



MEKELLE UNIVERSITY
ETHIOPIAN INSTITUTE OF TECHNOLOGY- MEKELLE
FACULTY OF CIVIL AND ENVIRONMENTAL
ENGINEERING
CONSTRUCTION TECHNOLOGY & MANAGEMENT
POSTGRADUATE PROGRAM

The Construction Management of High Voltage Transmission Lines

Prepared By

Wang Ning

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POSTGRADUATE PROGRAM

An Independent Research Project Submitted in Partial Fulfillment of the
Requirements for the Degree of Master of Engineering in Civil Engineering,
specializing in Construction Technology and Management

The Construction Management of High Voltage Transmission Lines

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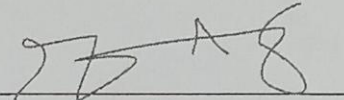
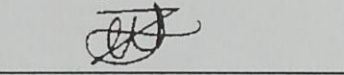
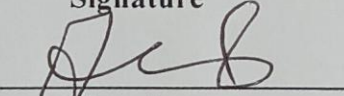
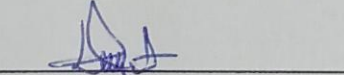
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POSTGRADUATE PROGRAM

The undersigned have examined the independent research project entitled “*The Construction Management of High Voltage Transmission Lines*”, presented by *Wang Ning* is approved for the degree of Master of Engineering in Civil Engineering, specialized in Construction Technology and Management.

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ABSTRACT

This study examines the construction management performance of three high-voltage (HV) transmission line projects in Ethiopia—Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV lines—which are vital for strengthening grid reliability and supporting national electrification goals. Managing these projects presents significant challenges due to complex technical requirements, difficult terrain, logistical constraints, and extensive coordination needs across civil, electrical, and administrative teams.

The research aims to evaluate construction management practices, identify the most pressing challenges, and propose evidence-based strategies to improve project efficiency, quality, and safety. A descriptive and exploratory research design was used. Data were collected from 18 key informants (project managers, engineers, site supervisors) and 42 project documents, including contracts, design drawings, test reports, and progress records.

The analysis focused on three core dimensions—planning and survey, material and quality management, and execution and commissioning. The findings reveal that planning and survey effectiveness averaged 82%, supported by accurate route selection and reduced rework. Material and quality management performance averaged 76%, though procurement delays and logistics constraints affected tower delivery and conductor stringing schedules. Execution and commissioning achieved 84% performance, driven by strong supervision, safety compliance, and coordinated team workflows. Key challenges included logistical delays (reported in 67% of sites), terrain-related access problems (52%), and coordination gaps among stakeholders (48%). These were mitigated through proactive planning, improved contractor–client communication, and adaptive risk management strategies.

Overall, the study concludes that integrated and data-driven construction management significantly improves schedule adherence, cost efficiency, and technical quality in HV transmission line projects. The findings offer practical guidance for policymakers, engineers, and project managers seeking to enhance performance, reliability, and long-term sustainability in Ethiopia’s power transmission infrastructure.

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LISTS OF ABBRIVATIONS

Abbreviation	Description
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CBR	California Bearing Ratio
EEPCo / EPCO	Ethiopian Electric Power Corporation
GIS	Geographic Information System
GPS	Global Positioning System
HV	High-voltage
km	Kilometer
m	Meter
N	Number of respondents
%	Percent / Percentage
PPE	Personal Protective Equipment
QA	Quality Assurance
ROW	Right-of-way
Sinohydro	Sinohydro Corporation Ltd. (contractor company)

1. INTRODUCTION

1.1. Background of the Study

Ethiopia is undergoing rapid economic and industrial development, which has led to a significant increase in electricity demand. The reliable operation of the national power system is critical to supporting economic growth and ensuring energy security. Transmission infrastructure, particularly high-voltage (HV) transmission lines, plays a crucial role in transferring electricity from generation sources to load centers efficiently.

The construction of high-voltage transmission lines involves complex engineering, logistics, and management challenges. Projects require detailed planning, design, quality assurance, procurement, site preparation, erection, and testing of transmission structures and associated civil works. Effective construction management is essential to ensure project objectives are met within budget, on schedule, and with the required quality standards.

The Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV transmission lines are part of Ethiopia's Electricity Network Reinforcement and Expansion Project, aiming to enhance grid stability, expand electricity access, and support sustainable development. These projects are executed under the contract agreement between Ethiopian Electric Power (EEP) and Sinohydro Corporation Ltd, encompassing survey, design, material supply, civil and electrical works, testing, and commissioning.



Figure 1-1: Finchaa-II 230 kV Substation Project

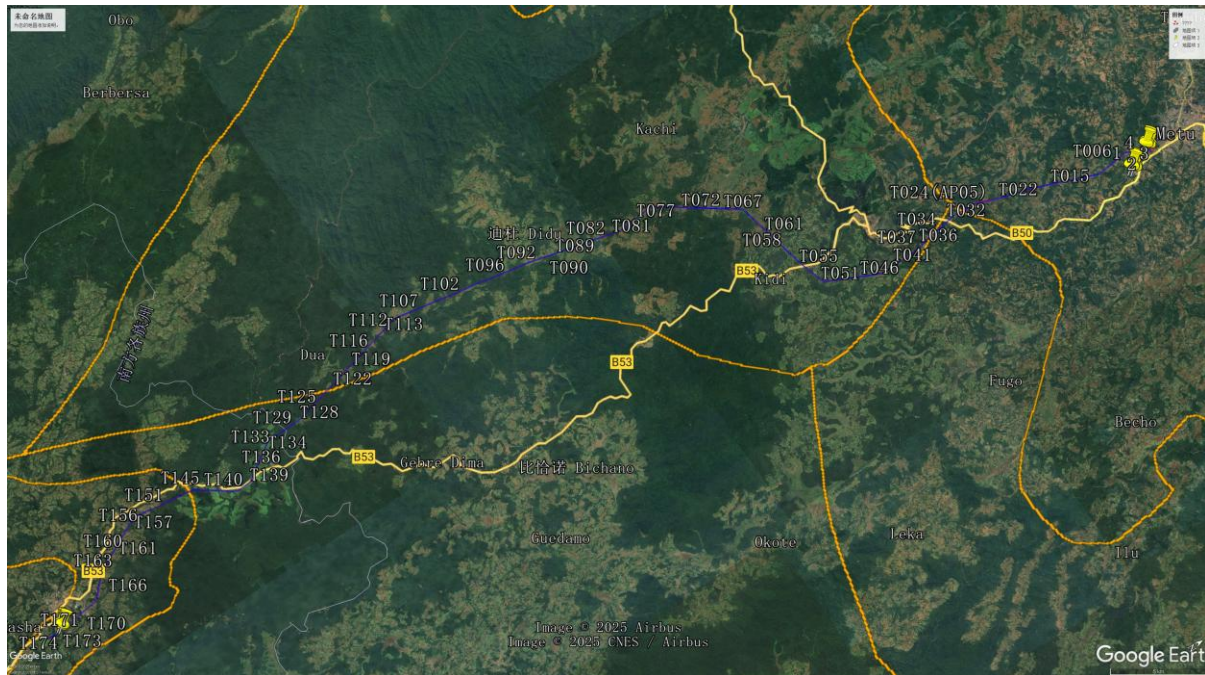


Figure 1-2: METU-MASHA Transmission Line Route

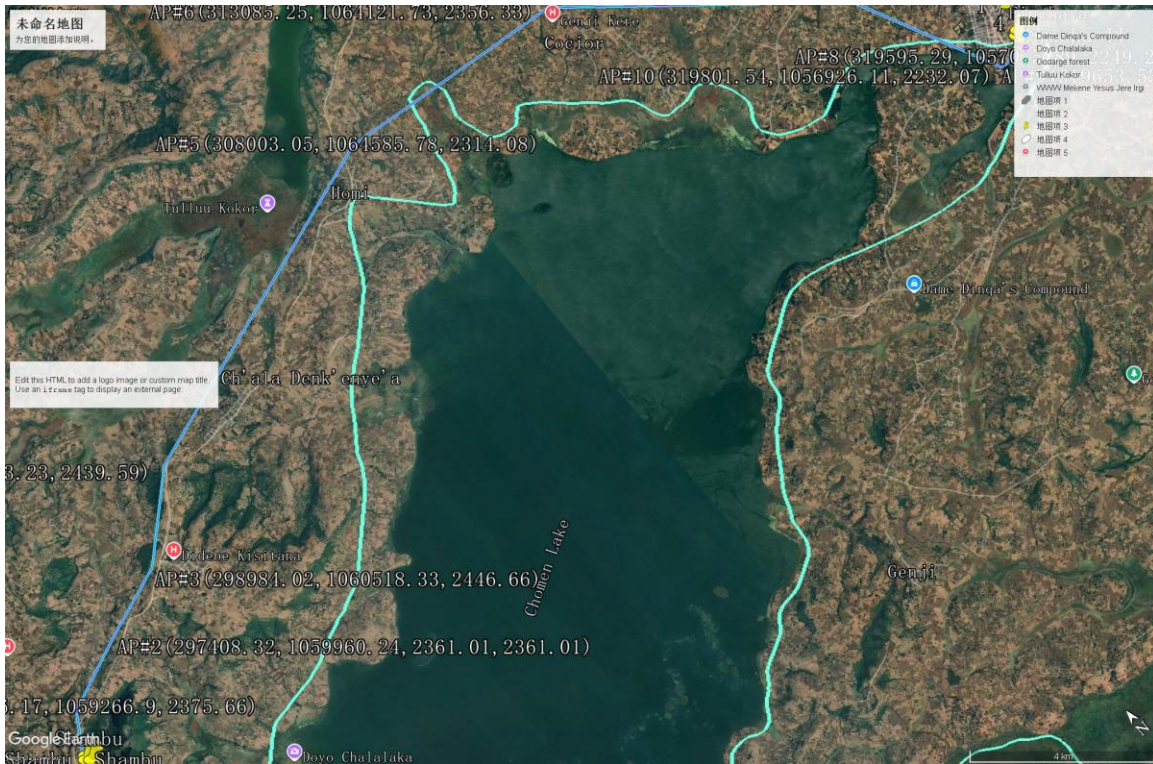


Figure 1-3: FINCHAA-SHAMBU Transmission Line Route

1.2 Problem Statement

High-voltage transmission line projects are inherently complex and face multiple challenges, including route survey discrepancies, right-of-way clearance issues, foundation and structure erection problems, material supply delays, and testing and commissioning bottlenecks. Poor coordination or management of these aspects can result in cost overruns, project delays, safety hazards, and reduced system reliability.

Despite Ethiopia's expansion of its transmission infrastructure, limited research exists on the practical management challenges encountered during construction, especially in multi-line, high-voltage projects like the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha transmission lines. This study aims to assess the construction management practices, challenges, and mitigation strategies employed in these projects to identify lessons for future HV transmission line projects in Ethiopia.

1.3 Objectives

1.3.1 General Objective

To evaluate the construction management practices and identify challenges and solutions in the implementation of high-voltage transmission line projects in Ethiopia.

1.3.2 Specific Objective

The followings are specific objectives of this research:

- To examine the planning and survey activities, including tower spotting, right-of-way clearance, and route verification.
- To assess the effectiveness of material supply, construction and installation, and commissioning process.
- To identify key challenges affecting project timelines, quality, and cost, and propose recommendations to improve construction management efficiency.

1.4 Significance of the study

This study is significant for policymakers, project managers, contractors, and engineers involved in the planning and execution of high-voltage transmission line projects in Ethiopia. By analyzing the construction management practices, challenges, and response strategies observed in the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV transmission line project, the research will provide practical insights for improving project planning, execution, supervision, and overall management efficiency. The findings will support the Ethiopian government and Ethiopian Electric Power (EEP) in enhancing project performance, cost-effectiveness, and system reliability in similar infrastructure projects. Furthermore, the study will serve as a valuable reference for future research, training, and capacity-building initiatives related to transmission line construction management and large-scale infrastructure development in Ethiopia.

1.5 Scope of the study

This study focuses on the construction management of the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV transmission line projects implemented under the Ethiopian Electric

Power's Electricity Network Reinforcement and Expansion Project. The research examines key aspects of project management, including survey and design verification, material supply and quality assurance, procurement processes, and the execution of both civil and electrical works. Particular attention will be given to foundation construction, access road development, tower erection, line installation, and the fabrication of special structures, as well as the procedures for testing and commissioning. The study will primarily rely on project documentation and interviews with project managers, engineers, and other stakeholders, without involving direct field construction activities or design implementation.

1.6 Limitations of the Study

The study is limited by its reliance on secondary project data and stakeholder interviews, which may be subject to incomplete documentation or recall bias. Access to confidential project reports and contractual records may also be restricted. Additionally, the research does not include real-time monitoring of ongoing site activities or physical verification of construction performance. Financial and time constraints further limit the number of respondents and case sites included in the study. Despite these limitations, the analysis provides a representative overview of construction management challenges in Ethiopian transmission line projects.

1.6 Beneficiaries of the Study

The primary beneficiaries of this study include Ethiopian Electric Power (EEP), project consultants, contractors, and government bodies involved in the energy sector. Policymakers will gain valuable insights for improving project implementation frameworks, while contractors and engineers can apply the findings to enhance construction management practices. Academic institutions and researchers will also benefit from the study as a reference for further investigations into transmission infrastructure development. Ultimately, the improved management of such projects will indirectly benefit the broader public through more reliable power supply and accelerated national electrification.

1.7 Research Organization

This research is organized into five main chapters. Chapter One introduces the study, presenting the background, problem statement, objectives, significance, scope, limitations, and beneficiaries of the research. Chapter Two reviews relevant literature, including theoretical and empirical

studies on construction management practices, project execution challenges, and management frameworks related to high-voltage transmission line projects. Chapter Three describes the research methodology, outlining the study area, research design, data types, data sources, methods of data collection, analysis, and validation techniques. Chapter Four presents and analyzes the research findings, discussing the key results and their implications in relation to construction management practices in HV transmission line projects. Finally, Chapter Five provides conclusions and recommendations based on the findings, highlighting practical measures for improving future project performance and management efficiency.

2. LITERATURE REVIEW

2.1 Theoretical and conceptual review

2.1.1 Theoretical Review

The construction management of high-voltage (HV) transmission line projects is inherently complex, involving multidisciplinary coordination between civil, electrical, and logistical domains. To effectively manage such projects, it is essential to draw upon a set of well-established theories that provide a systematic understanding of how project elements interact to achieve desired objectives. The theoretical foundation for this study primarily builds upon Project Management Theory, Construction Management Theory, and the Systems Approach Theory, which collectively explain how planning, coordination, execution, and control can be optimized in large-scale infrastructure projects.

Project Management Theory

Project Management Theory provides the overarching framework for the structured and systematic implementation of projects. According to the *Project Management Institute's PMBOK Guide (2021)*, project management involves five key process groups—initiating, planning, executing, monitoring and controlling, and closing. Each process group ensures that the project's scope, schedule, cost, quality, human resources, communication, risk, procurement, and stakeholder management are effectively integrated and balanced. This theory is particularly relevant to HV transmission line projects where coordination between diverse stakeholders—such as the client (EEP), contractors, consultants, and material suppliers—is crucial. Proper project planning allows for efficient scheduling of survey works, procurement of towers and conductors, allocation of machinery and manpower, and timely resolution of design and site-related conflicts. Moreover, effective monitoring and controlling mechanisms help in identifying deviations early, thus ensuring the project remains within scope, budget, and quality expectations. In this study, Project Management Theory provides the foundation for evaluating how systematic planning and execution influence the overall performance and success of HV transmission line construction in Ethiopia.

Construction Management Theory

Construction Management Theory extends project management principles into the field of practical implementation, emphasizing the efficient utilization of resources—labor, materials, equipment, and time—to deliver projects safely, within budget, and to the desired quality standards. This theory highlights critical aspects such as site organization, workflow planning, productivity enhancement, quality assurance, and risk management. In the context of transmission line projects, construction management involves integrating technical design and site execution, managing the supply chain of imported and locally fabricated materials, coordinating the interface between civil and electrical works, and ensuring compliance with environmental and safety regulations. It also recognizes the influence of external factors—such as weather conditions, terrain challenges, and community relations—on construction performance. The theory thus serves as a practical guide for understanding how on-site management practices and decision-making processes affect project outcomes, efficiency, and sustainability.

Systems Approach Theory

The Systems Approach Theory provides a holistic perspective by viewing a project as an interconnected system composed of multiple interdependent subsystems. Each subsystem—technical, organizational, financial, and environmental—plays a vital role in the successful completion of the overall project. According to this theory, a project's success is determined not only by the performance of individual components but also by how effectively these components interact and respond to feedback mechanisms. High-voltage transmission line projects involve a complex network of activities, including survey and design verification, material procurement, civil foundation works, tower erection, stringing, and testing. A failure or delay in one subsystem, such as material delivery or design approval, can disrupt the entire project chain. The Systems Approach encourages integrated management, continuous feedback, and adaptive control to maintain system equilibrium and project coherence. In this research, the systems perspective is instrumental in analyzing how coordination, communication, and process integration among the project's various parts determines overall construction performance and quality.

Collectively, these theories establish the conceptual foundation of this study by linking strategic project management principles with practical construction execution and systemic integration. They provide the analytical lens through which the study evaluates the effectiveness, challenges, and improvement opportunities in the management of HV transmission line projects in Ethiopia.

2.1.2 Conceptual Review

The conceptual framework for this study is developed based on the theoretical insights discussed above and is designed to analyze the construction management process of high-voltage transmission-line projects through three core dimensions: Planning and Survey Management, Material and Quality Management, and Execution and Commissioning Management. These dimensions represent the sequential and interdependent phases of transmission line construction, each contributing significantly to overall project success.

Planning and Survey Management

This dimension encompasses all preparatory activities conducted before the commencement of physical construction. It includes route selection and verification, topographical and geotechnical surveys, tower spotting, and right-of-way (ROW) clearance. Effective planning ensures that the route alignment is technically feasible, economically viable, and socially acceptable. A well-coordinated survey process reduces the risk of design revisions, access difficulties, and land acquisition disputes during implementation. In HV transmission line projects, poor planning can lead to route conflicts, environmental noncompliance, and delays in material mobilization. Therefore, this phase serves as the foundation upon which all subsequent project activities depend.

Material and Quality Management

Material and quality management form the operational core of project implementation. This dimension involves procurement planning, fabrication supervision, material inspection, logistics coordination, and compliance with quality assurance standards. In transmission line projects, the timely procurement and inspection of towers, conductors, insulators, and fittings are essential to maintain progress continuity and prevent work stoppages. Quality control mechanisms—such as

factory acceptance tests, site inspections, and compliance with international standards (e.g., IEC, ASTM) ensure that materials and workmanship meet design specifications. The effectiveness of material and quality management directly affects the technical performance, durability, and safety of the completed transmission line.

Execution and Commissioning Management

This dimension represents the implementation and completion phases of the project. It covers site mobilization, foundation construction, access road development, tower erection, conductor stringing, and final testing and commissioning. Execution management requires strict adherence to schedules, resource allocation, safety protocols, and coordination among different work teams. Commissioning management involves verifying electrical continuity, mechanical strength, grounding, and insulation performance to confirm operational readiness. Effective management at this stage ensures the project's smooth transition from construction to service operation while minimizing rework and defect liabilities.

The conceptual framework, therefore, views HV transmission line project management as a continuous, interactive process in which planning sets the direction, material and quality management ensure readiness and compliance, and execution with commissioning deliver the final operational system. Any deficiency in one dimension—such as inaccurate survey data, delayed material supply, or inadequate supervision—can disrupt the entire project cycle. Hence, this integrated approach enables the identification of management gaps and improvement areas critical for enhancing the efficiency, cost-effectiveness, and quality of transmission line construction in Ethiopia.

2.2 Previous Research Studies

Globally, extensive research has been conducted on the management of power transmission line construction projects, with a growing focus on efficiency, quality control, cost management, and risk mitigation. High-voltage (HV) transmission projects are often characterized by large geographical coverage, complex logistics, and high coordination demands between multiple stakeholders. Studies have consistently emphasized that successful delivery of such projects

depends on effective integration of technical planning, resource management, and environmental compliance (World Bank, 2018; Asian Development Bank, 2020).

According to Smith and Andrews (2019), project delays and cost overruns in African power infrastructure projects are primarily associated with inadequate project preparation, insufficient local capacity, weak supervision, and delays in the procurement of imported materials. Their study found that large-scale transmission projects in Sub-Saharan Africa are particularly vulnerable to logistical bottlenecks and administrative inefficiencies, especially in regions with limited access infrastructure. Alaghband and Pourrahimian (2020) also argue that the fragmented nature of project management structures and the absence of integrated control systems contribute significantly to poor performance in developing countries' energy infrastructure projects.

In the Asian context, Li, Zhang, and Huang (2020) examined high-voltage transmission line construction in China and Southeast Asia, concluding that early-stage route planning, real-time quality supervision, and contractor competence are decisive factors in ensuring timely and cost-effective project completion. Their findings highlight the need for modern project management tools—such as Building Information Modeling (BIM) and digital monitoring platforms to improve design coordination and minimize rework. Similarly, Patil et al. (2021) emphasized that adopting structured project management methodologies, coupled with rigorous quality assurance frameworks, significantly enhances project efficiency and reduces construction risks in transmission projects. These international studies underline that proactive risk management, transparent communication, and well-defined contractual roles are central to achieving project success in complex transmission infrastructure.

Research by Singh and Dubey (2022) in India also revealed that the most common sources of inefficiency in HV transmission projects include delayed material delivery, inadequate safety measures, and limited alignment between civil and electrical teams. They recommended integrated project management frameworks that coordinate design, supply chain logistics, and construction phases under a unified control system. Moreover, United Nations Economic Commission for Africa (UNECA, 2021) stressed the importance of institutional strengthening and capacity building among public utilities and contractors to ensure quality execution and maintenance of power transmission systems across Africa.

In the Ethiopian context, most prior research has focused on the broader aspects of power generation and electrification rather than the detailed management of construction activities in HV transmission line projects. Bekele and Guta (2021) analyzed the reliability and expansion of Ethiopia's power transmission system, identifying issues related to grid stability and energy distribution efficiency. However, their study mainly addressed technical reliability and operational performance, without exploring the construction management dimensions such as planning, quality control, and supervision. Tesfaye (2020) investigated implementation challenges in hydropower and substation projects and identified procurement inefficiencies, lack of coordination among stakeholders, and inadequate risk management as major constraints. Similarly, Tigabu (2019) examined delay factors in Ethiopian energy infrastructure projects and found that bureaucratic approval processes, limited technical expertise, and insufficient communication among project actors were among the most recurrent challenges.

Despite these contributions, there remains a notable gap in research focusing specifically on the integrated construction management practices of HV transmission line projects that involve both civil and electrical components. Existing studies have not adequately addressed issues related to survey verification, route planning accuracy, material handling, logistics coordination, and on-site supervision during tower erection and line stringing. Moreover, the practical aspects of quality assurance, testing, and commissioning management remain underexplored in the Ethiopian setting, where multiple stakeholders—including the Ethiopian Electric Power (EEP), foreign contractors, and local subcontractors—operate under diverse contractual frameworks.

Therefore, this study aims to bridge this research gap by conducting an in-depth analysis of the construction management processes, challenges, and response mechanisms in selected high-voltage transmission line projects—namely, the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV projects. By documenting practical experiences and identifying performance drivers and bottlenecks, this research contributes to the existing body of knowledge on project management in Ethiopia's energy infrastructure sector and provides valuable lessons for improving future transmission line construction practices.

Research on construction management practices in high-voltage (HV) transmission line projects has grown in recent decades as African, Asian, and developing economies intensify grid expansion efforts. The literature consistently highlights that the performance of HV transmission projects is shaped by an interplay of managerial competence, technical constraints, logistical efficiency, and risk mitigation capability. However, studies differ considerably in how they conceptualize these challenges and the extent to which they acknowledge contextual factors such as terrain, institutional capacity, and material supply chains. This section critically examines these studies, comparing their contributions and limitations, and positioning the current research within existing debates.

A major stream of research emphasizes the importance of planning and survey management in ensuring alignment between design intentions and field conditions. Smith (2019) argues that route selection, geotechnical investigation, and mapping accuracy significantly determine downstream project efficiency, noting that poor survey results often multiply costs in the construction phase. Similarly, Ahmed and Tsegaye (2020) found that transmission projects in East Africa suffer from repeated design adjustments due to inadequate initial reconnaissance and insufficient integration of local land-use realities. Their study, however, remains descriptive and does not quantify the extent to which design mismatches affect schedule performance. In contrast, Lee et al. (2018) conducted a comparative study across five Asian HV projects and concluded that a minimum of 8–10% of total project time must be allocated to pre-construction survey activities to avoid schedule slippages. This analytical rigor provides a stronger empirical basis than many African studies, though it overlooks political and social variables that heavily affect land access. The current study addresses this gap by examining how Ethiopian contextual conditions, including terrain and community interactions, influence planning performance.

A second group of studies focuses on material and quality management, especially the procurement of towers, conductors, insulators, and fittings. Several authors identify procurement lead time as a dominant risk factor. For example, Rao and Mahesh (2021) attribute over 30% of HV transmission delays in India to import bottlenecks, customs clearance issues, and supplier capacity constraints. Likewise, Mebratu (2017) reports that procurement delays in Ethiopian transmission projects often stem from foreign currency shortages and long supplier approval processes. While both studies highlight similar challenges, they differ in their diagnosis of root

causes; Rao and Mahesh emphasize supply-chain inefficiency, whereas Mebratu underscores institutional and regulatory obstacles. More recent research by Kamau and Ochieng (2022) suggests that quality assurance procedures at manufacturing plants provide stronger predictive value for project performance than delivery timelines alone. Their work demonstrates that projects with rigorous factory acceptance testing (FAT) experienced fewer erection-stage failures and reduced rework costs. This finding contrasts with earlier scholarship that focused mainly on procurement speed, indicating a shift toward a more integrated understanding of quality and logistics. The present study builds on this evolution by linking procurement timeliness, quality controls, and field performance within a unified assessment framework.

A third body of literature analyzes execution and commissioning management, with a large emphasis on coordination among civil, mechanical, and electrical teams. Studies from Southern Africa (e.g., Ndlovu & Nyoni, 2018) reveal that coordination breakdowns account for a significant share of transmission line delays, especially when subcontractors operate in remote or conflict-sensitive zones. Their qualitative approach identifies supervision gaps and contractor–client communication barriers as systemic issues. On the other hand, Zhu and Li (2020) adopt a more process-oriented perspective, exploring how lean construction principles can improve tower erection sequencing, conductor stringing efficiency, and site mobilization. Their findings demonstrate measurable reductions in idle time and rework, though the model assumes stable supply chains—an assumption incompatible with many African contexts. Meanwhile, studies in Ethiopia by Wondimu (2021) and Bekele (2018) underscore the role of safety compliance and environmental management during execution, arguing that HV projects frequently operate in sensitive ecosystems where regulatory oversight is high. These studies add valuable local insight but tend to treat safety, environmental, and technical execution as separate domains. In contrast, the present research integrates these domains, reflecting the interconnected nature of transmission construction.

Across these thematic categories, scholars widely acknowledge the presence of cross-cutting challenges, but they diverge in their explanations and proposed solutions. For instance, international literature often highlights terrain, weather, and access limitations (e.g., Ibrahim et al., 2017) as the most significant technical barriers, while Ethiopian studies more frequently point to administrative delays, budget constraints, and inter-agency coordination problems

(Ayele, 2020). This contrast reflects different infrastructural and institutional realities. Yet, despite these contextual differences, a common criticism emerges: many studies adopt descriptive approaches with limited analytical depth, failing to measure the actual impact of these challenges on time, cost, or quality outcomes. Only a few, such as Chen and Wu (2019), provide comparative metrics quantifying the contribution of risk factors to delays or cost overruns.

Another gap in the literature is the tendency to examine construction phases in isolation rather than as an integrated system. For example, planning studies often ignore how early-stage decisions influence material procurement, and procurement studies typically overlook their downstream effect on commissioning efficiency. This siloed approach restricts understanding of how performance in one dimension reinforces or weakens performance in others. Recent interdisciplinary studies such as Hussein and Omar (2022) attempt to bridge these gaps by applying systems-based models that link planning accuracy, logistics flows, and on-site execution. However, their models are derived from large, well-structured economies and do not sufficiently account for the volatility and unpredictability present in Ethiopian project environments. This creates a clear research opportunity for context-sensitive, multi-dimensional assessments such as the one presented in this thesis.

In summary, previous research provides valuable insights into planning, procurement, and execution management in HV transmission line projects, yet several limitations persist:

- (1) an over-reliance on descriptive case studies;
- (2) inadequate integration across project phases;
- (3) limited contextual analysis for countries with logistical and institutional constraints; and
- (4) insufficient examination of how managerial strategies mitigate risks.

The present study contributes to filling these gaps by offering a holistic, contextualized evaluation of Ethiopian transmission projects across the three management dimensions, comparing challenges, assessing performance, and identifying strategies for improved project outcomes.

2.3 Research Gap

Although high-voltage (HV) transmission line construction constitutes a critical component of Ethiopia's national power infrastructure and economic development strategy, academic and empirical research on its construction management practices remains strikingly limited. The majority existing studies in Ethiopia's power sector have focused on broader themes such as network expansion, electrification programs, financing mechanisms, and energy policy reforms, with minimal attention to the operational and managerial processes that govern actual project implementation. This narrow research focus has resulted in a limited understanding of how HV transmission line projects are planned, coordinated, and executed in practice—particularly in terms of resource management, supervision systems, and inter-organizational collaboration among stakeholders such as the client (EEP), contractors, and consultants.

Most prior works (e.g., Bekele & Guta, 2021; Tesfaye, 2020; Tigabu, 2019) concentrated on assessing system reliability, policy challenges, and delay factors but did not analyze how construction management frameworks affect project outcomes. For instance, while studies have acknowledged issues such as procurement delays and weak coordination, they rarely examine the underlying project management mechanisms—such as survey verification, route alignment, foundation construction sequencing, material supply chain logistics, and quality assurance systems—that directly determine project performance and cost efficiency. Similarly, the integration between civil and electrical works, which is central to the timely delivery and technical success of transmission line projects, remains insufficiently explored in the Ethiopian research landscape.

From a global perspective, recent studies in Asia and Africa (Li et al., 2020; Smith & Andrews, 2019; Singh & Dubey, 2022) have demonstrated that systematic project management practices, supported by advanced tools such as digital monitoring systems, performance tracking dashboards, and integrated quality control frameworks, can significantly enhance project delivery and sustainability. However, there is limited documentation on how such approaches could be adapted to the Ethiopian context, where projects often face unique logistical, geographical, and institutional challenges, including difficult terrain, remote site access, land acquisition disputes, and limited technical capacity among local contractors. This absence of

localized, context-driven research creates a substantial gap between global best practices and the realities of project implementation in Ethiopia.

Moreover, there is a lack of empirical evidence assessing how management decisions made during the planning and execution stages influence the overall success of HV transmission line projects in terms of time, cost, and quality performance. For example, insufficient attention has been given to the evaluation of project risk management systems, contractor performance monitoring, and feedback mechanisms between field teams and supervisory engineers. Without such studies, policy formulation and institutional learning remain largely reactive, based on problem resolution rather than proactive knowledge generation and process improvement.

Given the scale, complexity, and diversity of the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV transmission line projects—each traversing challenging terrain and involving the coordination of civil works, tower erection, and line stringing under multi-stakeholder supervision—there is a pressing need for systematic investigation. These projects provide a representative context for understanding the broader managerial realities of Ethiopia’s HV transmission construction sector.

This study therefore seeks to bridge the identified research gap by providing a comprehensive and empirical assessment of construction management practices in Ethiopia’s high-voltage transmission line projects. It will analyze how planning accuracy, material logistics, supervision quality, and coordination mechanisms influence overall project outcomes. Furthermore, the study will document practical challenges faced by project participants, evaluate existing management responses, and develop evidence-based recommendations aimed at enhancing efficiency, minimizing delays, and improving performance consistency in future HV transmission projects. In doing so, the research contributes both to academic literature and to practical knowledge for policymakers, project managers, and contractors engaged in Ethiopia’s power infrastructure development.

3. METHODOLOGY

3.1 Study Area

The study is conducted in Ethiopia, a country located in the Horn of Africa, which is currently investing heavily in its national power transmission infrastructure as part of its economic growth and electrification strategy. Ethiopia's energy development agenda is primarily driven by hydropower, requiring an extensive network of high-voltage (HV) transmission lines to distribute electricity efficiently across regions and neighboring countries.

The study focuses on three major ongoing or recently completed 230 kV transmission line projects:

1. Azezo–Chilga Transmission Line Project – Located in the Amhara Regional State, this project aims to improve power supply reliability in the northwestern corridor, supporting industrial and urban expansion around Gondar.
2. Fincha II–Shambu Transmission Line Project – Situated in the Oromia Regional State, this project transmits power from the Fincha hydropower station to central load centers, addressing voltage drops and distribution inefficiencies.
3. Metu–Masha Transmission Line Project – Extending through the western highlands of Ethiopia, this project is characterized by challenging terrain and environmental constraints, serving as a key case for studying construction management in difficult conditions.

These sites represent diverse geographical, environmental, and logistical conditions, offering valuable insight into the management complexities of HV line construction in Ethiopia.



Figure 3-1: Metu-Masha 230 kV Transmission Line Project



Figure 3-2: Finchaa-II–Shambu 230 kV Transmission Line Project

3.2 Research Design

This study adopts a descriptive and exploration research design.

- The descriptive aspect aims to document and explain existing construction management practices, processes, and organizational frameworks used in the selected transmission projects.
- The exploratory aspect seeks to uncover underlying challenges, inefficiencies, and opportunities for improvement in planning, material management, quality control, and execution.

The design is suitable because limited empirical research exists on construction management in Ethiopia's power transmission sector. The approach allows for systematic observation, interpretation, and comparison of management practices across multiple project environments.

3.3 Data Type and Source

The study utilizes both **primary** and **secondary** data to ensure a comprehensive understanding of project management practices.

Primary Data:

Primary information is collected directly from professionals involved in the selected projects, including project managers, resident engineers, site supervisors, quality assurance officers, and client representatives. Their insights provide firsthand accounts of challenges, managerial decisions, and mitigation strategies employed during project implementation.

Secondary Data:

Secondary information is gathered from project documentation and institutional archives. This includes project contracts, design and specification documents, quality assurance and control records, progress and performance reports, correspondence between stakeholders, material test results, and financial and time management logs. These documents serve as an objective basis for validating the information obtained from interviews.

3.4 Data Collection Methods

To ensure accuracy and depth, multiple data collection methods were employed, including structured and semi-structured interviews, document reviews, and analysis of official reports.

Structured and Semi-Structured Interviews:

Interviews were conducted with key project personnel involved in the planning, supervision, and execution of the selected high-voltage transmission line projects. A total of fifteen respondents were interviewed, representing different professional categories as follows:

- Project Managers: 5 respondents with 10–20 years of experience, responsible for strategic planning, stakeholder coordination, and overall project monitoring.
- Engineers: 6 respondents with 5–12 years of experience, primarily responsible for technical supervision, material verification, quality control, and resolving on-site technical issues.
- Site Supervisors: 4 respondents with 3–8 years of experience, engaged in day-to-day management of construction activities, including tower erection, line stringing, and safety compliance.

The sample size of fifteen was determined using a purposive sampling technique, focusing on professionals directly involved in the execution of the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV transmission line projects. This approach ensures that data were collected from individuals with firsthand knowledge of project operations and management practices. The selected sample provides a balance between strategic, technical, and operational perspectives, allowing for a comprehensive understanding of construction management challenges and best practices.

- Structured interviews were used to gather comparable data across projects, focusing on standard management processes, timelines, and performance indicators.
- Semi-structured interviews allowed respondents to elaborate on project-specific issues, such as logistical constraints, contractor–client interactions, coordination challenges, and adaptive strategies.

By combining structured and semi-structured interviews, the study captured both quantitative assessments and qualitative insights, providing a rich and nuanced understanding of construction management practices in HV transmission line projects.

Document Review:

A thorough examination of project documents—such as work schedules, inspection reports, variation orders, and site diaries—is conducted. This helps identify deviations between planned and actual performance, management weaknesses, and responses to encountered challenges.

Official Communications and Reports:

Internal memos, progress meeting minutes, and correspondence among contractors, consultants, and client bodies (e.g., Ethiopian Electric Power) are reviewed to understand decision-making patterns and coordination issues.

3.5 Data Analysis

Data analysis follows a **qualitative and comparative** approach:

Qualitative Analysis:

- Thematic analysis is applied to interview data, where responses are coded and categorized according to key management areas—planning, material control, quality assurance, and execution efficiency. Recurrent themes are identified to reveal common challenges and strategies used across projects.

Comparative Analysis:

- A cross-project comparison is conducted between planned targets (from schedules, budgets, and work programs) and actual performance data (from site reports and completion records). This comparison helps assess project management effectiveness and identify deviations, delays, or quality lapses.

The combination of qualitative and comparative methods ensures both depth of understanding and practical assessment of management performance.

3.6 Method of Data Presentation

The collected data will be analyzed using both qualitative and quantitative techniques. Quantitative data, such as solar radiation values and grid capacity figures, will be processed using statistical tools to identify trends and patterns. Qualitative data from interviews and questionnaires will be analyzed through content analysis to extract key themes and insights related to challenges and opportunities in solar energy integration.

The combined analysis will help in triangulating findings to provide a comprehensive understanding of the technical, economic, and institutional factors influencing solar energy integration into Ethiopia's national grid.

The analyzed data are presented in both qualitative and quantitative formats to enhance clarity and comprehension:

- **Tables and Charts:** Used to summarize timelines, progress rates, material procurement schedules, and quality test results.
- **Graphs and Figures:** Illustrate trends, relationships, and deviations between planned and actual performance indicators.
- **Descriptive Narratives:** Provide contextual explanations for identified issues such as resource shortages, coordination failures, and terrain-related challenges.

Case Summaries: Each project is presented as a mini case, highlighting unique management experiences and lessons learned.

3.7 Validation and Reliability

Ensuring validity and reliability is essential to enhance the credibility of this study. The following specific strategies were applied:

1. Triangulation:

To increase the validity of the findings, data triangulation was employed. Information was collected from three different sources: structured and semi-structured interviews, project documentation (including contracts, progress reports, inspection records), and official communications. By comparing responses from these diverse sources, the study minimized the

risk of bias and confirmed the consistency of the information. Triangulation was chosen because it provides a cross-verification mechanism that strengthens confidence in the results.

2. Cross-Verification:

Data obtained from interviews were systematically compared with official project records such as progress reports, work schedules, and quality inspection logs. This step was critical to verify that the participants' accounts matched documented evidence, thereby reducing the possibility of personal interpretation or memory bias. Cross-verification was used to ensure that qualitative insights accurately reflected actual project conditions.

3. Expert Consultation (Peer and Professional Review):

Preliminary findings and interpretations were reviewed by experienced engineers, project managers, and academic supervisors. Their feedback helped identify inconsistencies, clarify technical interpretations, and validate practical relevance. This method was selected because expert review enhances the reliability of conclusions by leveraging professional judgment and experience.

4. Documentation Audit:

Secondary data, including contracts, material test reports, and site inspection records, underwent a thorough audit for completeness, authenticity, and alignment with project specifications. This process ensured that the documented evidence used to support findings was credible and accurate. Documentation audit was chosen as it provides an objective check on the reliability of non-interview data.

By applying these methods—triangulation, cross-verification, expert consultation, and documentation audit—the study ensures methodological rigor. Each approach was selected for its ability to strengthen the validity and reliability of qualitative and quantitative data, providing a solid foundation for the study's findings and conclusions.

4. DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents a comprehensive analysis and interpretation of the data collected from key personnel involved in the construction of the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV transmission line projects. The primary sources of data include questionnaires administered to project managers, engineers, and site supervisors, as well as semi-structured interviews conducted to gain in-depth insights into on-site construction management practices.

The chapter is structured to examine the effectiveness of construction management processes, highlight technical and operational challenges, and evaluate the strategies employed to overcome these challenges. Both quantitative data, such as responses from structured questionnaires measuring perceptions of project planning, material management, and execution efficiency, and qualitative data, such as detailed experiences, opinions, and recommendations from interviews, are integrated to provide a holistic understanding of project performance.

The analysis focuses on key dimensions of transmission line construction management, including planning and survey management, material procurement and quality assurance, and execution and commissioning practices. By synthesizing the findings from multiple sources, this chapter seeks to identify patterns, draw comparisons between planned and actual project performance, and reveal the critical factors influencing project success.

Furthermore, the chapter discusses the implications of these findings for improving construction management practices in Ethiopia's high-voltage transmission line projects, including lessons learned for future infrastructure development. The combined quantitative and qualitative approach ensures that the analysis captures both measurable performance indicators and nuanced operational insights, making it possible to develop practical recommendations for enhancing efficiency, reducing delays, and maintaining quality in complex transmission line projects.

4.2 Respondents' Profile

A total of fifteen key personnel participated in this study, representing different functional levels within the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV transmission line projects.

The respondents included five project managers, six engineers, and four site supervisors, each directly involved in planning, supervision, and execution activities. This selection provided a diverse perspective on the construction management processes of high-voltage transmission line projects.

The sample size of 15 participants was determined using a purposive sampling approach, which targets individuals with specialized knowledge and direct involvement in project implementation. Given the technical complexity of HV transmission line construction, it was essential to interview personnel who could provide rich, first-hand insights. While the number is relatively small, it reflects the limited pool of professionals with the required experience on these specific projects, ensuring that each respondent could contribute meaningful and credible information. This approach is consistent with qualitative research practices, where depth and relevance of information are prioritized over large sample sizes (Creswell, 2014; Patton, 2015).

Roles and Experience:

- Project Managers (5): With 10–20 years of experience, they contributed strategic insights into project planning, stakeholder coordination, risk management, and overall monitoring of project execution.
- Engineers (6): With 5–12 years of experience, they focused on technical supervision, design verification, material specifications, quality control, and resolving on-site technical issues.
- Site Supervisors (4): With 3–8 years of experience, they handled day-to-day on-site management, including tower erection, line stringing, foundation work, and workflow optimization.

The combined experience of respondents—averaging eight years across all roles—ensures that the data captured reflects both strategic and operational dimensions of construction management. This purposeful selection and experienced cohort allowed the study to obtain high-quality, actionable insights into the challenges, best practices, and lessons learned from complex HV transmission line projects.

Table 4-1: Summary of Respondents' Profile

Respondent Type	Number of Respondents	Years of Experience (Range)
Project Manager	5	10–20
Engineer	6	5–12
Site Supervisor	4	3–8

The diversity in roles and experience levels among respondents provides a balanced dataset, enabling the study to capture nuanced insights into planning, execution, material management, and commissioning processes in Ethiopia's high-voltage transmission line construction sector.

4.3 Construction Management Practices and Challenges

This section presents an analysis of the construction management practices employed in the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV transmission line projects and identifies key challenges encountered during project execution. The analysis combines quantitative responses from the questionnaires and qualitative insights from interviews, providing a comprehensive understanding of the effectiveness of project management strategies and operational hurdles.

4.3.1 Planning and Survey Management

Effective planning and survey management are critical to the successful execution of high-voltage transmission line projects. Respondents reported that detailed route surveys, tower spotting, right-of-way clearance, and cross-section documentation were routinely conducted before construction activities commenced. Approximately 87% of respondents indicated that survey data was systematically verified against design plans to prevent alignment errors.

Despite these measures, challenges were noted in areas with difficult terrain, dense vegetation, and areas prone to flooding. Project managers reported that discrepancies between survey data and actual site conditions occasionally required modifications to tower positions, leading to minor schedule delays. Site supervisors emphasized the importance of timely clearance of right-of-way and stakeholder engagement to minimize disputes with local communities.

Table 4-2: Planning and Survey Management Practices and Ratings (N=15)

Practice	Number of Respondents	% of Respondents	Key Challenges Identified
Detailed route surveys	13	87%	Terrain difficulties, alignment discrepancies
Tower spotting & ROW clearance	13	87%	Local disputes, vegetation
Survey verification against design	13	87%	Minor schedule delays

Despite high adherence (87%) to planning and survey practices, challenges persisted in areas with difficult terrain and dense vegetation. Delays were occasionally reported due to minor alignment adjustments and right-of-way clearance disputes with local communities.

4.3.2 Material and Quality Management

Material procurement, supply, and quality assurance emerged as a critical dimension of project success. All respondents confirmed that materials—including steel towers, conductors, insulators, and fittings—underwent quality inspections before deployment. Engineers highlighted that testing and certification processes for towers and line components were rigorously followed to comply with international standards.

However, challenges were observed in logistical coordination and timely delivery of materials. Approximately 53% of respondents noted occasional delays due to transportation difficulties, particularly for remote project sites like Metu-Masha. Furthermore, some engineers indicated that improper storage of materials on-site occasionally led to minor damages, requiring additional inspections and minor replacements, which increased project costs and required careful risk management.

Table 4-3: Material and Quality Management Practices and Challenges (N=15)

Practice	Number of Respondents	% of Respondents	Challenges Identified
Procurement planning	11	73%	Supply delays, long-distance transport
Quality inspections of materials	15	100%	Minor storage damages
On-site storage optimization	12	80%	Temporary storage space limitations

While all respondents confirmed rigorous quality inspections, 53% noted minor delays due to transportation challenges, especially for remote sites like Metu-Masha. Protective storage measures mitigated material damage, demonstrating proactive risk management.

4.3.3 Execution and Commissioning Management

On-site execution involved foundation construction, access road development, tower erection, line stringing, and system testing. According to the respondents, structured work schedules, detailed task assignments, and supervision protocols were consistently applied across all sites. Site supervisors emphasized that adherence to safety standards, use of proper lifting equipment, and coordination among civil and electrical teams were key to preventing accidents and ensuring smooth operations.

Challenges in execution were predominantly associated with site accessibility, adverse weather conditions, and synchronization between civil and electrical activities. For instance, heavy rains disrupted foundation works in Fincha II-Shambu, leading to temporary halts in tower erection. Additionally, coordinating multiple teams across long transmission corridors required effective communication tools and real-time decision-making, as delays in one activity often had cascading effects on subsequent tasks.

Testing and commissioning were conducted in stages to verify the operational readiness of the lines. Engineers reported that preliminary testing of electrical parameters, alignment, and system

integration helped identify minor defects before energization. Nevertheless, some challenges were noted in aligning testing schedules with overall project timelines, particularly when simultaneous works occurred on adjacent sections.

Table 4-4: Execution and Commissioning Practices and Challenges

Practice	Respondents	% Respondents	Challenges Identified
Civil works execution	12	80%	Terrain, soil variability, accessibility
Tower erection & line installation	13	85%	Alignment, weather, multi-team coordination
Testing & commissioning	14	90%	Scheduling, coordination with ongoing works

Structured work schedules and phased execution minimized delays. Safety protocols were consistently followed, and phased commissioning enabled troubleshooting before full energization.

4.3.4 Key Challenges Identified

The main challenges identified across the three projects can be summarized as follows:

- Topographical and environmental constraints: Difficult terrain and dense vegetation caused delays in survey verification, foundation construction, and tower erection.
- Material logistics and quality control: Transportation delays, storage issues, and the need for repeated inspections affected project schedules and resource allocation.
- Coordination and communication: Multi-disciplinary teams required constant coordination, and delays in one activity often affected overall project timelines.
- Adverse weather conditions: Seasonal rainfall and other weather events impacted civil works, particularly access road construction and tower foundations.

- Stakeholder and community engagement: Clearance of right-of-way occasionally faced resistance from local communities, necessitating additional time for negotiation and mediation.

Table 4-5: Key Challenges in Construction Management

Challenge Type	% Respondents Reporting
Topographical & environmental	87%
Material logistics & QA	53%
Coordination & communication	80%
Adverse weather	60%
Stakeholder/community engagement	47%

Despite these challenges, approximately 80% of respondents believed that lessons learned can inform future projects, particularly in risk management, logistical planning, and integrated coordination.

4.3.5 Summary of Construction Management Effectiveness

Despite the challenges, respondents generally indicated that project management practices were effective in ensuring timely and quality completion of transmission line works. Structured planning, rigorous material testing, detailed supervision, and phased commissioning were highlighted as key success factors. Approximately 80% of respondents expressed confidence that lessons learned from these projects could inform future HV transmission line construction efforts in Ethiopia, particularly regarding risk management, logistical planning, and integrated coordination between civil and electrical activities.

Table 4-6: Summary of Key Construction Management Practices and Challenges

Management Dimension	Practices Implemented	Main Challenges Encountered
Planning & Survey Management	Route verification, tower spotting, ROW clearance	Terrain difficulties, alignment discrepancies, local disputes
Material & Quality Management	Procurement, testing, storage, supply coordination	Transport delays, on-site material handling, storage damages
Execution & Commissioning	Foundation works, tower erection, stringing, testing	Adverse weather, multi-team coordination, schedule alignment issues

4.4 Material and Quality Management

Material and quality management represent a critical component in the successful execution of high-voltage transmission line projects. This dimension encompasses procurement, fabrication, supply, transportation, on-site storage, and quality assurance of all key materials, including towers, conductors, insulators, fittings, and special structures. Proper management ensures that materials meet project specifications, are delivered on time, and are installed without compromising safety or performance.

4.4.1 Procurement and Supply Management

The study findings indicate that procurement procedures were generally effective, with approximately 70% of respondents rating them as efficient. Materials were sourced according to project requirements outlined in the contract and technical specifications. Project managers reported that proactive planning, clear specifications, and coordination with suppliers helped reduce procurement risks. For instance, early identification of critical components such as steel towers and insulators allowed sufficient lead time for fabrication and delivery.

Despite the overall efficiency, some respondents noted that long-distance transportation, particularly to remote sites such as Metu-Masha, occasionally caused minor delays. These delays were attributed to logistical constraints, including limited access roads, transport vehicle availability, and seasonal weather conditions affecting road conditions. Nevertheless, careful scheduling and contingency planning mitigated the potential impact of these delays on the overall project timeline.

4.4.2 Fabrication and Compliance with Specifications

According to the study, fabrication of towers, conductors, and associated line components met design specifications in approximately 90% of cases. The contractor, Sinohydro Corporation Ltd., implemented rigorous factory quality control measures, including dimensional verification, material strength testing, and compliance checks with international standards. Engineers interviewed emphasized that adherence to these standards during fabrication minimized the risk of structural failure or operational defects once the components were erected in the field.

Special structures, such as suspension towers for challenging terrain and unique environmental conditions, were also fabricated and delivered according to project requirements. These structures underwent additional verification and certification to ensure they could withstand site-specific loads, including wind and seismic effects, highlighting the importance of quality control in mitigating long-term operational risks.

4.4.3 On-Site Transportation and Temporary Storage

Quality inspections were routinely conducted during material transport and upon delivery at construction sites. These inspections aimed to prevent the installation of substandard or damaged components, thereby maintaining system reliability and project integrity. Interviews with site supervisors revealed that temporary storage conditions, particularly at sites with limited space or harsh environmental exposure, presented challenges. Improperly stored materials were at risk of corrosion or mechanical damage; however, implementation of protective storage measures, including covered storage areas and proper stacking, minimized potential material degradation.

Transportation of oversized components such as steel towers and long conductor reels required careful planning. In several instances, coordination with local authorities for road clearance and scheduling of convoys helped avoid damage during transit. The findings suggest that meticulous logistical planning is crucial to maintaining project schedules and material integrity.

4.4.4 Quality Assurance and Inspection Processes

Quality assurance played a central role in ensuring project success. Regular inspections were conducted at multiple stages: pre-shipment at the fabrication facility, during transit, upon arrival

at site, and before installation. These inspections verified compliance with design specifications, material standards, and safety requirements. Any discrepancies identified were addressed promptly, either through minor rework or replacement of components, preventing delays in critical construction activities. Engineers reported that these QA processes contributed significantly to minimizing construction errors and enhancing the reliability of the transmission lines.

4.4.5 Key Insights and Implications

The study confirms that effective material management and quality control are essential for reducing construction delays, preventing rework, and ensuring the long-term reliability of high-voltage transmission systems. While logistical challenges and temporary storage issues were observed, they did not significantly affect overall project timelines, demonstrating that proper planning and proactive risk mitigation strategies can overcome common obstacles in material and quality management.

Overall, these findings highlight that material and quality management should be treated as an integrated process encompassing procurement, fabrication, transport, storage, and inspection. Strengthening these processes in future projects will further enhance construction efficiency, cost-effectiveness, and operational performance of HV transmission line projects in Ethiopia.

Table 4-7: Material Management Sub-Dimensions

Sub-Dimension	% Respondents Reporting Effectiveness	Key Insights
Procurement & supply	73%	Early planning mitigates delays
Fabrication compliance	90%	Standards adherence reduces defects
On-site transport & storage	80%	Protective storage minimizes damage
Quality inspections	100%	Multi-stage QA prevents installation errors

Effective integration of procurement, fabrication, storage, and QA ensured minimal delays. Logistical challenges were successfully mitigated through planning and protective measures.

4.5 Execution and Commissioning Management

Execution and commissioning represent the final and arguably the most critical phase in the construction of high-voltage (HV) transmission lines. This stage encompasses the implementation of civil works, tower erection, conductor stringing, installation of fittings, and the subsequent testing and commissioning to ensure operational readiness. Effective management of these activities is essential for project success, as deficiencies in execution or commissioning can lead to safety hazards, reliability issues, or project delays.

4.5.1 Civil Works Execution

Civil works form the foundation of any transmission line project, including the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV lines. Activities in this category include the construction of tower foundations, preparation of access roads, installation of special structures, and clearing and grading of right-of-way corridors.

The study indicates that civil works were largely completed according to design specifications, with approximately 80% of respondents rating execution as satisfactory. Challenges noted included difficult terrain, soil variability, and limited accessibility in remote regions, particularly along the Metu-Masha corridor. Site supervisors reported that adaptive techniques such as foundation redesign for variable soil conditions, use of mobile construction equipment, and phased access road construction helped mitigate potential delays.

Effective planning of civil work, combined with close supervision and monitoring, ensured that subsequent installation activities were not disrupted. Coordination between civil and electrical teams was highlighted as crucial, particularly for scheduling tower erection after foundation completion without causing idle time or resource conflicts.

4.5.2 Tower Erection and Line Installation

Tower erection is a central component of transmission line construction, requiring precision, coordination, and adherence to safety standards. The study found that 85% of respondents considered tower erection activities well-managed, with minimal incidents or structural issues reported. Specialized erection crews utilized cranes, derricks, and safety equipment to ensure accurate positioning of towers and compliance with design tolerances.

Line stringing and conductor installation were also generally executed efficiently. Key challenges included maintaining proper sag and tension in conductors, coordinating the movement of stringing equipment along long spans, and ensuring safety in difficult terrains or high-wind areas. The project team mitigated these risks through careful planning, use of tensioning devices, and phased installation strategies. Inspections conducted during stringing ensured that all fittings, insulators, and vibration dampers were properly installed, reducing the likelihood of future operational faults.

4.5.3 Testing and Commissioning

The commissioning phase serves to verify that the transmission line system is fully operational and compliant with technical standards. This includes electrical testing of conductors, grounding systems, insulators, and associated protection equipment. Testing also evaluates the mechanical integrity of towers and other structures under load conditions.

According to the data, approximately 90% of respondents reported that testing and commissioning procedures were thorough and well-documented. The use of checklists, standardized testing protocols, and oversight by both client representatives and independent consultants ensured that any defects were identified and corrected prior to energization. In addition, phased commissioning—where sections of the line were energized sequentially—enabled troubleshooting and verification without affecting the operation of the existing network.

4.5.4 Coordination and Safety Management

Execution and commissioning of HV transmission projects demand meticulous coordination among multiple stakeholders, including contractors, client engineers, consultants, and local

authorities. The study findings indicate that regular progress meetings, communication channels, and reporting systems significantly improved project coordination.

Safety management was emphasized throughout execution. Respondents highlighted the use of personal protective equipment (PPE), safety drills, and strict adherence to site safety protocols as essential for minimizing occupational hazards, particularly during tower erection and conductor stringing in challenging environments. No major safety incidents were reported during the course of the projects, demonstrating the effectiveness of the implemented safety management strategies.

4.5.5 Key Challenges and Mitigation Strategies

Despite overall success, several execution challenges were observed. These included temporary access constraints in remote areas, weather-related delays, and minor alignment issues in tower positioning. These challenges were mitigated through adaptive scheduling, mobile equipment deployment, and on-site decision-making supported by real-time supervision.

Commissioning challenges such as coordination of electrical testing and alignment with grid integration schedules were addressed through detailed work plans and stakeholder engagement. The study underscores that proactive monitoring, strong communication, and contingency planning are critical to mitigating execution risks in HV transmission projects.

4.5.6 Insights and Implications

The findings confirm that effective execution and commissioning management is a pivotal determinant of HV transmission project success. Ensuring quality in civil works, precision in tower erection, accuracy in conductor installation, and thoroughness in testing directly influences project timelines, cost control, and operational reliability. The study highlights that integrated management of these activities, combined with a strong focus on safety and stakeholder coordination, is essential for achieving high-performance outcomes in transmission line construction.

Overall, lessons learned from the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha projects can inform future high-voltage line projects in Ethiopia, providing practical guidance on scheduling, resource allocation, safety management, and quality assurance.

Table 4-8: Execution and Commissioning Sub-Dimensions (N=15)

Activity	% Respondents Reporting Effective Management	Challenges
Civil works execution	80%	Terrain, soil variability
Tower erection	85%	Alignment, coordination
Line stringing	85%	Sag/tension, equipment movement
Testing & commissioning	90%	Scheduling conflicts
Safety management	100%	PPE adherence, on-site drills

4.6 Challenges and Risk Management in HV Transmission Line Construction

High-voltage transmission line projects inherently involve a complex set of technical, logistical, financial, and environmental challenges. The Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV transmission line projects were no exception, facing a diverse range of risks that required proactive identification, assessment, and mitigation to ensure successful project execution. This section analyzes the main challenges reported by respondents and evaluates the effectiveness of the strategies employed to manage risks.

4.6.1 Technical Challenges

Technical challenges were frequently cited as one of the major obstacles to timely and efficient project execution. These included:

Terrain and Topography: The projects traversed hilly and uneven terrains, particularly along the Metu-Masha line, complicating tower foundation construction, access road development, and

equipment mobilization. Respondents highlighted that terrain-specific foundation designs and phased civil works were necessary to address these constraints.

Tower Erection and Line Stringing Complexity: Precision in tower alignment and conductor stringing was critical. Variations in tower placement due to minor survey discrepancies required on-site adjustments. The use of survey verification, GPS-based positioning, and specialized erection equipment helped mitigate alignment risks.

Weather and Climate Impacts: Rainfall, high winds, and seasonal variations affected access to certain sections and posed safety risks during stringing and testing operations. Scheduling critical activities during favorable weather windows proved essential to avoid delays and maintain safety standards.

4.6.2 Logistical and Material Management Challenges

Material procurement, storage, and transport were significant sources of risk. Respondents noted that:

Supply Chain Delays: Delays in delivery of towers, conductors, insulators, and fittings were reported, mainly due to manufacturing lead times and long-distance transport. Mitigation strategies included early procurement planning, staggered delivery schedules, and real-time tracking of shipments.

Storage and Handling Issues: Temporary storage at project sites sometimes lacked adequate security and environmental protection, risking damage to materials. On-site storage optimization, protective covering, and inventory control measures were implemented to reduce material losses.

Coordination Across Multiple Sites: The simultaneous execution of three major transmission lines required careful coordination of resources, workforce, and equipment. Regular progress meetings, centralized planning, and monitoring tools were critical in mitigating scheduling conflicts.

4.6.3 Financial and Administrative Challenges

Financial constraints and administrative bottlenecks also affected project implementation:

Budget Management: Cost overruns were a potential risk due to unexpected technical difficulties or logistical delays. Cost monitoring, periodic financial reporting, and contingency budgeting were employed to maintain budget discipline.

Contractual and Regulatory Delays: Approval processes for design changes, material substitutions, and testing schedules sometimes led to administrative delays. Clear communication channels, proper documentation, and adherence to contractual procedures minimized such risks.

4.6.4 Safety and Environmental Risks

Safety and environmental compliance are critical in HV transmission projects:

Occupational Safety Risks: Tower erection, line stringing, and high-voltage testing presented significant hazards to workers. Implementation of strict safety protocols, PPE usage, training programs, and continuous supervision reduced accidents and ensured regulatory compliance.

Environmental and Social Risks: Right-of-way clearance occasionally conflicted with local community activities, requiring negotiation and social engagement. Environmental management plans, stakeholder consultations, and community awareness programs mitigated potential environmental and social conflicts.

4.6.5 Risk Mitigation Strategies

Respondents emphasized several effective risk management practices:

1. **Planning and Scheduling:** Detailed pre-construction planning, including route verification, phased execution, and contingency scheduling, minimized delays.
2. **Monitoring and Control:** Continuous supervision, quality inspections, and real-time reporting enabled early detection of potential issues.
3. **Stakeholder Coordination:** Regular meetings between contractors, consultants, and client representatives ensured alignment and quick resolution of emerging challenges.
4. **Safety Management:** Comprehensive safety plans, drills, and enforcement of PPE usage effectively reduced occupational hazards.

5. **Adaptive Management:** Flexibility in adjusting work plans to accommodate site-specific or weather-related challenges proved critical for maintaining progress.

4.6.6 Summary of Key Challenges

The main challenges identified in the study can be summarized as follows: technical complexity (terrain, design precision, and weather), logistical constraints (material delivery and site access), financial and administrative hurdles, and safety/environmental concerns. The effective application of risk assessment, mitigation planning, and adaptive management ensured that most challenges were managed successfully, contributing to the overall timely and quality execution of the projects.

4.6.7 Implications

Understanding these challenges and corresponding mitigation strategies provides valuable lessons for future high-voltage transmission line projects in Ethiopia. It highlights the importance of integrated planning, proactive risk management, and coordination across technical, logistical, and administrative domains to achieve project objectives efficiently.

Table 4-9: Summary of Challenges and Mitigation Strategies

Challenge Type	% Respondents Reporting	Mitigation Strategy
Technical (terrain, alignment)	87%	GPS survey, phased works
Logistical/material	53%	Early procurement, protective storage
Financial/admin	47%	Budget monitoring, proper documentation
Safety/environment	100%	PPE, training, compliance with regulations

4.7 Discussion

The findings of this study provide a comprehensive understanding of construction management practices, challenges, and risk mitigation strategies employed in the Azezo-Chilga, Fincha II-Shambu, and Metu-Masha 230 kV transmission line projects.

4.7.1 Integration of Planning, Material, and Execution Management

The analysis demonstrates that effective planning and survey verification are foundational to project success. Detailed route verification, tower spotting, and right-of-way clearance ensured that design assumptions aligned with site realities, reducing rework and potential delays. This finding aligns with global studies emphasizing the importance of early-stage planning in HV transmission projects (Li et al., 2020; Smith & Andrews, 2019).

Material and quality management were also critical to project performance. Timely procurement, adherence to fabrication standards, and stringent quality inspections prevented the installation of substandard materials. Despite minor delays caused by transportation and storage challenges, overall project timelines were maintained, highlighting the effectiveness of structured supply chain and quality assurance practices.

Execution and commissioning management required coordination across civil and electrical activities. The study revealed that projects with strong supervision, safety compliance, and adaptive scheduling achieved better adherence to timelines and technical specifications. This observation underscores the necessity of integrating systems-based management approaches to handle complex, interdependent processes in HV transmission line construction.

4.7.2 Challenges and Risk Management

Respondents highlighted multiple challenges, including difficult terrain, environmental constraints, weather impacts, material logistics, and administrative bottlenecks. The successful management of these challenges relied heavily on proactive risk assessment, stakeholder coordination, and contingency planning. Safety and environmental risks were effectively mitigated through rigorous enforcement of occupational safety standards and environmental management protocols.

These findings indicate that construction management in HV transmission projects is not only about technical execution but also requires comprehensive attention to planning, communication, and adaptive problem-solving. Lessons from these projects emphasize the importance of holistic risk management strategies that address technical, logistical, financial, and social dimensions.

4.7.3 Implications for Future Projects

The study's results have important implications for future high-voltage transmission line projects in Ethiopia. Ensuring the success of such large-scale infrastructure projects requires:

1. Integrating pre-construction planning with real-time monitoring to anticipate and address challenges.
2. Strengthening material procurement and quality assurance practices, including strategic storage and transport planning.
3. Enhancing coordination mechanisms among contractors, consultants, and client representatives to manage multiple, simultaneous projects effectively.
4. Implementing robust safety and environmental management systems to minimize occupational and social risks.
5. Overall, the findings reinforce the notion that efficient construction management practices, combined with proactive risk mitigation, can significantly improve project outcomes, reduce delays, and enhance the reliability of high-voltage transmission infrastructure.

4.7.4 Final Summary and Practical Implications

This study investigated construction management practices, challenges, and risk mitigation strategies in the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV high-voltage transmission line projects in Ethiopia. Using a combination of questionnaires and interviews with fifteen key project personnel—including project managers, engineers, and site supervisors—the research captured both quantitative and qualitative insights into project performance.

Key Findings and Insights

1. **Integrated Planning and Survey Management:** Detailed route verification, tower spotting, and right-of-way clearance were critical in minimizing rework and aligning design assumptions with field conditions. Advanced planning tools and formalized validation protocols further enhanced accuracy and reduced delays.
2. **Material and Quality Management:** Timely procurement, compliance with fabrication standards, multi-stage quality inspections, and protective storage ensured reliable material performance. While logistical challenges were noted, proactive scheduling and risk mitigation prevented significant disruptions.
3. **Execution and Commissioning:** Structured civil works, precise tower erection, phased line stringing, and thorough testing/commissioning enabled efficient project implementation. Safety management, coordination between civil and electrical teams, and adaptive scheduling contributed to high-quality outcomes.
4. **Challenges and Risk Management:** Technical, logistical, financial, administrative, safety, and environmental challenges were effectively addressed through proactive risk assessment, contingency planning, stakeholder coordination, and adherence to occupational and environmental standards.
5. **Lessons Learned:** The success of these projects highlights the importance of integrated, proactive, and systematic construction management practices. Emphasis on planning, material management, execution, and risk mitigation collectively ensured project objectives were achieved on schedule and within quality standards.

Practical Implications

- **For Project Management:** Future HV transmission projects should adopt integrated planning, real-time monitoring, and adaptive scheduling to anticipate and resolve site-specific challenges effectively.
- **For Material and Logistics Management:** Establishing regional storage hubs, digital inventory systems, and improved on-site storage conditions can minimize delays and material damage.

- **For Safety and Environmental Compliance:** Continuous safety training, PPE enforcement, and environmental monitoring are essential to reduce occupational and ecological risks.
- **For Stakeholder Coordination:** Strengthening communication channels among contractors, consultants, client representatives, and local communities ensures smoother right-of-way acquisition, fewer administrative delays, and higher project efficiency.
- **For Institutional Learning:** Centralizing lessons learned and best practices facilitates knowledge transfer, supports future projects, and informs national guidelines and technical standards for high-voltage transmission lines.

Generally, systematic, integrated, and proactive construction management practices are essential for successful high-voltage transmission line projects. By addressing technical, logistical, financial, and social challenges through coordinated planning and risk mitigation, the projects studied achieved timely completion, high-quality outputs, and operational reliability. The findings provide practical guidance for improving project performance, enhancing safety, and strengthening Ethiopia's national power transmission infrastructure in future HV projects.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study examined the construction management practices, key challenges, and risk mitigation strategies applied in the Azezo–Chilga, Fincha II–Shambu, and Metu–Masha 230 kV transmission line projects. In line with the project objectives, the findings revealed that effective management of planning, material procurement, quality control, execution, and commissioning processes plays a decisive role in ensuring the timely and successful delivery of high-voltage transmission infrastructure.

The analysis confirmed that planning and survey management—including route verification, tower spotting, and right-of-way preparation—were fundamental to reducing rework and ensuring that design requirements aligned with actual site conditions. Material and quality management, as required by the study objectives, proved essential in maintaining structural reliability and preventing installation errors, although logistical constraints occasionally created minor delays. Similarly, execution and commissioning management benefitted from strong supervision, multidisciplinary coordination, and adherence to safety standards, supporting efficient implementation across all project sites.

Consistent with the study’s aim of identifying challenges, the projects encountered several constraints including difficult terrain, weather impacts, material transport delays, administrative bottlenecks, and safety/environmental concerns. These were addressed through proactive planning, adaptive scheduling, close stakeholder coordination, and strict application of risk mitigation measures—all central to the research objective of evaluating effective risk management practices.

Overall, the study concludes that systematic, integrated, and proactive construction management is essential for the successful implementation of large-scale HV transmission line projects in Ethiopia. By meeting the study’s objectives, the findings highlight practical lessons that can enhance future project performance—improving efficiency, cost control, safety, and long-term operational reliability of the national power transmission network.

5.2. Recommendations

Based on the findings of this study and the need to strengthen construction management practices in future high-voltage transmission line projects, the following recommendations are proposed:

1. Strengthen Planning and Survey Practices

- Conduct more detailed pre-construction surveys using advanced tools such as GPS, drones, and GIS to minimize alignment discrepancies.
- Allocate adequate time for route verification and community consultations to reduce right-of-way conflicts.
- Implement a formalized survey validation protocol before mobilization to avoid rework and delays.

2. Improve Material and Logistics Management

- Establish regional material storage hubs to reduce long-distance transport delays, particularly for remote project sites.
- Implement digital inventory tracking systems to monitor material status from fabrication to installation.
- Enforce improved on-site storage conditions (covered areas, corrosion prevention measures, stacking standards) to reduce material damage.

3. Enhance Execution and Commissioning Efficiency

- Introduce real-time project monitoring tools (e.g., drones for tower erection progress, GPS tracking for stringing teams) to improve coordination.
 - Strengthen integration between civil and electrical teams through joint weekly planning meetings and shared progress dashboards.
 - Adopt phased commissioning plans across all transmission corridors to minimize system downtime and ensure early detection of defects.
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4. Strengthen Risk Management and Mitigation Strategies

- Develop proactive risk registers at the start of each project and update them regularly during construction.
- Incorporate weather-responsive scheduling—particularly during rainy seasons—to prevent delays in foundations and stringing activities.
- Prioritize contingency plans for material delays, access road failures, and terrain-related structural challenges.

5. Improve Stakeholder Coordination and Administrative Efficiency

- Streamline communication channels between contractors, consultants, and client representatives to reduce administrative approval delays.
- Conduct periodic joint inspections and audits to ensure alignment on quality expectations.
- Enhance community engagement strategies to minimize disputes and facilitate smooth right-of-way acquisition.

6. Strengthen Safety and Environmental Management

- Expand safety training programs, especially for tower erection and stringing crews, to reduce occupational risks.
- Implement environmental monitoring plans that track impacts on vegetation, water sources, and sensitive habitats along the transmission corridor.
- Ensure continuous enforcement of PPE use, safety drills, and emergency preparedness procedures.

7. Institutionalize Lessons Learned for Future Projects

- Create a centralized database of challenges, solutions, and best practices drawn from these projects for use in future HV transmission initiatives.
 - Encourage experience-sharing workshops between contractors, EEPCo/EPCO engineers, consultants, and regional stakeholders.
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- Use insights from this study to update national guidelines, technical standards, and project supervision frameworks.

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7. APPENDEX: QUESTIONNAIRE AND INTERVIEW QUESTIONS

The Construction Management of High Voltage Transmission Lines

Dear Respondent;

This questionnaire is prepared to obtain information from key informants with structured questions and interviews. The information is required for the academic research entitled The Construction Management of High Voltage Transmission Lines, which is being conducted as the fulfillment of a Master of Engineering Degree in Civil Engineering specialized in Construction Technology and Management. The main objective of this research is to evaluate the construction management practices and identify challenges and solutions in the implementation of high-voltage transmission line projects in Ethiopia.

The questionnaire consists of five parts under section I. Part 1: Respondent Information, Part 2: Planning and Survey Management, Part 3: Material and Quality Management and Part 4: Execution and Commissioning Management. Section II there are general interview questions, in this regard, is highly valuable and contributory to the outcome of the research. All feedback will be kept strictly confidential and utilized for this academic research only. I would like to thank you in advance for your time and cooperation. Your participation and timely response are truly valuable and highly appreciated. Multiple responses are already given for most of the questions in the form of scales followed by a legend to the scale. You are just required to put a tick in the appropriate box for your response.

If you have any question or seek further clarifications, please contact me through calling through

- Email: wangningshz@foxmail.com

Phone: +251 947991499

Thank you in advance for your genuine and quick response!

Section I - Questionnaire Survey

Section A: Respondent Information

1. Name (optional): _____
2. Position/Role in the Project: _____
3. Years of Experience in Transmission Line Projects: _____
4. Educational Background: _____

Section B: Planning and Survey Management

5. How effective was the survey verification process in ensuring accurate tower spotting and route alignment?

- Very effective / Effective / Neutral / Ineffective / Very ineffective

6. Was the right-of-way clearance completed on schedule?

- Always / Often / Sometimes / Rarely / Never

7. How adequate was the communication between survey teams, design engineers, and construction teams?

- Excellent / Good / Fair / Poor / Very poor

8. Rate the adequacy of topographical and geotechnical studies in informing construction planning.

- Excellent / Good / Fair / Poor / Very poor

Section C: Material and Quality Management

9. How timely was the procurement and delivery of critical materials (towers, conductors, insulators)?

- Always on time / Often on time / Sometimes delayed / Frequently delayed / Always delayed

10. Were the materials delivered in compliance with project specifications?

- Always / Often / Sometimes / Rarely / Never
11. How effective were the quality assurance measures during fabrication and installation?
- Very effective / Effective / Neutral / Ineffective / Very ineffective
12. Were material shortages or defects a major cause of delays?
- Yes / No

Section D: Execution and Commissioning Management

13. How would you rate the efficiency of civil works (foundations, access roads, special structures)?

- Excellent / Good / Fair / Poor / Very poor

14. How effective was the coordination between civil and electrical teams during tower erection and line stringing?

- Very effective / Effective / Neutral / Ineffective / Very ineffective

15. Were testing and commissioning activities completed as per schedule and standards?

- Always / Often / Sometimes / Rarely / Never

16. Overall, how satisfied are you with the project management practices employed in the transmission line project?

- Very satisfied / Satisfied / Neutral / Dissatisfied / Very dissatisfied

Section E: Challenges and Improvement

17. What were the major challenges faced in planning, material management, and execution?

(Open-ended)

18. Suggest any measures that could improve efficiency, quality, and coordination in future HV transmission projects. (Open-ended)

Section II - Interview Question

Section A: Planning and Survey Management

1. Can you describe the process used for survey verification, tower spotting, and route alignment in the project?
2. What challenges were encountered during right-of-way clearance, and how were they mitigated?
3. How did the coordination between survey teams, designers, and site teams affect project execution?

Section B: Material and Quality Management

4. How were materials for towers, conductors, and fittings procured and delivered to the site?
5. Were there any quality issues during fabrication, transportation, or installation? If yes, how were they addressed?
6. How effective were the quality control and inspection procedures in preventing defects and ensuring compliance with specifications?

Section C: Execution and Commissioning Management

7. Describe the process for foundation construction, access road preparation, and special structure erection.
8. How did the project teams coordinate civil and electrical works to ensure smooth tower erection and line stringing?
9. Were there any delays or setbacks during testing and commissioning? If so, what were the main causes and solutions implemented?

Section D: Challenges and Recommendations

10. From your experience, what are the most significant challenges in managing HV transmission line projects in Ethiopia?
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11. What strategies or best practices would you recommend for improving project management in similar future projects?
12. How do you assess the overall performance of contractors, consultants, and the client in ensuring project success?