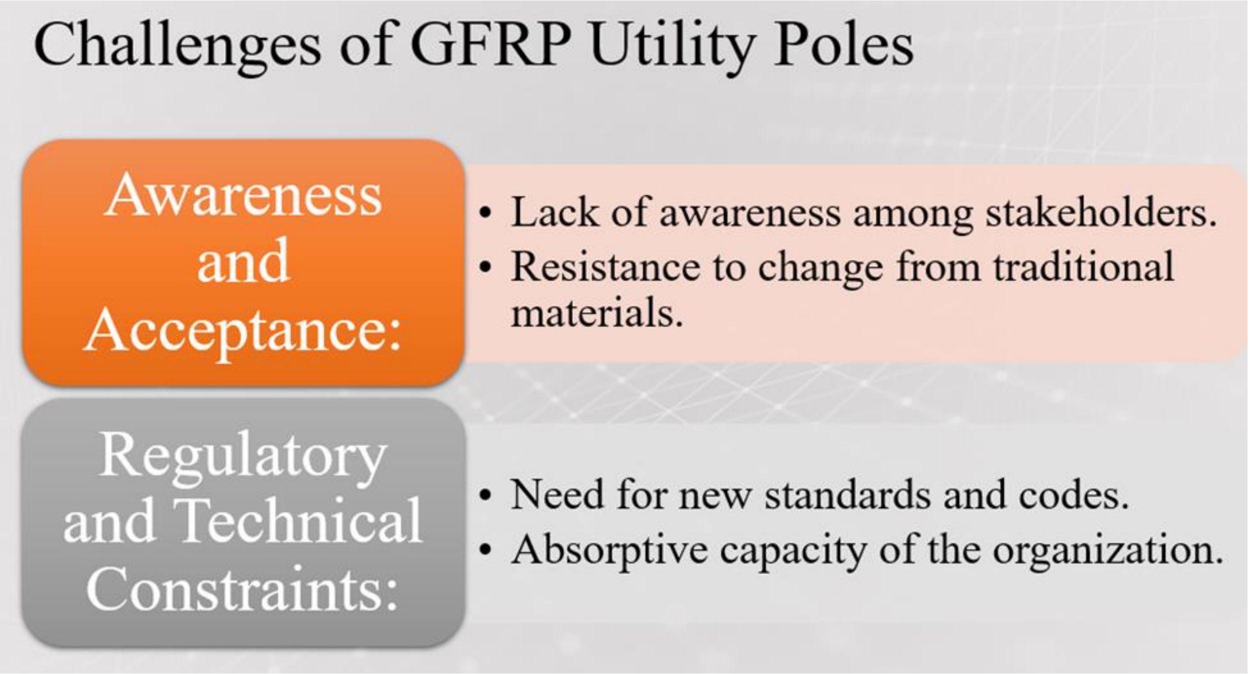
FACTS ABOUT EEU

(Ethiopian Electric Utility, 2023; TRAIDE Ethiopia, 2022)

ETHIOPIAN ENERGY SECTOR HIERARCHY



Aspect	Details
Total Transmission & Distribution Line Length	116,912 km
Values	Sustainability, Innovation
Mission	Deliver cost-effective, safe, reliable, and high-quality power (striving for international standards in customer care and corporate governance)
Vision	Energizing the Ethiopian economy and people (by 2030)
Energy Access Rate	48% (11% off-grid)

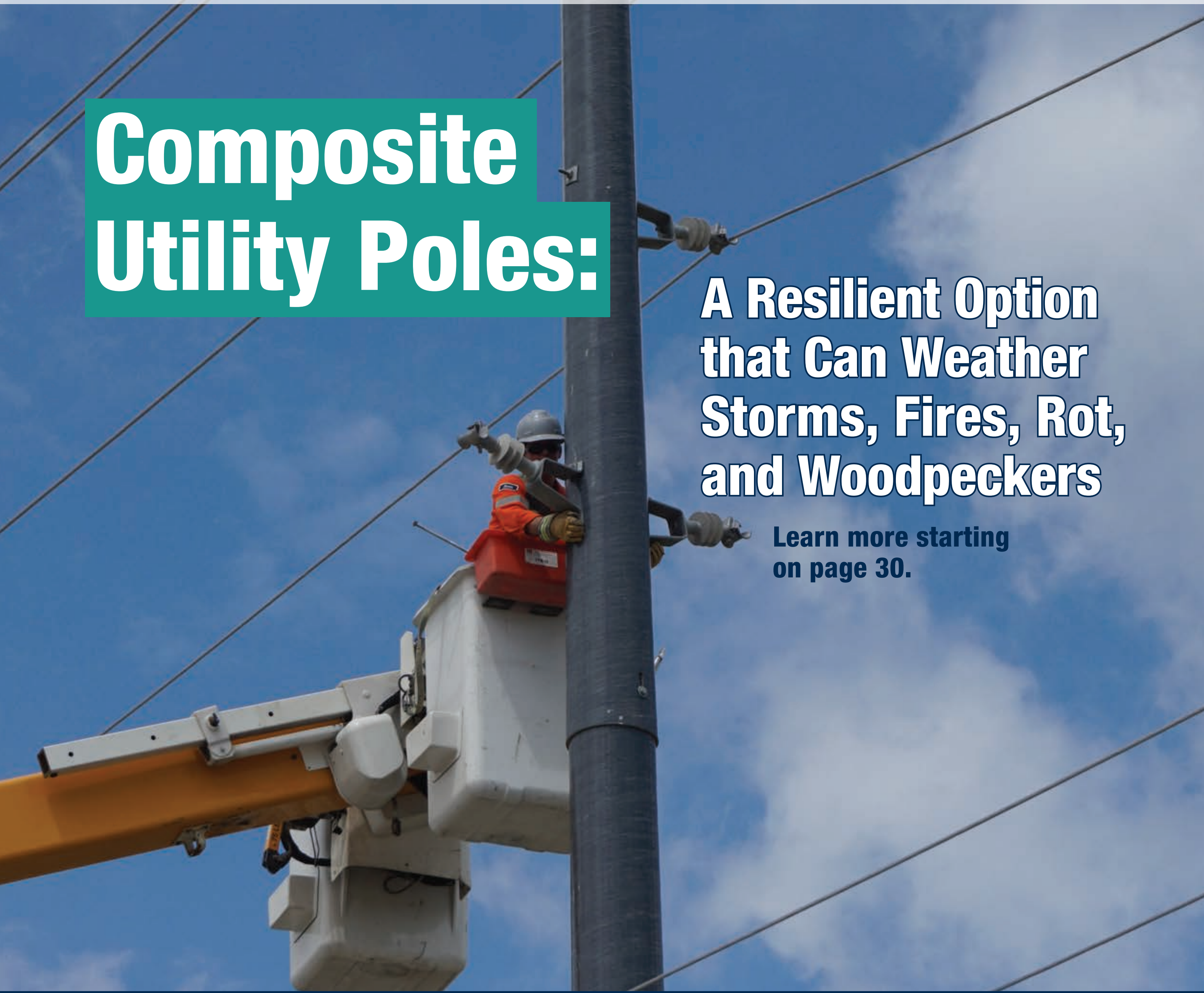

Challenges of GFRP Utility Poles
Awareness and Acceptance:
• Lack of awareness among stakeholders.
• Resistance to change from traditional materials.
Regulatory and Technical Constraints:
• Need for new standards and codes.
• Absorptive capacity of the organization.

PWABC Public Works Association of British Columbia
APWA Alberta Public Works Association
CPWA Canadian Public Works Association Saskatchewan Chapter
CPWA Canadian Public Works Association Association canadienne des travaux publics Manitoba Chapter
AMSA Alberta Municipal Supervisors Association

THE OFFICIAL PUBLICATION OF THE PUBLIC WORKS ASSOCIATION OF BRITISH COLUMBIA, THE ALBERTA PUBLIC WORKS ASSOCIATION, THE SASKATCHEWAN PUBLIC WORKS ASSOCIATION, THE MANITOBA PUBLIC WORKS ASSOCIATION, AND THE ALBERTA MUNICIPAL SUPERVISORS ASSOCIATION

THE ROADRUNNER

WINTER 2021



Composite Utility Poles:

A Resilient Option that Can Weather Storms, Fires, Rot, and Woodpeckers

Learn more starting on page 30.

FIND OUT WHAT'S HAPPENING ONLINE

Canada Post Mail Publications Agreement Number: 40609661

Composite Utility Poles: A High-Performance Solution

By Galen Fecht, RS Technologies Inc.

There is now a high-performance composite alternative to those ubiquitous wood utility poles that line our streets and sidewalks. The humble utility pole, or telephone pole as it is commonly referred to, carries more than just telephone lines. In fact, any given utility pole will typically support a host of essential services like electricity (i.e. hydro power), voice, and data communication that are critical to empowering our daily lives.

Wood poles have been used for over 175 years and, in that time, they have done a decent job of supporting overhead line networks. But times are changing. The “old growth” wood poles of yesterday were stronger than they are now. First generation poles were treated with preservative chemicals like creosote to slow down rot, whereas today’s wood pole is likely to be a less dense, tree farm-sourced pole treated with less effective preservatives, with less strength, higher deflection, and requiring earlier replacement. This shift

TOP: A lightweight, modular composite pole being assembled for a wetland installation.

LEFT: A three-year old, structurally compromised wood pole riddled with woodpecker holes and displaying five instances of woodpecker hole remediation attempts (the plastic wrap on the pole).

in wood pole performance, coupled with the increasingly severe weather and environmental events that many of us are experiencing (think of wildfires and hurricanes), makes the case for pivoting to a more resilient and longer lasting type of utility pole.

Steel and concrete poles are alternative choices, but they have their respective drawbacks. Steel poles are subject to corrosion and are conductive, which presents challenges for utility line crews performing live line installation and maintenance work, and public safety risks when there is an insulator fault. Concrete poles are extremely heavy, which complicates logistics and installation procedures.

So, what else is available as an alternative to the status quo?

The answer is composite poles, which are light weight and deliver reliable, engineered performance. These tubular poles are also known as fibre-reinforced polymer (FRP) or fibreglass poles. Composite poles are comprised of structural fibres, from which the pole derives it strength, and a thermoset resin, which is the "glue" that transfers load stress to and between the fibres. Although composite poles have been in use since the 1960s, it is only within the last 10 years that they have been more widely adopted by electric utility and communication companies. While many factors are driving increased adoption, the rationale can be boiled down to the fact that composite poles solve many of the problems that afflict wood, steel and concrete poles.

What about cost? Are composite poles more expensive than wood poles? A 40 to 50 ft. composite pole commonly used in an overhead electric distribution line will typically be three to five times the cost of a comparable $500 wood pole. But, as with many things we purchase in life, up front price isn't the entire story. Planning, engineering, labour, transportation, equipment, inspection, and maintenance costs for that $500 wood pole typically add up to about $9,500, bringing the total wood pole cost to $10,000 or more.

Comparatively, the installation of a $2,500 composite pole is about $12,000, which represents only a 20 per cent premium on a total installed cost basis. For pole lengths beyond 50 ft., there is a negative correlation between cost difference and pole length for wood poles and composite poles (i.e. as pole length increases, the cost difference reduces). As we will see, in many situations, this extra cost more than pays for itself.

One reason to use a composite pole instead of a wood pole is simply because wood poles do not last as long as they should. On average, wood poles are expected to last 40 years. However, there are some installations where a wood pole will last only a fraction of that time before it needs to be replaced. In North America, woodpeckers and pests like carpenter ants are responsible for hundreds of millions of dollars in damage to wood poles annually. In some instances, a wood pole can be structurally unfit to support its initial design load in only two or three days after its installation if it is aggressively targeted by woodpeckers. Should that happen to a wood pole, another $10,000 investment is required to again replace the compromised wood pole.

Woodpeckers, ants, and other wildlife can't damage a composite pole. Replacing the woodpecker damaged wood pole with a composite pole eliminates the need to replace the pole for the next 80 years, which is the average service life of some composite poles. Appreciating that woodpeckers are territorial, a composite pole is a good investment to mitigate future damage and frequent replacement costs.

Premature rot is another situation when a wood pole might not last as long as it should. Because utility poles are embedded into the ground, accelerated wood rot often occurs in wetland areas or regions with high water tables. The use of a composite pole solves the rot problem and, in these applications, is also a superior choice from an environmental perspective. Composite poles also do not contain harmful preservative chemicals that ultimately leach into the ground from wood poles. This makes composite poles an excellent choice in areas where drinking water wells are located, or in sensitive wetland environments.

Speaking of wetlands, these areas typically need specialized equipment to install utility poles, such as tracked vehicles or mobile cranes, and often require swamp mats to facilitate site access. These are additional time and cost considerations that can easily double the installed cost of a pole. This example leads to another reason to use composite poles: where the total installation cost is higher than average. The more remote or off-road a pole location is, the higher the cost to install and maintain that pole. Because composite poles are about 1/3 the weight of a comparable wood pole, lighter duty equipment can be used which typically results in a lower installed cost for a composite pole compared to a wood pole in remote locations.

Yet another application for high-performance composite poles is where reliability is paramount. High winds, ice storms and other natural events are becoming increasingly commonplace. During storms or fires there can be hundreds if not thousands of wood pole failures, which create power outages and delay restoration efforts. Engineered composite poles are designed to withstand extreme loads because they can absorb high amounts of elastic strain energy. Composite poles can flex and better withstand loads, such as a tree falling on a line. Often, it's the conductor cable or the hardware that attaches the conductor to the pole, that acts as the weak link. Once the load on the pole is released, composite poles return to their vertical orientation and a line crew can merely re-string the conductor to restore electrical service. This is in stark contrast to wood poles that can fail in a cascading manner, requiring large numbers of poles to be procured, transported, and installed, all in advance of the conductor cable being re-strung and service restored.

Moreover, composite poles are fire resistant and can remain standing during and after wildfire events. The bottom line is that composite poles reduce the chances of electrical service interruptions – and they shorten the length of the outages when they do indeed occur.

Currently, composite poles make up less than one per cent of poles installed in the grid, so there is no doubt that wood poles will continue to be used in the future. However, considering both the reliable everyday performance of composite poles as well as their proven performance in severe weather and fire events – considering composite poles for a wide range of applications makes a lot of sense.

Galen Fecht is the Director, Technical Service and the ASCE FRP Committee Chair. For more information, contact RS at info@RSpoles.com.

UTILITY POLE COMPARISON CHART

	StressCrete Pre-Stressed Spun Concrete	Wood	Steel	Static Cast Concrete	Ductile Iron	Composite	Laminated Wood
Engineering and Strength	Engineered product designed to customer's exact requirements including number and placement of through holes. Easy to field drill if necessary.	Not an engineered product which can be field drilled	Engineered product which is difficult to field drill and must be protected	Engineered product which can be field drilled	Engineered product which is difficult to field drill and must be protected	Engineered product which can be field drilled and must be protected	Engineered product which is difficult to field drill
	Guaranteed minimum strength that remains constant throughout its entire service life (lifetime warranty)	Average strength (not guaranteed) that diminishes over time	Strength is dependant on correctly installed slip joints and maintenance of corrosion	Guaranteed minimum strength	Strength is dependant on correctly installed slip joints and maintenance of corrosion	Strength is dependant on correctly installed slip joints and maintenance	Guaranteed minimum strength with bi-directional loading
	Highly reliable assisting with storm hardening initiatives	Low reliability during extreme weather events	Reliable	Non-round shape reduces carrying capacity in extreme winds	Long term reliability unknown	Long term reliability unknown	Reliable
Durability and Maintenance	Zero maintenance	Periodic preservative maintenance may be required every 5-10 years to prevent rot and decay	Periodic maintenance to ensure surface integrity is not compromised	Low maintenance	Unknown	Coating must be maintained to protect from UV	Periodic preservative maintenance may be required every 5-10 years to prevent rot and decay
	Not fatigue sensitive	Not fatigue sensitive	All welded and splice joints are fatigue sensitive	Not fatigue sensitive	All splice joints are fatigue sensitive	Unknown	Not fatigue sensitive
	Fire resistant and does not rot or rust. Not susceptible to freeze-thaw effects.	Susceptible to fire, rot and woodpeckers, requiring periodic inspections to determine structural integrity	Most susceptible to degradation at the ground line and below grade	Susceptible to freeze-thaw effects, rust and spalling	Most susceptible to degradation at the ground line and below grade	Damage such as scrapes during handling must be repaired to prevent deterioration	Susceptible to fire, rot and woodpeckers requiring periodic inspections to determine structural integrity
Environmental	Contains components that are natural or can be reused or recycled	Treated with harsh preservatives making disposal difficult	Can be reused or recycled	Can be reused or recycled	Can be reused or recycled	Unknown	Treated with harsh preservatives making disposal difficult
Mounting Holes	Pre-cast mounting holes which eliminates the need for field modifications	Typically require field drilling and modification to install	Pre-drilled mounting holes	Typically come with pre-cast mounting holes	Pre-drilled mounting holes	Pre-drilled mounting holes	Pre-drilled mounting holes
Construction	Centrifugally cast, pre-stressed reinforced concrete with round hollow core; one piece for easy installation	Naturally grown product; one piece	Multiple pieces that must be jacked together requiring longer installation	Square cross section with increased wind loading and high mass; one piece	Press fit joints that are pinned together or two piece pole options	One piece or multiple pieces that must be jacked together requiring longer installation	One piece or spliced sections
Installation Type	Direct buried which is fast and very cost effective	Direct buried	Baseplate installation which is costly to install. Direct embedment which requires additional coating or grounding sleeve to prevent corrosion.	Direct buried	Direct embedment which requires additional coating or grounding sleeve to prevent corrosion	Direct buried	Direct buried
Typical Lifespan and Cost	75+ years, low lifetime cost	25-40 years, maintenance and inspection costs	40-60 years, maintenance and inspection costs	40-60 years, depending on conditions	Lifespan unknown, maintenance and inspection costs	Lifespan unknown, maintenance and inspection costs	Lifespan unknown, maintenance and inspection costs
Warranty	Lifetime warranty	Varies, if available	Varies, if available	Varies, if available	Unknown	Varies, if available	Varies, if available
Industry Experience	Over 60 years	Varies	Varies	Varies	Since 2008	Varies	Varies

pultron® COMPOSITES

Cost Savings with FRP Composites

SHARE THIS ARTICLE:

Glass fiber-reinforced polymer (GFRP) composites are an increasingly popular material choice. **One of the big drivers of this demand is the reduced upfront cost of GFRP products over the last two decades.**

Increasing economic pressures, consumer demand, and the need for sustainable practices are encouraging companies and government agencies to look beyond the status quo. Traditional materials are now being surpassed by GFRP products which can deliver optimal

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compared to other materials

Wood is heavy and eventually rots, steel is expensive and rusts – GFRP composites are replacing both, often as critical structural or industrial components.

The increased use of GFRP pultrusions has led to significantly larger, more efficient production runs, which has in turn allowed pultrusion manufacturers to pass these savings on to the customer. **For example, the real cost of Mateenbar™ from Pultron's factory has been reduced by over 50% in the last 15 years.**

Such reductions have made GFRP composites a cost-effective option when compared to other materials. This is the result of continued technology breakthroughs within the pultrusion industry:

- Increased sizes of production runs have allowed pultrusion manufacturers to invest in R&D to improve efficiencies in the manufacturing process. The process is now faster and with less waste. **At Pultron, all our machinery is custom-built to ensure consistent output and speed.**
- Making pultruded composite products requires little power and water throughout the entire process.
- **Steel prices have skyrocketed and aluminum prices are experiencing a 13-year high. Raw materials have not increased in price to the same extent as steel and aluminum.** In many cases, the upfront cost of GFRP composites is now less than traditional materials.

savings is where GFRP composites continue to deliver the greatest value.

The cost of the product is only part of the equation when assessing commercial viability. Other considerations include:

- labor
- transportation
- other materials and additives: for example, concrete structures with GFRP rebar often require less concrete cover and no expensive additives for rust prevention.
- operational costs
- maintenance and repair
- life-cycle
- decommissioning.

Considering the cost of an asset across the lifetime is now seen as 'best practice' as opposed to focusing on the initial upfront cost. The International Institute for Sustainable Development states that whole-of-life costing changes the procurement mindset from the “best value for money” to the “best value across the asset life cycle”. This approach is better for asset owners, the environment, and communities in the long term.

At Pultron, our purpose is to produce customized composite solutions that are commercially viable and deliver durability, efficiency, and costs. **These typically involve replacing traditional materials that do not deliver the best price-performance ratio.**

Case study: How strengthening with FRP made economic sense at the Port of Rotterdam

Ports are under increasing pressure to move freight quickly and with no disruption to the schedule. Shipping delays caused by construction delays, equipment breakage, and concrete repairs will inevitably have a costly domino effect throughout the supply chain.

Engineers working on the terminal upgrade at Europe's busiest port, Port of Rotterdam (pictured) specified Mateendowel™ to be used in the concrete slabs to manage this risk.

Mateendowel™ is a corrosion-free joint system used in roading and replaces steel and stainless steel dowels. Savings will be achieved over the entire life cycle of the port:

- **Reduced Installation Costs.** Mateendowel™ is lightweight (4x lighter than steel) making it safer to handle and faster to install.
- **Reduced pre-preparation and materials.** The smooth surface of the dowel has low bond strength. There is no need to grease dowels or add bond breaker sleeves (which would be

dowels offer long life. Because they do not rust, they do not expand causing concrete breakage (spalling) and needing immediate repair, forcing downtime at this busy port.

- **Increased design life.** Mateendowel™ is corrosion-resistant and chemical-resistant. It is expected to last for more than 100 years.

The Highly Durable Alternative

Steel corrosion has a huge impact on the economy and environment. **According to NACE International, the cost of corrosion globally is estimated to be US$2.5 trillion.**

The corrosion-resistant properties are well-known but FRP materials deliver strengthened structures. Companies and government agencies are now choosing these materials over steel to eliminate the risk of corrosion.

When a structure cannot withstand the environmental elements, the result is increased cost in maintenance and early replacement. The cost of maintenance, as discussed in our feature GFRP composite rebar delivers sustainable and resilient infrastructure, and can account for up to 60% of the total cost of an infrastructure project.

They are Lightweight

GFRP materials are four times lighter than steel and only 70% of the density of aluminum. They are light and strong. **In fact, the strength-to-weight ratio is four times that of high tensile steel.**

The low density and lightweight properties mean the cost of transportation is significantly reduced.

than 50% in some cases.

FRP Material Technology is Future Ready

With upfront costs lower than ever, there are opportunities to improve on what has been done before or investigate GFRP composite for the future.

It's exciting to see what will be next in the world of pultrusion.

Have questions about composites and pultrusion? Get in touch.

About the author: Pete Renshaw is the Business Development Director at Pultron and serves as the Chief Technical Officer for Mateenbar Limited. He has over 25 years of experience working with pultruded composite product development.

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Review

A Review of Grid Code Requirements for the Integration of Renewable Energy Sources in Ethiopia

Baseem Khan [1,*], Josep M. Guerrero [2], Sanjay Chaudhary [2], Juan C. Vasquez [2], Kenn H. B. Frederiksen [3] and Ying Wu [2]

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Abstract: Rapid integration of renewable energy into the electric grid has ramifications for grid management and planning. Therefore, system operators have formulated grid code requirements to ensure that the grid continues to operate in a secure, safe, and cost-effective manner. The current state of grid code in Ethiopia, as well as the need for it, is discussed in this article. It lays out the technological grid integration requirements, with a focus on small and microgrids, which are especially important for the integration of renewable. The barriers to grid code normalization and renewable energy grid compatibility testing are identified, and suggestions for continued grid code development in Ethiopia based on Danish observations are provided. Further, a detailed comparative analysis of the Ethiopian grid code with the IEEE 1547-2003 and IEEE 1547-2018 standards is presented.

Keywords: grid code; minigrid; microgrid; renewable energy integration

Citation: Khan, B.; Guerrero, J.M.; Chaudhary, S.; Vasquez, J.C.; Frederiksen, K.H.B.; Wu, Y. A Review of Grid Code Requirements for the Integration of Renewable Energy Sources in Ethiopia. *Energies* **2022**, *15*, 5197. https://doi.org/10.3390/en15145197

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1. Introduction

The availability of energy is a major factor in global economic shifts. Energy security is a vital problem for industrialization and economic progress, as it helps to alleviate poverty, improve food production, improve clean water availability, update healthcare centers, raise standards of education, and generate work opportunities for young people, especially women. One out of every five individuals in the world does not have access to power. Several individuals still use charcoal, wood, agricultural waste, as well as other solid fuels for cooking and other daily activities; consequently, they suffer from several health problems that shorten their lives. Inadequate power availability has an impact on a family's income, industrial productivity, education, and health. Due to emissions from greenhouse gases, contemporary energy-producing units based on fossil fuels have an adverse impact on the climate and the environment [1]. At a national and international level, these atmospheric shifts cause water and food problems. Security of energy supply from renewable energy sources is crucial for sustainable development. Although there has been a significant improvement in alternative sources of energy, there are still several constraints that must be resolved in order to achieve large-scale sustainable growth. Many breakthroughs in technology, financial strategy, marketing strategies, regulatory, and governance frameworks are essential for sustainable power generation. In terms of global growth, African countries have a relatively low rate of sustainable development due to insufficient energy generation and availability [2]. There are three major energy concerns in sub-Saharan Africa: inadequacy of energy generation, insufficient energy access, and global warming. To limit the effects of global warming, these difficulties must be handled so that 100% availability of power may be achieved via renewable energy-producing infrastructure.