Université Cheikh Anta Diop de Dakar

INTERNATIONAL MASTER PROGRAMME IN ENERGY AND GREEN HYDROGEN (IMP-EGH)

MASTER’S THESIS

Speciality: Economics/Policies/Infrastructures and Green Hydrogen Technology

Topic :

Implementation Risk Assessment and Management Applicable to the Dry Hydrogen in Arid Regions Project

Presented on the 12th of September, 2023 by:

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2022/2023 Academic Year

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ACKNOWLEDGEMENTS

I extend my sincere appreciation and gratitude to my supervisors, Prof. Peter Letmathe, Marcel Kottrup, and Pape Bilal Diakhaté, for their invaluable support and guidance throughout this process. A special acknowledgment goes to Prof. Maria Movsessian, whose recommendations during the biweekly progress reports provided valuable insight. Special appreciation is extended to all experts who took the time to provide responses to the questionnaire spreadsheet. Your inputs played a crucial role in making this endeavour a success. I am grateful to Precious Azubuike for his insightful comments that greatly aided my thesis. To my friends, I will like to thank you for all the things we shared and the fun memories we made during the last two years. Special thanks go out to my family for their constant and tireless support and encouragement throughout the whole period of my studies and life. Last but not least, I would like to say thank you to the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) and the German Federal Ministry of Education and Research (BMBF) for granting me this scholarship opportunity.

ABSTRACT

The global shift towards renewable energy and carbon removal strategies, aligned with the targets in the Paris Agreement, has given rise to innovative projects like the Dry Hydrogen in Arid Regions. Proposed to be implemented in Côte d'Ivoire, the project employs solid sorbents and renewable energy to capture carbon dioxide and water vapour, generating hydrogen and valuable fuels. This approach not only mitigates water scarcity issues but also aligns with low-carbon objectives. The study focused on exploring and managing risks during the implementation phase of the project, with a spotlight on potential cost overruns and project delays. Through an in-depth analysis of renewable energy project risks, the study provides insights and recommendations for the successful execution of the Dry Hydrogen in Arid Regions project and similar projects, thus contributing to effective risk management strategies in this context. This thesis outlines a robust risk assessment methodology that incorporates the quantitative analysis technique of Monte Carlo simulation. Drawing from the insights of experts, a deterministic risk register is formed as the basis for subsequent Monte Carlo simulations. Risk treatment options including modifying objectives, avoidance, influencing probability, and more were explored. Challenges in aligning estimated and actual project costs were acknowledged, with performance objectives considered to take precedence over project duration for emerging technologies. Risk categories encompassing financial, technical, political, environmental, contractual, social, and operational/administrative aspects were identified. Notable risks with greater influence on negative impacts include risk of expropriation or war, changes in government policies and regulations, corruption and bribery and changes in the cost of materials. These insights empower stakeholders with crucial information for informed decision-making and effective risk management.

Keywords: Carbon Capture, Cost Overruns, Project Implementation, Risk Management, and Risk Treatment.

RÉSUMÉ

Le virage mondial vers les énergies renouvelables et les stratégies de captage de carbone, en accord avec les objectifs de l'Accord de Paris, a donné lieu à des projets innovants tels que le Projet d'Hydrogène Sec en Régions Arides. Proposé pour être mis en œuvre en Côte d'Ivoire. Le projet utilises des sorbants solides et de l'énergie renouvelable pour capturer le dioxyde de carbone et la vapeur d'eau, générant ainsi de l'hydrogène et des carburants précieux. Cette approche permet non seulement de pallier les problèmes de pénurie d'eau, mais aussi de s'aligner sur les objectifs de réduction des émissions de carbone. L'étude s'est concentrée sur l'exploration et la gestion des risques pendant la phase de mise en œuvre du projet, en mettant en lumière les risques potentiels de dépassement de coûts et de retards. À travers une analyse approfondie des risques liés aux projets d'énergie renouvelable, l'étude fournit des aperçus et des recommandations pour l'exécution réussie du Projet d'Hydrogène Sec en Régions Arides et de projets similaires, contribuant ainsi à des stratégies efficaces de gestion des risques dans ce contexte. Cette thèse expose une méthodologie robuste d'évaluation des risques qui intègre la technique d'analyse quantitative de la simulation de Monte Carlo. Tirant parti des perspectives des experts, un registre de risques déterministes est élaboré comme base pour les simulations ultérieures de Monte Carlo. Les options de traitement des risques, telles que la modification des objectifs, l'évitement, l'influence sur la probabilité, ont été explorées. Les défis liés à l'alignement des coûts estimés et réels du projet ont été reconnus, les objectifs de performance étant considérés comme prioritaires par rapport à la durée du projet pour les technologies émergentes. Les catégories de risques englobant les aspects financiers, techniques, politiques, environnementaux, contractuels, sociaux et opérationnels/administratifs ont été identifiées. Les risques notables ayant une plus grande influence sur les impacts négatifs incluent le risque d'expropriation ou de guerre, les changements dans les politiques et réglementations gouvernementales, la corruption, ainsi que les changements dans le coût des matériaux. Ces aperçus fournissent aux parties prenantes des informations cruciales pour une prise de décision éclairée et une gestion efficace des risques.

Mots-clés: Capture de Carbone, Dépassements de Coûts, Mise en Œuvre de Projet, Gestion des Risques et Traitement des Risques.

LIST OF ABBREVIATIONS

Abbreviation	**Definition**
AfDB	African Development Bank
BECCS	Bioenergy Carbon Capture and Storage
BMBF	Federal Ministry of Education and Research
CDR	Carbon direct removal
CO_2	Carbon dioxide
CPI	Corruption Perception Index
CRI	Global Climate Risk
DAC	Direct Air Capture
DACC	Direct Air Carbon Capture
DACCS	Direct Air Carbon Capture and Storage
DryHy	Dry Hydrogen in Arid Regions
FERMA	Federation of European Risk Management Association
GCM	General Circulation Models
Gt	gigatonne
GW	gigawatt
IEA	International Energy Agency
IIA	International Actuarial Association
IRGC	International Risk Governance Council
ISO	International Standard Organization
kJ	kilo joule
kWh	kilowatt-hour
L-DAC	Liquid Direct Air Capture
MCDA	Multi-Criteria Decision Analysis
MCS	Monte Carlo Simulations
mol	mole
MVP	Mean-Variance Portfolio
MWh	Megawatt-hour
NETs	Negative Emission Technologies
^oC	degrees Celsius
PESTEL	Political, Economic, Social, Technological, Environmental, and Legal
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
ppm	parts per million
PRI	Political Risk Insurance
ROA	Real Options Analysis
S-DAC	Solid Direct Air Capture
SHAMPU	Shape, Harness and Manage Project Uncertainty
SOEC	Solid Oxide Electrolysis Cell
tCO_2	tonne of carbon dioxide
UNACTAD	United Nations Conference on Trade and Development
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment programme
UNFCCC	United Nations Framework Convention on Climate Change
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use

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CHAPTER 1: INTRODUCTION

1.1 Background

The Paris Agreement seeks to limit global warming to 2°C against pre-industrial levels while pursuing aggressive targets of reaching 1.5°C (United Nations Framework Convention on Climate Change, 2015). This ambitious goal has accelerated the adoption of renewable energy technologies and carbon direct removal (CDR) strategies globally (Fuss et al., 2018). Several studies have highlighted the potential of CDR technologies to effectively and cost-efficiently limit global warming to acceptable levels with Bioenergy Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture (DACC) as notable technologies (Fuss et al., 2018; Wiegner et al., 2022). While BECCS faces challenges related to land constraints, including displacement of natural habitats and competition with agriculture, DACC technology involves relatively less land use as compared to BECCS and a lower agricultural impact (Hanna et al., 2021). Additionally, DACC can be implemented in areas with very rugged terrain unsuitable for agricultural production making it a promising long-term carbon dioxide removal solution capable of controlling emissions from hard to abate sources (Meckling & Biber, 2021).

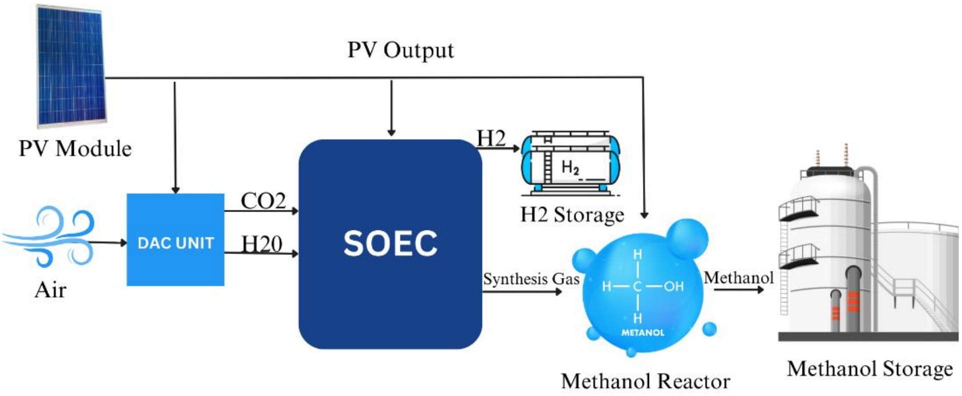
Direct Air Carbon Capture, also referred to as Direct Air Capture (DAC) technology, is a relatively new technology still in its early stages of development that utilizes liquid or solid sorbents to capture carbon dioxide from the air (Ozkan et al., 2022). Major challenges linked to its deployment are the associated high upfront costs and energy-intensive operation (Wiegner et al., 2022). The regeneration step in the DAC process is the most energy-intensive requiring 900°C for liquid solvent DAC systems and between 80°C – 120°C for solid sorbent DAC systems (Ozkan et al., 2022). Solid sorbents have become subject to extensive research and development to limit the energy requirement of the regeneration step. However, a major challenge to the use of solid sorbents is the co-adsorption of water which further exacerbates the energy requirement (Drechsler & Agar, 2020; Veneman et al., 2015). Although this presents a challenge in energy utilization, it also offers an opportunity for a hybrid process that adapts the Solid-DAC system for carbon dioxide and water adsorption (Qiu et al., 2022). The Dry Hydrogen in Arid Regions (DryHy) project proposes a hybrid process based on water co-adsorption in solid DAC systems.

The Dry Hydrogen in Arid Regions (DryHy) project, hereon referred to as the DryHy project, involves a direct air capture system utilizing a solid sorbent capable of adsorbing carbon dioxide and water from the air using energy generated from renewable sources, particularly solar photovoltaics. The carbon dioxide and water vapour absorbed can then be subjected to a high-temperature electrolysis process within a solid oxide electrolysis cell, to produce hydrogen and synthesis gas. This synthesis gas, rich in carbon monoxide and hydrogen, serves as the crucial precursor for subsequent production processes. This innovative energy initiative taking place in Côte d'Ivoire is backed by a research grant and spans a duration of 6-years. The consortium is formed by academic and industrial German partners with experience in renewable energy and innovation-related research and the field of e-mobility solutions. The project focuses on the production of methanol by utilizing the carbon dioxide and water vapour captured from the air. The synthesis gas generated from the high-temperature electrolysis process is introduced into a methanol reactor, where a catalytic process takes place, transforming it into methanol a valuable and versatile fuel. This innovative process, built on the foundations of air capture technology, holds immense potential for reducing carbon dioxide concentrations in the air and promoting a transition towards a low-carbon future without depleting available water resources.

In arid and semi-arid regions, renewable energy resources hold significant prominence. These regions, characterized by their dry and low-rainfall climates, are endowed with abundant renewable energy potentials (Guo et al., 2022). However, these regions face significant water availability challenges (Arab Water Council, 2009), thereby posing a barrier to the widespread adoption of water electrolysis. In these areas where water scarcity is already a pressing issue, securing freshwater for everyday needs is an arduous task, further complicating the allocation of water for electrolysis which demands substantial quantities. This scarcity prioritizes the need for innovative solutions that explore alternative water sources to enable the productive utilization of available renewable resource potential.

The DryHy project addresses the issue of water scarcity linked to the utilization of water sources for electrolysis. By tapping into the abundant water vapour in the air, the proposed Direct Air Capture (DAC) technology not only alleviates concerns related to groundwater depletion but also minimizes the environmental impact associated with traditional water sources. While still undergoing testing and refinement, the development of the DryHy project holds promise for a more sustainable and water-efficient approach to electrolysis. By leveraging the water vapour present in the atmosphere, it offers a viable solution that mitigates the risks associated with groundwater depletion and ensures the continued availability of water resources for other essential needs. Furthermore, adopting a renewable energy source of energy makes the DAC process carbon neutral. Figure 1.1 presents a schematic of the DryHy pilot plant.

Figure 1.1. *DryHy Pilot Plant Scheme*



Source: Author's Own Illustration

1.2 Purpose and Limitation

Engineering and construction projects require plans and cost estimates to ensure that objectives are achieved on time, within budget, and to the desired quality (Karlsen & Lereim, 2005). However, the inherent nature of risks associated with project implementation often results in project delays and cost overruns in most project endeavours (Akinradewo & Awodele, 2016; Kwon & Kang, 2019). Various sources contribute to project risks, including factors such as country-specific, contractual, financial, legal, logistic, human resources, and technical aspects (Dick-Sagoe et al., 2023). When these risks materialize, they can lead to direct costs, delays, compromised quality, reputational damage, and compromised safety and health. Ultimately, all realized risks result in increased project costs (López & Fernández, 2019). To account for such risks, project estimates must have reserves or contingencies. These contingencies are project funds set aside to manage any extra costs incurred during project implementation (Karlsen & Lereim, 2005).

Building on this background, this thesis aims to delve into the comprehensive exploration of implementation risks linked to the DryHy project, with a specific case study focused on Cote d'Ivoire. **The primary objective is to identify, quantify, and effectively manage the risks associated with the implementation phase of the project**. This study will focus on two primary risk impacts: Cost overruns and project delays. However, greater emphasis will be placed on cost overruns.

1.2.1 Research Questions

The research will address several key questions:

1. What are the implementation risks associated with the DryHy project?
2. How can the identified risks be quantified from an investor’s point of view?
3. How can this knowledge be applied to a different geographical location?

By analysing and answering these research questions, this study aims to provide valuable insights and practical recommendations for the successful implementation of the DryHy project and similar ventures in Cote d'Ivoire. Furthermore, the quantification of risks will help provide better estimates of the cost of risks, serving as a more dependable metric for contingency planning purposes.

1.2.2 Scope of the Research

The scope of this thesis is focused on examining and managing the risks associated with the implementation phase of the DryHy project. It is important to note that the analysis will primarily concentrate on risks that are unique to energy projects but can be relevant to the specific case study. Additionally, the research will encompass a comprehensive overview of general technological risks, although it will not delve into the intricacies of the adopted technology. As the DryHy project represents a pioneering endeavour, the identification and quantification of risk sources will be firmly grounded in an exhaustive literature review and a meticulous application of research findings to the case study.

Through the comprehensive integration of insights and perspectives derived from a multitude of empirical studies, a literature review holds the exceptional capacity to address research questions in a manner that surpasses the limitations inherent in individual studies (Snyder, 2019).

By leveraging these research methods, this thesis seeks to provide valuable insights into effectively quantifying and managing the project's implementation risks and contribute to the existing knowledge in the field of energy projects in arid and semi-arid regions.

1.3 Disposition

This thesis is divided into four chapters and a conclusion. The first chapter, Introduction, provides a general overview of carbon direct removal technologies used in reducing atmospheric carbon dioxide (CO_2) from the atmosphere with a key focus on the Direct Air Capture technology. The second chapter focuses on a literature review aimed at providing definitions for important concepts and identifying risks associated with renewable energy projects. It further expatiates on country-specific risks linked to the proposed project implementation country: Cote d'Ivoire. In the third chapter, the employed methodology for identifying, quantifying, and addressing risk factors, along with the research tools utilized, is elucidated. The fourth chapter provides a brief discussion of the outcomes stemming from the application of the methodology and the results obtained. The final conclusion encompasses the insights drawn from previous chapters and proposes recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

The notion of risk emerges from our acknowledgment of uncertainty in the future, stemming from our inherent inability to predict the specific consequences that may arise as a result of our current decisions and actions (Anderson et al., 2019). Whether it be in business, research, or any other undertaking, a range of events and outcomes can arise, presenting both opportunities for positive outcomes and threats to success (Federation of European Risk Management Association, 2003). Recognizing and effectively managing these potential upsides and downsides is crucial for achieving success and maximizing potential benefits. This section aims to discern prevalent risks commonly associated with the implementation of renewable energy projects, as documented in a diverse range of literature sources. We begin with a basic definition of risk and risk management and proceed into describing the Direct Air Capture Technology. Furthermore, we identify risks in renewable energy projects from literature sources. A meticulous approach will be adopted to ascertain that all identified risks remain strictly relevant to the project implementation phase, thus aligning precisely with the scope and focus of this thesis. By diligently examining existing knowledge and insights, this chapter ventures to provide a comprehensive overview of the inherent risks that must be considered during the implementation of renewable energy projects.

2.2 Definitions

2.2.1 Risk

Defining the exact nature of risk presents a considerable challenge, as it encompasses a multitude of factors and its measurement is a subject of ongoing debates and controversies (Skjong et al., 2011). Within the scope of literature, the term 'risk' carries diverse interpretations, further adding to its complexity and the absence of a universally agreed-upon definition (Šotić, 2015). Such diverse usage necessitates a comprehensive exploration to comprehend its various connotations and implications across different domains and disciplines. Perspectives on risk vary. Lowrance and Klerer (1976) succinctly define risk as a measure of both the probability and severity of adverse effects, capturing its inherent uncertainty. The Project Management Body of Knowledge (PMBOK) Guide, provided by the Project Management Institute, characterizes risk as uncertain events or conditions that can influence a project's objectives, encompassing both positive and negative effects (Project Management Institute, 2008). Additionally, the International Actuarial Association (IIA) defines risk as “the potential for an outcome with negative consequences," underscoring its potential impact on decision-making (International Actuarial Association, 2010, p. 14). Furthermore, the International Risk Governance Council (IRGC) conceptualizes risk as the uncertain consequence of an event or activity concerning something valued by humans (International Risk Governance Council, 2006). By drawing from these diverse perspectives, a comprehensive understanding of the multifaceted concept of risk emerges, laying the foundation for its analysis and management in this thesis.

2.2.2 Risk Management

Risk management as defined by the International standard organization is a process where activities are coordinated "to direct and control an organization with regards to risk" (International Standard Organization, 2018, p. 1). Risk management typically encompasses the collective mindset, methodologies, and organizational frameworks through which an entity strategically handles and addresses potential risks (Gonen, 2012). In essence, it encompasses the entire spectrum of activities, including risk identification, analysis, evaluation, response planning, and ongoing risk monitoring and review (Rasmos, 2014). The Project Management Institute (PMI) defines risk management as; "The processes of conducting risk management planning, identification, analysis, response planning, and monitoring and control on a project" (Project Management Institute, 2008, p. 273).

2.3 Direct Air Capture Technology

The concept of Direct air capture (DAC) as a mitigation strategy against climate change was first introduced by Lackner (1999). It involves the capture of carbon dioxide (CO_2) directly from ambient air using specialized systems either for storage or for use in other processes (Lyons et al., 2021). DAC combined with long-term carbon storage is referred to as Direct Air Carbon Capture and Storage (DACCS) and is classified among negative emissions technologies (NETs) in the portfolio of solutions to prevent global warming above 2^oC by 2100 (Minx et al., 2018; National Academy of Sciences, Engineering and Medicine, 2019). Globally, 18 direct air capture facilities are operational in the United States, Canada, and Europe (International Energy Agency, 2021). The primary industrial developers of DAC systems are Carbon Engineering (Canada), Climeworks (Switzerland), and Global Thermostat (USA) (McQueen et al., 2021). Although there exist a plethora of diverse materials and DAC processes under study, there are two major types of DAC systems farthest along in development, namely: Solid DAC (S-DAC) which adsorbs CO_2 on the surface of a solid material, and Liquid DAC

(L-DAC) which requires a liquid sorbent to dissolve CO_2 (Hanna et al., 2021; Wiegner et al., 2022). The former requires low-temperature heat (< 150^{o}C) while the latter requires high temperatures for operation (~ 900^{o}C) (Hanna et al., 2021). This energy requirement encompasses the energy for releasing CO_2 from the sorbent and the energy required to regenerate the sorbent (Fuss et al., 2018). McQueen et al. (2021) describe the solid sorbent approach as involving an air contactor that blows air through a solid adsorbent, where CO_2 is adsorbed on the solid adsorbent. The solid adsorbent with CO_2 is then exposed to heat and/or vacuum to release the CO_2. The sorbent is cooled before the process is restarted. In the liquid sorbent approach, strong alkali or alkali-earth hydroxide that has a high affinity for CO_2 is employed to absorb gaseous CO_2 from the air, resulting in a stream of CO_2-rich liquid. The CO_2 is then released via heat or electricity supply (Sanz-Pérez et al., 2016). Solvent-based approaches typically use structured packing to increase the contact surface area between the gas and liquid phases (National Academy of Sciences, Engineering and Medicine, 2019; Wiegner et al., 2022).

A key issue with Direct Air Capture (DAC) systems is the energy requirement as DAC systems are energy-intensive (Fuss et al., 2018). Sanz-Pérez et al. (2016) report that atmospheric air is known to contain very little concentrations of carbon dioxide (CO_2) of about 400 parts per million (400ppm), this small concentration requires more energy input to separate CO_2 from other gases in air. Using free energy mixing, the theoretical minimum work required to separate CO_2 from ambient air is ~2 kJ/mol of CO_2 (Sanz-Pérez et al., 2016). Furthermore, Lyons et al. (2021) add that capturing 1Gt of CO_2 using solar-powered DAC requires approximately 2000 terawatt hours (TWh) of electricity per year.

2.4 Challenges and Risks in the Direct Air Capture Technology

The deployment of the Direct Air Capture (DAC) technology depends on three major factors: Available funding, the choice of DAC process, and the choice of energy supply (Hanna et al., 2021). In identifying DAC technology risks, these factors provide insight into potential hotspots. Several studies have highlighted the cost of current DAC technologies as a key issue in its deployment (McQueen et al., 2021; Minx et al., 2018; Ozkan et al., 2022). This cost factor poses significant financial risk in the implementation of the technology including concerns related to economic viability, opportunity cost, and technological progress of DAC technology. Compared to other Negative Emission technologies (NETs), the cost of carbon capture is relatively high with some sources estimating costs between 600 – 1000$ per tCO_2 (McQueen et al., 2021; Ozkan et al., 2022) while others estimate between 100 – 1000$ per tCO_2 captured (National Academy of Sciences, Engineering and Medicine, 2019; Realmonte et al., 2019). This prohibitively high cost could render DAC systems less favourable as compared to other cheaper NETs thereby reducing their potential for large-scale deployment.

DAC systems demand substantial energy for their operation (Fujikawa et al., 2021). This elevated energy demand is attributed to various factors: The low concentration of CO_2 in the surrounding air, which mandates the treatment of large air volumes to capture considerable CO_2 quantities, the inherent difficulty in separating CO_2 from other gases due to its distinct properties, and the necessity to regenerate sorbents or solvents used in the capture process (Fujikawa et al., 2021; Leonzio et al., 2022). Several studies have attempted to estimate the energy consumption of DAC. For example, a study analysing technologies for carbon dioxide capture from the air estimated that DAC technologies could require between 366-764 kWh of electrical energy per metric ton of CO_2 captured (Fasihi et al., 2019). Similarly, another study assessing the DAC technology based on a cyclic adsorption-desorption process by Climeworks showed that it would require around 400 kWh of electricity and 1600 kWh of thermal energy per ton of CO_2 captured (Ozkan, 2021). Furthermore, there are concerns about the scalability of the technology, as current DAC systems have a limited capacity to capture CO_2 on a large scale. To address these concerns, researchers are exploring innovative solutions such as utilizing renewable energy sources and improving the efficiency of DAC systems (Sodiq et al., 2023).

There are also social and ethical risks associated with air capture technology. DAC systems require large spaces of land to be able to capture as much air as required. The International Energy Agency (2021) reports that capturing 1 gigatonne (Gt) of CO_2 per year would require up to 23,000 km^2 of land to include photovoltaic installations that would supply electricity to the plant. Furthermore, some DAC system pathways require significant quantities of water for their operation, especially the liquid solvent-based DAC systems which exhibit greater water depletion, 3–12 times more per 1 t CO_2 captured compared to the solid sorbent-based DAC due to its utilization of an aqueous hydroxide solution for CO_2 capture, which evaporates during operation (Qiu et al., 2022). In contrast, sorbent-based DAC relies on solid amine-based sorbents, resulting in significantly lower water consumption during production and use (Lebling et al., 2022; Qiu et al., 2022). Thus, there may be conflicts over land use and resource allocation, particularly in areas where water and energy resources are scarce (Strielkowski et al., 2021).

Additionally, there are concerns about the toxicity of sorbents used in DAC systems which could also have major environmental and social risk impacts. According to Realmonte et al. (2019), liquid DAC plants require significant amounts of hydroxide solutions. The production of these hydroxide solutions yields chlorine gas as the main by-product which is a highly poisonous gas and can find applications in chemical warfare.

Finally, there are regulatory and policy risks associated with air capture technology. As a relatively new technology, there are currently no established regulations or policies governing its development and deployment. This lack of regulation could lead to a variety of potential issues, such as uneven implementation and inadequate oversight (Schenuit et al., 2021).

2.5 Risks in Renewable Energy Projects

Renewable energy technologies potentially present a reduced risk profile when compared to conventional energy technologies, as they are not tied to fossil fuel prices. However, they still entail considerable technological, financial, and regulatory risk exposure, depending on the technology, country, and regulatory regime (Ioannou et al., 2017). The level of construction risks associated with renewable energy projects varies depending on the specific technology employed. The outcome of these risks then becomes cost overruns and delays in project completion (Burger et al., 2014). Several studies have been published on risks and risk management in renewable energy projects. The following section explores risks in renewable energy projects as documented in the diverse range of literature consulted for this work. Emphasis will be laid on risks specific to the implementation phase of energy projects.

In a study on estimating the risk of investing in the construction of power plants, Hosseini et al. (2015) identified several key issues to be considered in the construction of power plants. These areas were broadly categorized under technical and non-technical factors. Factors such as: Possessing technical knowledge, the complexity of the technology, and the total cost of equipment and material were classified under technical factors while environmental impact, social and cultural impacts, area of land required, political landscape, and influences of weather and climate were categorized under non-technical factors. Keith et al. (2018) identified three crucial risk categories for the implementation of an industrial Direct Air Capture (DAC) plant in Canada, using an aqueous KOH sorbent: Project risks, strategic risks, and contextual risks. Project risks are related to equipment, supply chain, and site-related factors. Strategic risks involve contractual agreements, negotiations, changes in project objectives, and resource management. Contextual risks consider current laws and regulations, geopolitical factors, and economic conditions. Gatzert and Kosub (2016) focused on the risks in onshore and offshore wind parks in Europe. The authors proposed seven risk categories that affect wind parks namely: Strategic and business risks, Transport/Construction risks, Operation/maintenance risks, Liability/legal risks, Market/sales risks, Counterparty risks, and Political, policy, and regulatory risks. Furthermore, they emphasize that policy and regulatory risks are among the most significant risks in offshore wind parks from the viewpoint of industry experts. Gatzert and Vogl (2016) also identified policy risks as a key risk factor affecting renewable energy projects, and go further to state that the uncertainty of policy support schemes e.g., feed-in tariffs by various governments constitutes a risk factor for private sector investment in renewable energy projects.

Burger et al. (2014) identified the following risks as critical to renewable energy projects: Resource risks; including variations in wind speeds, solar irradiation, water flows, and all other weather-dependent parameters, and goes further to emphasize the limited nature of risk mitigation strategies in addressing resource-related risks. They finally assert that the investor will have to accept these risks as they appear. Furthermore, technical risks, political and regulatory risks, and operational risks including the availability of a skilled workforce, theft of components, and natural hazards were also identified. Chapman and Ward (2003) identified the introduction of design changes as a key issue in the implementation stage of projects. They highlighted possible consequences including disruption of schedules, cost overruns, and reduced output quality. Furthermore, they also identified human error and management error as other risk factors to be considered in project implementation and provided a list of possible causes of human errors including: Failure to detect unusual situations or rare events, incorrect assessment of situations, lack of incentives for high-level performance, lack of concentration, inadequate work environment, and equipment or procedures.

A study conducted by the United Nations Environment Programme (2004) identified and quantified risk barriers that could threaten renewable energy investments. Risks were categorized as cognitive barriers related to low level of awareness, political barriers associated with regulatory and policy issues, and analytical and market barriers. However, risk factors relevant to the implementation stage are resource availability and supply risk, efficacy risk relating to the technology adopted, high upfront costs, and physical damage issues.

Ioannou et al. (2017) provided an elaborate list of risks associated with sustainable energy projects. These risks were categorized into political, economic, social, technological, legal, and environmental. They further created risk subcategories with different issues identified under each category. Changes in the national economy, political instability, complex approval processes, contracting risks, accidents, sabotage or theft, environmental damage risk, and natural hazards are among the risks identified. Mirkheshti and Feshari (2017) identified the following risks as barriers to offshore wind energy projects in Iran: Insufficient access to capital, insufficient expertise, insufficient public acceptance, damage or theft during transportation or construction, quality of materials and spare parts, quality of raw materials, assembling and installation, technology limitation, natural hazards, repair and replacement, damages to the environment, complex approval processes, and risk of war and terrorism as critical aspects to be considered in the development of offshore wind energy projects.

Nuriyev et al. (2019) identified the following risks: Political stability, legal issues, corruption, volatility of the exchange rate, local communities' discontent with the environmental issues, insufficient investments, limited experience in the development of renewables, limitations in the availability of local specialists, and knowledge and experience deficiency, error in the estimation of the resources, and infrastructure limitations. Michelez et al. (2011) also identified the following issues as crucial in identifying risks in renewable energy projects: Technology maturity, dependency on weather, permitting, and large land take.

In general, the insights from the literature specifically point to key issues related to the implementation of renewable energy projects. These diverse categories of risks identified from various sources will form the basis for the risk identification in this thesis. Considering the profound and unique nature of the DryHy project, this research aims to provide an initial comprehensive documentation of the risks associated with the implementation of the DryHy project, thus addressing the gap in the existing literature on the subject. The inherent nature of risk categories, such as political risks and climate change risks, dictates their location specificity, where their likelihood of occurrence varies significantly across diverse geographical contexts. Political risks, encompassing factors like governmental instability, policy changes, and regulatory frameworks, can differ in intensity and probability depending on the specific country or region under consideration. Similarly, climate change risks, including extreme weather events exhibit geographical variations as different areas experience distinct climatic patterns and vulnerabilities. Recognizing and accounting for these location-specific differences in risk likelihood is paramount when assessing and managing risks in various regions, ensuring that mitigation strategies and contingency plans are tailored to the specific geographical context at hand (United Nations Conference on Trade and Development, 2023)

2.6 Country-Specific Risks: Côte d’Ivoire

According to Noothout et al. (2016), country risks encompass all elements that have the potential to negatively impact the returns of investments within a nation. They additionally emphasize that factors like political stability, the extent of corruption, economic progress, structure and efficacy of the legal framework, and variations in exchange rates are specific elements related to a country that warrant consideration. Similarly, the United Nations Conference on Trade and Development (2023) identifies the following risks as host–country risks: Political instability, conflicts, expropriation risks, and legal and regulatory policies. Consequently, a deliberate effort is undertaken to identify and explore through literature, the significant risks that are specific to the host country and associated with the project implementation.

2.6.1 Political Landscape

Côte d’Ivoire began to experience political instability in 1993 after the death of its post-independence President Félix Houphouët-Boigny (Chene, 2016). In 2010, a re-ignition of the political conflict following a 2007 peace agreement was witnessed when the ruling government refused to concede defeat (Wickberg, 2013). Although the civil war ended in 2011 when the current president finally assumed office, the lack of acknowledgment and lack of justice against the perpetrators of war and post-war atrocities have resulted in a sense of distrust and discord that threatens the escalation of the post-election violence (Institute for International Security and Counterterrorism, 2014). Among internal issues such as ethnic and tribal tensions, armed militants and heavy circulation of arms are the biggest security threats faced by Côte d’Ivoire (Institute for International Security and Counterterrorism, 2014). In addition, Côte d’Ivoire struggles with widespread corruption. The reality is that bribery is generally seen as an effective way to conduct day-to-day governmental activities. According to a World Bank survey, 30% of firms surveyed indicated that they are required to pay bribes to secure government contracts (Wickberg, 2013). Additionally, Transparency International regularly publishes the Corruption Perception Index (CPI) scores, which measure the perceived levels of public sector corruption in various countries. The CPI scale ranges between 0 and 100, with 0 signifying very corrupt, 43 signifying average and 100 signifying very clean (Transparency International, 2022). The current CPI score for Côte d’Ivoire is 37 signifying a level of corruption below average on a global scale. However, on a regional scale, the regional average score for sub-Saharan Africa is 32, therefore placing Côte d’Ivoire above average in sub-Saharan Africa. The scores obtained from Transparency International provide credible evidence of the prevalence of corruption and bribery in Côte d'Ivoire, thus validating the findings of Wickberg, and underscoring the importance of evaluating corruption as a legitimate risk factor.

2.6.2 Weather and Climate

Côte d'Ivoire experiences a predominantly hot and humid climate, varying from equatorial along the southern coasts to tropical in the central regions, and becoming semi-arid in the far north (United Nations Office for Disaster Risk Reduction & Centro Internazionale in Monitoraggio Ambientale, 2019). Except the far north, most parts of Côte d'Ivoire encounter relatively minimal fluctuations in rainfall from year to year (African Development Bank, 2018). Tomalka et al. (2022) published a climate risk profile for Côte d’Ivoire. They report that climate change is expected to have significant impacts on the infrastructure sector in Côte d’Ivoire. High precipitation rates are expected to lead to flooding especially in low-lying coastal areas, while high temperatures can cause structural failures and accelerated degradation of infrastructure. Furthermore, the United Nations Office for Disaster Risk Reduction and Centro Internazionale in Monitoraggio Ambientale reports that floods impact around 45,000 individuals annually, representing roughly 0.2% of Côte d'Ivoire's total population. The most affected areas are regions close to the coastal provinces both in the current and future climate.

There are currently no clear results on the increase in future precipitation patterns in Côte d’Ivoire. Studies conducted by the African Development Bank (2018) based on General Circulation Models (GCM) on the projected changes in precipitation from 2018 to 2100 show a normal or slight decrease in rainfall frequency in the southern and central regions, while the frequency of extreme rainfall may remain constant or increase in the future. Similar results are obtained for the Komoe River Headwaters region, indicating no consistent signal in rainfall frequency but do project that extreme rainfall may either remain normal or increase into the future. Additionally, the Global Climate Risk Index (CRI), developed by Germanwatch which analyses and quantifies impacts of extreme weather events, provides a long-term CRI score of 141.33 for Côte d'Ivoire from 2000 – 2019. This score when compared to the scores of the most affected countries by extreme weather events within the same period including Puerto Rico 7.17, Myanmar 10.00, Haiti 13.67, and the Philippines 18.17, all ranking in the first four most affected countries, places Côte d'Ivoire in the categories of countries less prone to extreme weather events (Eckstein et al., 2019). These findings suggests that extreme weather events in Côte d'Ivoire may pose a lesser concern in terms of impacting cost overruns during project implementation. However, there remains a possibility of project delays due to extreme weather conditions or prolonged rainfall in the country.

CHAPTER 3: METHODOLOGY

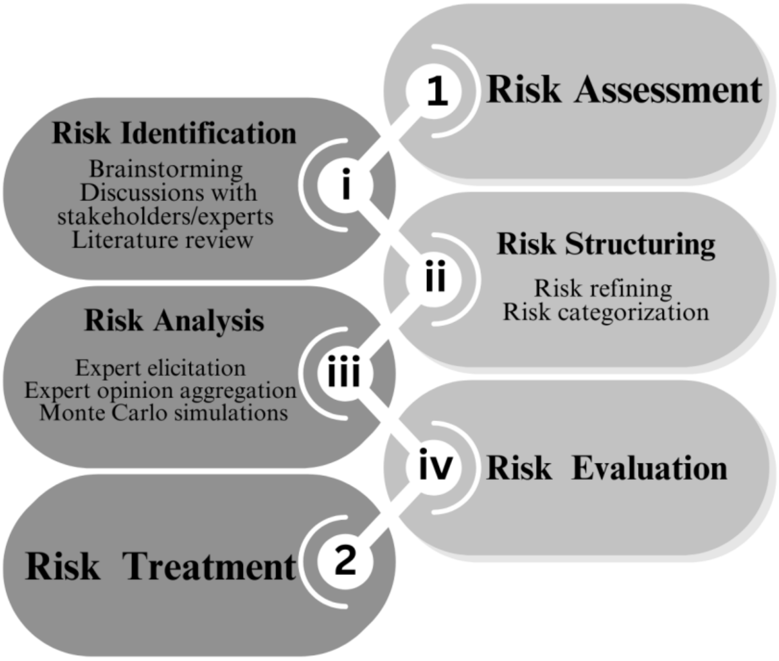
3.1 Overview

Risk assessment and risk treatment are integral parts of the risk management process (International Standard Organization, 2018). To achieve the research objectives within this thesis, a comprehensive assessment of risks and their subsequent mitigation is imperative. Risk assessment holds paramount importance in the domain of project management, entailing the critical processes of risk identification, analysis, and evaluation as prescribed by the International Standard Organization (ISO) standards (International Standard Organization, 2018). In this vein, a methodical and comprehensive risk assessment methodology has been formulated, drawing upon the ISO 31000:2018 risk assessment framework as its foundation. To further augment the risk assessment process, the methodology integrates a generic risk management framework known as the SHAMPU (Shape, harness, and manage project uncertainty) framework (Chapman & Ward, 2003). By merging the SHAMPU framework with the ISO framework, an intricate and comprehensive risk assessment framework is developed, tailored to the specific requirements of this research endeavour. The methodology is organized into a systematic series of steps, which are divided into two primary categories: Risk assessment and Risk treatment. The first phase involves identifying risks, organizing and refining them into categories, and quantifying risks through expert assessments. The second phase focuses on selecting and implementing suitable measures to address the identified risks. This rigorous and methodical approach ensures the systematic analysis and evaluation of risks, enabling the generation of invaluable insights in addressing the research questions.

3.2 Development of the Framework

The risk assessment framework outlined in ISO 3100:2018, as part of the risk management process, offers organizations guidance on managing risks through three fundamental steps: risk identification, risk analysis, and risk evaluation (International Standard Organization, 2018). Similarly, the shape, harness and manage project uncertainty (SHAMPU) risk assessment framework presents a five-phase approach: Identify the issues, structure the issues, clarify ownership, estimate variability, and evaluate implications (Chapman & Ward, 2003). In formulating the framework adopted in this thesis, the ISO 31000:2018 standard formed the basis of the process due to its international recognition as a widely accepted standard. However, a step from the SHAMPU framework: ‘structure the issues’ was incorporated, which in the context of this thesis will be termed ‘risk structuring’ and entails risk refining and risk categorization as these steps are considered critical in the risk assessment process. Figure 3.1 illustrates the resulting risk assessment framework, integrated with the risk treatment, forming the methodology employed in this thesis.

Figure 3.1. Risk Assessment Framework and Risk Treatment



Source: Author's Own Illustration

By incorporating the ‘structure the issue’ phase, the identified risks are better structured to ease understanding and provide a clearer picture of the overall risk landscape. Furthermore, risk categorization makes it easy to group similar risks based on common characteristics such as their nature, sources, and resulting outcome, thereby enhancing the formulation of effective risk management strategies in the risk treatment process.

3.3 Risk Identification

Risk identification involves identifying forthcoming occurrences that need to be recognized as potential risk events (Gonen, 2012). The initial phase of the risk assessment, as delineated in the adopted framework, focused on identifying risks associated with the implementation of the project. To accomplish this, three approaches are taken: Brainstorming, discussions with stakeholders/experts, and an in-depth literature review.

3.3.1 Brainstorming

Brainstorming entails fostering and promoting open and unrestricted discussions within a group of individuals who possess expertise and knowledge in a particular subject or domain (López & Fernández, 2019). Several brainstorming sessions were organized, facilitating the generation of ideas and insights. These sessions involved discussions with colleagues and acquaintances with knowledge in the field of sustainable energy and project management. The result of this process was a pool of ideas from varying perspectives regarding issues that should be considered in the implementation of the DryHy project.

3.3.2 Discussions with Stakeholders/Experts

Valuable discussions were held with experts involved in renewable energy initiatives in West Africa. These discussions provided insights and practical perspectives on the challenges and risks faced during project implementation. Engaging with these experts and other relevant professionals allowed for a comprehensive exploration of the unique risks encountered in this specific context. In total, four experts with experience in implementing sustainable energy projects in West Africa were consulted. Two experts were consulted through face-to-face discussions, while the remaining two were engaged via phone calls.

3.3.3 Semi-Systematic Literature Review

An extensive literature review was undertaken to explore existing knowledge and research on renewable energy projects. Snyder (2019) suggests that a semi-systematic literature review is preferred when the research goal requires a less rigid and more adaptable method than a fully systematic review since it allows for a more creative and exploratory collection of data from various sources and disciplines, thus providing a broader perspective on the research topic. To fulfil the purpose of conducting a semi-systematic literature review, a comprehensive analysis of published studies was undertaken. This review specifically focused on examining the topics of direct air capture technology, risks associated with renewable energy projects, and risks specific to the context of West Africa. Following a predefined review protocol (see Appendix A), the literature review aimed to gather and synthesize relevant information from a variety of disciplines regarding risks in the implementation of energy projects, allowing for a more creative and holistic approach compared to a systematic review. Searches were conducted in reputable journals such as Web of Science, ScienceDirect, ResearchGate, and Google Scholar using various combinations of search terms to identify relevant articles and publications. Dissertations and theses were excluded from the consulted sources.

By combining the outcomes of brainstorming sessions, stakeholders/expert discussions, and literature review, a robust and diverse list of potential risks was compiled. These risks encompassed various aspects of project implementation, such as technical complexities, financial uncertainties, regulatory compliance, community engagement, and environmental factors. The aim was to capture a wide range of potential risks that may arise during the implementation stage, ensuring a comprehensive assessment of the project's risk landscape.

3.4 Risk Structuring

3.4.1 Risk Refining

Following the comprehensive compilation of the inventory of risks, a meticulous refining process was conducted. This critical step involved a meticulous review of each identified issue to ascertain its significance and determine whether it warranted further attention. Risks that were found to be irrelevant or insignificant in the context of the project were thoughtfully excluded from the subsequent analysis, leaving behind only those risks that demanded further scrutiny and proactive management. The objective of this refining process was to streamline the risk assessment, ensuring that it concentrated on the most crucial and impactful risks that could potentially impede the project's success. By eliminating non-essential risks, the refinement phase aimed to enhance the effectiveness and efficiency of the overall risk management process, enabling resources to be concentrated on addressing the risks that truly mattered.

3.4.2 Risk Categorization

To facilitate expert assessment and analysis, the refined risks were methodically categorized into specific risk categories as shown in Table 3.1. Due to the lack of a generally acceptable categorization for renewable energy risks (Nuriyev et al., 2019), several studies have proposed varying categorization techniques for risks in sustainable energy projects. For example; the International Actuarial Association (2010) categorizes risks into statistical and non-statistical risks. They go further to define statistical risks as risks that can be mathematically or statistically modelled and non-statistical risks as those that cannot be statistically modelled. Ioannou et al. (2017) identify six risk categories for sustainable energy projects: Political, economic, social, technological, environmental, and legal (PESTEL). Other categorizations include those provided by Gatzert and Kosub (2016): Strategic and business risks, transport/construction risks, operation/maintenance risks, liability/legal risks, market/sales risks, counterparty risks, and political, policy and regulatory risks, and categorizations identified in Awuni (2019) which provides a more detailed risk categorization: Technology risk, financial risk, contractual risk, political risk, environmental risk, social risk, economic and force majeure risk. The exploration of these varying categorizations of risks formed the basis of the categorization used in this study.

The purpose of categorizing these risks was to ensure that they could be effectively evaluated by experts possessing the relevant expertise in specific risk categories. This categorization process allowed for a more focused and specialized examination of the risks, enabling experts to provide accurate assessments and insights based on their domain knowledge. By categorizing these risks, the risk assessment methodology aimed to ensure that each risk received the appropriate attention and evaluation, leading to a comprehensive understanding of the potential challenges and vulnerabilities associated with the project implementation.

Table 3.1. *Risk Categories and Description*

Risk Category	Description	Reference
Financial risks	All risks associated with the financial factors: Financial transactions and investments	(Awuni, 2019)
Technical/ Technological risks	Risks associated with the adopted technology and technical aspects of the project	(Awuni, 2019; Ioannou et al., 2017)
Political risks	Country specific risks arising from changes in specific country policies or regulations.	(Awuni, 2019; Gatzert & Kosub, 2016; Ioannou et al., 2017)
Contractual risks	Risks arising from contract agreements with all involved or contracted parties.	(Awuni, 2019)
Social risks	The potential risks originating from engagements with local communities and the social implications of a project within the country of implementation	(Awuni, 2019; Ioannou et al., 2017)
Environmental risks	Risks arising from environmental factors such as natural disasters, climate change, and other environmental issues	(Awuni, 2019; Ioannou et al., 2017)
Operational/ Administrative risks	Risks related to all operational and administrative aspects of the project implementation	(Gatzert & Kosub, 2016; Noothout et al., 2016)

3.5 Risk Analysis

3.5.1 Expert Elicitation

Risk assessments often rely on statistical data and historical information for analysing and evaluating risks. However, in cases where such data is lacking or insufficient, expert input becomes valuable (Ahmad Shukri & Isa, 2021). Expert knowledge can help compensate for the absence of statistical data, providing insights and expertise to enhance the risk assessment process (Skjong et al., 2011). The use of expert data as a basis for quantitative risk assessment has been criticized by some for the introduction of subjectivity by the experts. However, Skjong et al. (2011) further argue that risk assessments with expert judgments are better than the alternative of no analysis. Risk probability assessment examines the chances of occurrence for each particular risk, while risk impact assessment delves into the potential consequences on project objectives, such as time and cost (Mirkheshti & Feshari, 2017).

In addressing the challenges posed by the limited availability of statistical data in assessing risks associated with the DryHy project, an expert opinion survey was employed. A group of experts with backgrounds in fields such as project management, business administration, engineering, and renewable energy systems, was consulted. The selection process was based on the following criteria: experts directly associated with the DryHy project, experts with a good knowledge of the implementation location, and experts with a willingness to participate. By harnessing the insights and judgments of these experts, a robust understanding of the identified risks was obtained. Questionnaires were developed based on the risk categories, soliciting estimates from experts regarding the likelihood and impact of each identified risk. Experts were requested to provide their assessments based on their familiarity and experience with the respective risk categories. These responses formed the basis for further analysis.

Based on the provided questionnaire spreadsheet sample (see Appendix B), experts were requested to assess the likelihood and impact of each risk outlined in the expert survey. The likelihood column required experts to provide a single probability estimate between 0 and 90%, rounded to the nearest 10. An option of selecting a likelihood of 0 was available only if the risk was perceived to have absolutely no chance of occurrence. This facilitated the identification of risks that were deemed irrelevant by the experts.

Regarding impacts, they were defined in terms of a percentage increase in either the estimated project cost (cost overruns) or project duration (project delays). Experts were asked to provide a maximum and minimum percentage impact for each potential impact. These percentages represented the expected increase in the total estimated project cost or project duration. The acceptable range for values was set between 0 and 100%. However, provision was made for experts to input values beyond this range if they felt the provided range was insufficient to accommodate the potential impact of the risk.

3.5.2 Expert Opinion Aggregation

A key assumption in analysing expert inputs is that all assessment is provided in good faith. The first step in the analysis process involved the analysis of the collected responses from the expert assessments. The analysis aims to generate a comprehensive understanding of the risks, their likelihood, and potential impacts. Inputs from multiple experts was combined using mathematical operations. The aggregation of expert inputs with an arithmetic mean is a favoured approach as recommended by Skjong et al. (2011) and also validated as a suitable method by Beliakov et al. (2015) . Although the mean is the most popular measure of central tendency (Beliakov et al., 2015), it is most affected by outliers (Hurley & Tenny, 2022). To address this shortfall, the median provides a better measure if a set of values contains outliers (Adams et al., 2019; Hurley & Tenny, 2022; Kämpke, 2010). Consequently, aggregation was done by selecting a measure of central tendency that best suits the inputs. A combination of the arithmetic mean and the median was used in aggregating the inputs depending on the nature of the data distribution (see Appendix C).

Based on the findings derived from the aggregation of expert inputs, a deterministic risk register was formulated (see Appendix D). The risk register encompassed all identified risks resulting in a common impact, such as cost overruns. It incorporated the aggregated likelihood and impact of all selected risk factors. The resulting risk register served as the foundation for the subsequent Monte Carlo simulations.

3.5.3 Monte Carlo Simulation

In the literature, several methods have been proposed to perform quantitative risk assessment. Ioannou et al. (2017) categorized risk-based approaches utilized in sustainable power generation planning into two groups: quantitative and semi-quantitative methodologies. The former deals with statistical risk factors than can be modelled with probability distributions and includes methods such as Mean–variance portfolio (MVP) theory, real options analysis (ROA), Monte Carlo Simulations (MCS), and stochastic optimisation techniques. While the latter considers both statistical and non-statistical risks and includes multi-criteria decision analysis (MCDA) and scenario analysis. In selecting a method for quantitative assessment in this thesis, the suitability of each method listed above was considered. The MVP is suitable for assessing and optimizing investment portfolios based on the trade-off between expected return and risk, while the ROA is commonly utilized to assess the influence of uncertainty on investment choices. Similarly, MCDA focuses on organizing and resolving decision and planning challenges that encompass multiple criteria. The MCS method was chosen as the preferred approach. The selection of the Monte Carlo simulation method was justified due to its divergence from the other presented methodologies. The reason for its preference lies in its flexibility and effectiveness as an extensively comprehensive and adaptable approach for analysing uncertainties and allows for the modelling of risk factors and the assessment of their impacts under varying occurrences (Vithayasrichareon & MacGill, 2012). Gupta and Thakkar (2018) support the selection of MCS as the preferred approach in risk assessment, affirming its prominence among the primary quantitative techniques used. They emphasize that sensitivity analysis, modelling and simulation, and decision trees are commonly employed methods in risk assessment. However, MCS stands out as the favoured technique in this domain.

The Monte Carlo simulation (MCS) is utilized in risk analysis to randomly sample input data from predetermined probability density functions using random or pseudo-random numbers. Through a substantial number of simulations, MCS generates repeated values for the model's output variables (Arnold & Yildiz, 2015; Ioannou et al., 2017). MCS presents numerous benefits, including the capability to quickly generate results when adjusting problem variables, the ability to assess risk associated with uncertain or stochastic input variables, the ability to model correlations and interdependencies within the system, and the availability of several commercial software (Ioannou et al., 2017; Khodakarami & Abdi, 2014; Sander, 2016). Several literature sources that have utilised MCS in quantitative risk analysis in renewable energy projects include: (Arnold & Yildiz, 2015; Da Pereira et al., 2014; Fahringer et al., 2011; Herman, 2002; Marmidis et al., 2008; Rocchetta et al., 2015; Vithayasrichareon & MacGill, 2012).

In aligning with the objectives of this thesis, which is the quantification of the identified risk factors during project implementation, Vegas-Fernández (2022) asserts the suitability of a probabilistic approach in getting better results as compared to the traditional deterministic “expected value (EV) method” defined as the product of the risk likelihood and the impact. Furthermore, they assert that the accurate mathematical representation of the total project risk cost involves calculating the probabilistic sum of all residual risks through the utilization of Monte Carlo simulations (MCSs). Sander (2016) also validates the suitability of the probabilistic approach in estimating the probable cost of risks of a project. MCSs compute the probabilistic total risk cost by utilizing input distributions obtained through discussions with technical professionals or, on occasion, from historical records (Khodakarami & Abdi, 2014).

In this step, the MCS model is applied to determine the combined risk cost of all risk factors in the resulting deterministic risk register from section 3.5.2. The MCS is realised with XLRisk add-in software for Microsoft Excel. XLRisk is an open-source Excel add-in that is designed for performing Monte Carlo Simulations. This plugin was chosen because of its open-source nature and its capability to produce outcomes similar to those obtained from proprietary high-end risk software like @Risk. From the deterministic risk register developed, probability distributions were assigned to the likelihood and the impact of the risk. Two probability distribution types were used: Uniform distribution and Bernoulli distribution. According to Michelez et al. (2011), modelling likelihood of occurrence commonly utilizes either the Bernoulli distribution or the binomial distribution as these distributions are most suitable for that purpose. To simulate the likelihood of each risk event, a Bernoulli distribution was applied to the aggregate likelihood assigned to each risk event. In each iteration, the risk could either occur or not, resulting in a value of 1 if the risk occurs or 0 if the risk does not occur. Likewise, modelling the impacts utilized a uniform distribution. The choice of a uniform distribution for the impacts was based on the sphere of application of a uniform distribution which is commonly applied in describing distributions that have no likely value (Michelez et al., 2011). In such situations, only two inputs, a minimum and a maximum value are required with all values within the range having an equal likelihood of occurrence without any bias in the outcomes (Herman, 2002). Based on these inputs, simulations were carried out for 10,000 scenarios using the XLRisk add-in software. The resulting simulated occurrence and simulated impact are multiplied to determine the risk amount. For details of the resulting probabilistic risk register with the simulated occurrence and impact (see Appendix E).

3.6 Risk Evaluation

Risk evaluation involves comparing risk analysis results with established criteria to inform decision-making. Based on the evaluation, decisions can include taking no action, pursuing risk treatment, conducting further analysis, maintaining controls, or re-evaluating objectives (International Standard Organization, 2018). It involves making decisions about proactive and reactive responses based on the results of the analysis (Chapman & Ward, 2003). Based on the results from the Monte Carlo simulation model, risks with the highest influence on the selected impact are identified. These risks are set aside for further decision-making regarding treatment, or mitigation.

3.7 Risk Treatment

The main objective of risk treatment is to execute strategies for managing risks (International Standard Organization, 2018). Chapman and Ward (2003) identified the following responses for dealing with risks: modify objectives, avoid, influence probability, modify consequences, develop contingency plans, keep options open, monitor, accept and remain aware. Similarly, other risk treatment options provided by International Standard Organization (2018) include risk sharing via contracts or insurance, and removing the risk source.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Overview

Although it is theoretically feasible to identify and assign costs to all components of a project and subsequently compile the estimated prices into an arithmetically accurate estimated project cost, it is crucial to acknowledge that this figure will never align with the actual project cost upon completion (Khodakarami & Abdi, 2014; Project Management Institute, 2008). For investors, the quantification of cost overruns during the project's implementation stage is a pivotal variable. This is because cost holds the utmost importance among the established benchmarks for project success, alongside schedule adherence and performance outcomes (Kwon & Kang, 2019). Additionally, risks associated with potential project delays hold significant importance. However, in the context of less mature technologies without established technical standards, performance takes precedence over construction time, making project delays potentially acceptable (Michelez et al., 2011). This chapter presents the findings from the initial steps of the risk assessment and culminates in the results of the analysis of expert estimates, with a specific focus on providing quantitative results that demonstrate the relationship between the likelihood and impact of these factors on the total estimated project cost. Additionally, it covers the risk treatment options available for the identified risks. By elucidating how variations in likelihood and impact estimates can influence cost, this analysis equips investors and project managers with valuable insights for decision-making and risk management in the DryHy project.

4.2 Results of the Risk Identification and Risk Structuring

Through the meticulous adherence to the identification and structuring phase of the methodology, the results of both processes are provided. Table 4.1, 4.2, 4.3, and 4.4 provides a comprehensive overview of the considered risk categories, the identified risks, and their corresponding descriptions.

4.2.1 Financial Risks

The financial aspect of any project is a critical success factor to the successful attainment of project goals and objectives. Factors such as inadequate funding are known to have major impacts on the successful outcome of a project (Lamprou & Vagiona, 2018). In practical project scenarios, the necessary investment is often not made as a single upfront payment. Instead, capital investment is typically staged and disbursed in a series of incremental outlays, allowing for the possibility of default at various stages throughout the project's life cycle (Trigeorgis, 1999). This background emphasizes the potential of budgetary constraints as a risk factor in the project life cycle. It relates to the likelihood of limitations in the disbursement of the initial allocated budget due to reasons such as a change in the project scope, strategic shift as a result of the funder’s change in policies and priorities resulting in a reallocation of funding, political interferences, and a host of other reasons. Inaccurate cost estimation can also have a significant impact on the project and it is measured as the extent to which the estimated costs align with the actual project costs. Significant deviations of the actual costs from the estimated cost can have considerable impacts on the project. Kwon and Kang (2019) state that inaccurate cost estimation stands out as a primary contributor to cost overruns in project undertakings. Factors leading to inaccurate cost estimation include: unknowns related to cost elements such as technology, human resource productivity, economic circumstances, pricing, inflation, and potential future risks and occurrences (Khodakarami & Abdi, 2014). Due to market fluctuations and instabilities in the prices of commodities, there exist a tendency of the prices of commodities to fluctuate. This could present itself as an opportunity in a situation where prices become lower than estimated or a threat when they become higher. Economic instability and inflation and fluctuating currency exchange rates are also risks that were identified as having the potential to impact the project implementation. Cash flows dominated by foreign currencies can be significantly affected by fluctuations in exchange rates considering the significant time gap between project planning and project implementation (Michelez et al., 2011). Table 4.1 provides a description of the identified financial risks.

4.2.2 Technical/Technological Risks

Technical risks encompass all risk factors related to the technology used in the project. Factors such as technological novelty and unpredictability are drivers of technology risk (Egli, 2020). The categorization used for technical risks in this thesis encompasses equipment and components used during the project implementation. Key technical issues identified as important for consideration include: Equipment failure or damaged components which relates to the tendency for technical components or equipment to develop faults that could result in them either needing to be replaced or serviced. Additionally, a risk factor that can be considered in the event of equipment failures or damaged components is the limited availability of spare parts and maintenance services, as any difficulty encountered in replacing damaged parts could result in project delays and extra costs in trying to secure the necessary parts. This issue originates from the awareness that most project components and equipment are not produced locally and therefore have to be imported from overseas. The introduction of design changes is another issue identified as it can also have significant impacts on project objectives. Changes in the initial design especially during the implementation stage is likely to result in delays and cost overruns in trying to adapt these introduced changes into the project. Inadequate system integration also requires assessment as the project involves the incorporation of different technologies to function cohesively as a unified system. These technologies should be compatible to ensure proper system integration. However, in the event of incompatibilities, cost overruns and delays become paramount. Table 4.1 describes the identified technical/ technological risks.

4.2.3 Political Risks

Political and regulatory risks have been highlighted in the literature as critical to project success (Gatzert & Kosub, 2016; Keith et al., 2018). The availability to manage possible losses resulting from political action by the host government can have major impacts on projects in politically risky countries (Michelez et al., 2011). Political risks are generally categorized as host country risks as they are location specific. In general, the impacts of political risks in the implementation stage of a project are largely related to project delays due to delays in permitting and licensing processes (Michelez et al., 2011). The political risks identified include Changes in government policies and regulations, political instability and civil unrest, corruption and bribery, regulatory compliance issues and the risk of expropriation or war. Table 4.2 describes the identified political risk.

4.2.4 Environmental Risks

Environmental factors are another key aspect to be considered in a project. Emerging as a direct outcome of climate change, extreme weather is poised to trigger not only physical havoc but also substantial financial implications (Ando et al., 2022). They are country specific risks as different countries and regions are prone to different environmental factors. These issues hold significance in the project context as they are likely to play a major role in influencing how well the project is able to reach its objectives. Environmental risks identified are: Climate change and extreme weather events, Land use, habitat impact, and ecological damage. Table 4.2 describes the identified environmental risks.

4.2.5 Contractual Risks

Projects usually involve the signing of contracts that are important in the whole project endeavour. These contracts are binding agreements among project stakeholders and are expected to be adhered to. However, there are situations where one stakeholder decides to default in the terms of the contract agreement thus leading to a chain of events that can have negative impacts on the project objectives. The contractual risks identified are Breach of contract and disputes with contractors or suppliers, inadequate legal frameworks and contract enforcement, Contract and sub-contract interface risk. Table 4.2 provides a description of the identified contractual risks.

4.2.6 Social Risks

According to Noothout et al. (2016), lack of social acceptance of renewable energy projects results in project delays or cancellations, and associated legal battles leading to extra costs incurred. However, social risks relating to public acceptance are predominantly considered during the planning and development stage of a project. In General, social aspects are important considerations in trying to maximize project objectives and they include stakeholder conflicts and community resistance, cultural and social acceptance challenges, displacement of local communities and land rights issues, health and safety concerns for workers and nearby communities, changes in the local economy and social inequity. Table 4.3 describes the identified social risks.

4.2.7 Operation/Administrative Risks

The operational and administrative aspects are key aspects in project implementation as they envelope all risk factors bounded around the operational procedures and administrative areas of the project. They encompass the potential consequences stemming from inadequate or unsuccessful internal processes, personnel, and systems, or from external events (Standard Bank Group, 2012). Identified risks include prospecting risk, transportation risks, lack of cooperating partners to share technical expertise, insufficient management know-how, sabotage, theft or vandalism, difficulties in securing skilled labour and technical expertise, scope creep, inadequate infrastructure and grid limitations, security risks, fire outbreak, negligence or human errors, and employee misconduct. Table 4.3 and 4.4 provides a description of the identified operation/administrative risks.

Table 4.1. Risks Associated with the Implementation Phase of the DryHy Project

Risk Category	**Risk Elements**	**Risk Description**	**References**
Financial Risks	Budgetary constraints **(F1)**	Constraints or restrictions on the project's available funds	(Gatzert & Kosub, 2016; Ioannou et al., 2017; Michelez et al., 2011; Nuriyev et al., 2019; Prostean et al., 2014)
	Inaccurate cost estimation **(F2)**	Underestimation of costs	(Dick-Sagoe et al., 2023; Khodakarami & Abdi, 2014)
	Changes in the cost of materials **(F3)**	Fluctuations in the prices of raw materials, components, or resources that are required for the project	(Khodakarami & Abdi, 2014; Michelez et al., 2011)
	Economic instability and inflation **(F4)**	Increase in wages, raw materials, and energy expenses due to inflation	
	Fluctuating currency exchange rates **(F5)**	If a project involves transactions in different currencies, fluctuations in exchange rates can affect the cost of import tariffs and wages in Côte d'Ivoire	(Noothout et al., 2016; Nuriyev et al., 2019)
Technological / Technical Risks	Equipment failures / Damaged component **(T1)**	Malfunction or breakdown of critical component or equipment	(Ioannou et al., 2017)
	Limited availability of spare parts, equipment, materials and maintenance services **(T2)**	Refers to the difficulty in securing replacement parts in the event of component failure, accessing required equipment, or maintenance or repairs of equipment and components	(Gatzert & Kosub, 2016)
	Introduction of design changes **(T3)**	Possible changes to the initial project design	(Chapman & Ward, 2003; Khodakarami & Abdi, 2014)
	Inadequate system integration **(T4)**	Compatibility issues due to challenges in incorporating various technologies in the system	

Table 4.2. Risks Associated with the Implementation Phase of the DryHy Project (cont.)

Political Risks	Changes in government policies and regulations **(P1)**	Policy changes or introduction of new regulations that may affect projects within a country	(Burger et al., 2014; Ioannou et al., 2017; Keith et al., 2018)
	Political instability **(P2)**	Unstable government structure prone to changes or collapse, social unrest, civil unrest that could impact project operations and investments	(Noothout et al., 2016; Nuriyev et al., 2019)
	Corruption and bribery **(P3)**	Risk arising from inefficient or non-transparent administration requiring the payment of bribes and undocumented commissions	(Noothout et al., 2016; Nuriyev et al., 2019)
	Risk of expropriation, war, or terrorism **(P4)**	Social unrest, civil unrest, or changes in government policies that could impact project operations and investments	(Mirkheshti & Feshari, 2017)
Environmental Risks	Land use, habitat impact and ecological damage **(E1)**	General effects of project activities on the natural environment	(Michelez et al., 2011; Mirkheshti & Feshari, 2017)
	Climate change and extreme weather events **(E2)**	Spells of bad weather conditions e.g., storms	(Ioannou et al., 2017; Mirkheshti & Feshari, 2017)
Contractual Risks	Breach of contracts and disputes with contractors or suppliers **(C1)**	Situations where one party fails to fulfil the terms and conditions outlined in a legally binding agreement, leading to conflicts, disagreements, or legal actions	(Ioannou et al., 2017; Keith et al., 2018)
	Contract and sub-contract interface risk **(C2)**	Situations, where multiple parties are involved in a project and project objectives, can only be achieved when all parties coordinate and communicate effectively	

Table 4.3. Risks Associated with the Implementation Phase of the DryHy Project (cont.)

Social Risks	Stakeholder conflicts and community resistance **(S1)**	Disagreements among various stakeholders involved in an energy project, and resistance from the local community	(Mirkheshti & Feshari, 2017; Noothout et al., 2016)
	Cultural and social acceptance challenges **(S2)**	Public acceptance issues to energy projects	(Michelez et al., 2011; Noothout et al., 2016)
	Displacement of local communities and land right issues **(S3)**	Land requirements leading to the displacement of local community resulting in conflicts over land rights	(Michelez et al., 2011)
	Health and safety concerns for workers and nearby communities **(S4)**	Health and safety issues arising from project activities	
Operational and Administrative Risks	The prospecting risk **(OA1)**	The probability of not finding the projected values for the temperature and quantity parameters. Potential variability associated with the exploration or assessment of resources	(Nuriyev et al., 2019)
	Transportation logistics failure **(OA2)**	Component damage or theft during transportation and potential delays due to logistics failure	(Gatzert & Kosub, 2016; Mirkheshti & Feshari, 2017; Prostean et al., 2014)
	Lack of cooperating partners to share technical expertise **(OA3)**		(Gatzert & Kosub, 2016)
	Insufficient management know – how **(OA4)**	The project management team may be inexperienced in handling the project endeavours	(Dick-Sagoe et al., 2023; Gatzert & Kosub, 2016)

Table 4.4. Risks Associated with the Implementation Phase of the DryHy Project (cont.)

Operational and Administrative Risks	Sabotage, theft, or Vandalism **(OA5)**	Components can be subject to theft, sabotage or vandalism	(Burger et al., 2014; Michelez et al., 2011; Mirkheshti & Feshari, 2017)
	Difficulties in securing skilled labour **(OA6)**	Lack of skilled or qualified labour to carryout project activities (Refer to the challenges or obstacles faced in recruiting qualified individuals with the necessary skills and expertise)	(Ioannou et al., 2017; Mirkheshti & Feshari, 2017; Noothout et al., 2016)
	Scope creep **(OA7)**	Expansion of project requirements or objectives beyond the initially defined scope	(Keith et al., 2018; Khodakarami & Abdi, 2014)
	Inadequate infrastructure **(OA8)**	Lack of good road networks to connect project site	(Nuriyev et al., 2019)
	Security risks **(OA9)**	Security challenges to the project and project implementation team	
	Fire outbreak **(OA10)**	Possible fire outbreak on project site or components during implementation	
	Negligence or human errors **(OA11)**	Unintentional actions or errors by employees or contractors, such as mishandling equipment, failing to follow security protocols, or falling victim to phishing attacks, can inadvertently create security vulnerabilities.	(Chapman & Ward, 2003)
	Employee misconduct **(OA12)**	Insider threats can arise from employees or contractors with malicious intent, such as theft of intellectual property, sabotage, or unauthorized disclosure of sensitive information	

Note. Risks without references were derived from the brainstorming and discussion sessions, and are absent in the consulted literature.

4.3 Results of the Risk Analysis

4.3.1 Results of the Expert Assessment

Among the risk categories, a subset was chosen for quantitative assessment due to the high number of identified issues. An evaluation of expert inputs based on the results of the expert survey was conducted to streamline the assessment process. Consequently, further analysis focused on a limited number of risks that demonstrated reoccurrence based on the insights derived from the literature review and recommendations of experts.

A total of 20 questionnaire samples were sent out as an online fillable spreadsheet. However, only 7 experts provided input on risk areas they were familiar with, resulting in a 35% response rate. Given the limited number of responses received, only risks that were completely assessed by at least 3 experts were selected for quantitative analysis. This criterion was established because aggregating any fewer responses was considered to be insufficient in capturing the diverse perspectives from the experts. Also, additional risk factors were excluded from the quantitative analysis based on insights from the literature review. Climate change and extreme weather events was excluded since the likelihood of extreme weather events leading to significant cost overruns is deemed insignificant based on estimates of projected trends in extreme climate events in Côte d'Ivoire obtained from (African Development Bank, 2018; United Nations Office for Disaster Risk Reduction & Centro Internazionale in Monitoraggio Ambientale, 2019). Currency fluctuations hold lesser significance for nations within the Eurozone; although, they could become pertinent in cases involving transactions conducted in different currencies (Noothout et al., 2016). Consequently, fluctuating currency exchange rates is also excluded considering the stability of the exchange rates between the Euro (EUR) and West African CFA franc (XOF) based on historical data obtained from (Deutsche Bundesbank, 2023). Risks selected for further analysis are shown in Table 4.5. Risks having dual impacts imply that the identified risk were evaluated for both potential cost overruns and project delays.

Table 4.5. Risks Selected for Quantitative Analysis

Risk Category	**Risk Element**	**Impact**
Financial risks	Budgetary constraints	Project delays
	Inaccurate cost estimation	Cost Overruns
	Changes in the cost of materials	Cost Overruns
	Economic instability and inflation	Cost Overruns
Technical Risks	Equipment failures/Damaged component	Cost Overruns/ Project delays
	Limited availability of spare parts and maintenance services	Project delays
	Inadequate system integration	Cost Overruns/ Project delays
Political Risks	Changes in government policies and regulations	Cost Overruns/ Project delays
	Political instability and civil unrest	Cost Overruns/ Project delays
	Corruption and bribery	Cost Overruns
	Risk of expropriation or war	Cost Overruns
Operational / Administrative Risks	Transportation logistics failure	Cost Overruns/ Project delays
	Lack of cooperating partners to share technical expertise	Project delays
	Sabotage, Theft or Vandalism	Cost Overruns/ Project delays
	Difficulties in securing skilled labour and technical expertise	Project delays
	Inadequate Infrastructure	Cost Overruns/ Project delays
	Fire outbreak	Cost Overruns/ Project delays
	Negligence or Human errors	Cost Overruns/ Project delays
Environmental Risk	Land use, habitat impact and ecological damage	Cost Overruns/ Project delays
	Climate change and extreme weather	Project delays

Risk items in Table 4.5 are comprehensively segregated based on impact categories for further analysis. Specifically, cost overruns and project delays were the primary impact categories under consideration. Risks that were anticipated to lead to cost overruns were segregated into a separate table (see Appendix F), while those likely to result in project delays were similarly categorized (see Appendix G). Risks that had the potential to impact both cost and project duration were placed in both categories.

4.3.2 Results of the Monte Carlo Simulation Model

The Monte Carlo simulation model operates through iterative simulations of various outcomes based on whether or not the identified risk events occur. In each iteration, the total risk amount is computed based on the number of risk events that occur. When the designated number of simulations is completed, the desired output from each simulation - in this case, the total risk amount - is computed. These computations form the basis for generating the overall simulation statistics and model results.

Monte Carlo simulations were conducted on the deterministic model generated for the cost overruns impact category (see Appendix D) following the procedure described in section 3.5.3. Specifically, the risk category leading to cost overruns (see Appendix F) was considered. For every risk event, the risk amount was obtained by multiplying the simulated occurrence by the simulated impact on the probabilistic risk register (see Appendix E). The total risk amount is obtained by summing the individual risk amounts. Simulation results are presented in Table 4.6.

As presented in Table 4.6, the simulation statistics offer an overview of the outcomes from the 10,000 simulations conducted using the XLRisk software. It includes measures such as the mean, median, and standard deviation, summarizing the results of the total risk amount across all simulations. Table 4.6 further provides percentiles of all outcomes from the different simulations. These percentiles convey levels of confidence on the realization of a specific total risk amount, based on the results across all simulations. For instance, the 50th percentile conveys a confidence level of 50%, corresponding to a total risk amount of 84% of the total estimated project implementation cost. Similarly, the 60th percentile conveys a confidence level of 60%, and corresponds to a total risk amount of 94.8%. Similar information can be obtained from Table 4.6 by identifying the total risk amount that aligns with a chosen percentile.

Table 4.6. First Simulation Statistics and Percentiles

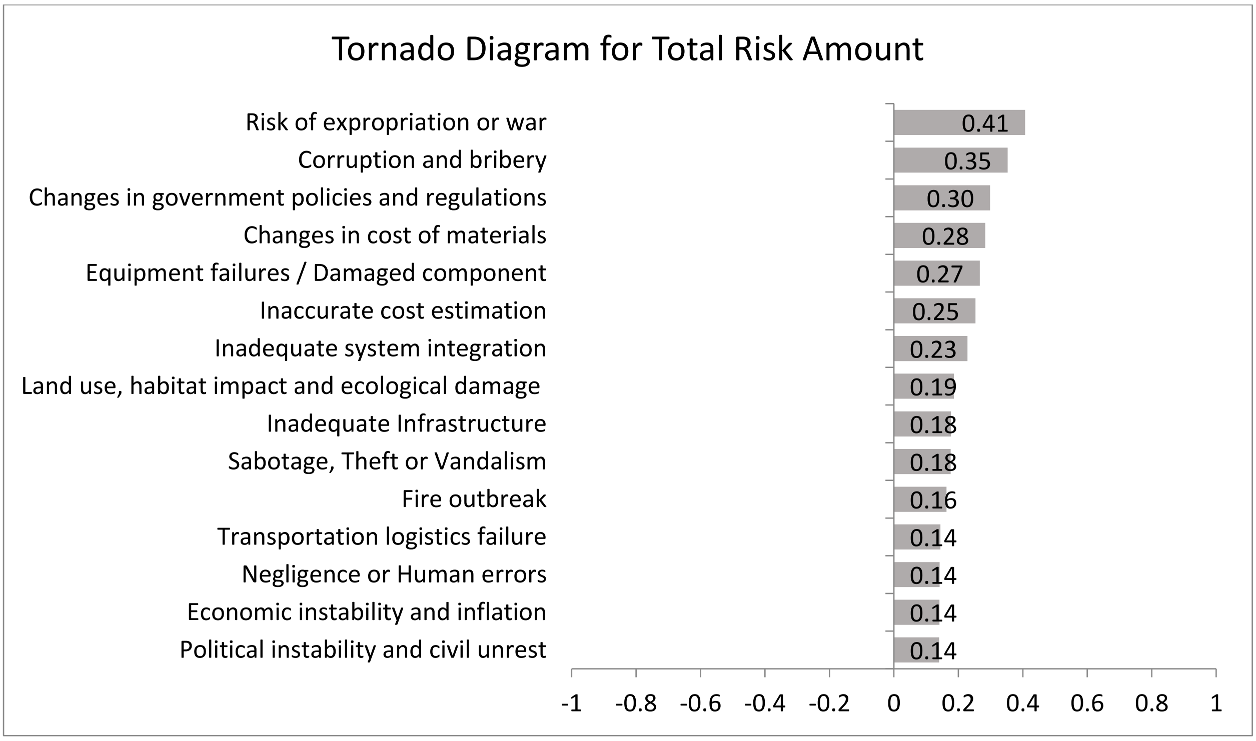
Simulation Statistics	
	Total Risk Amount
Mean	87.15197265
Median	84.04746644
Mode	0
Std. Deviation	39.9031388
Variance	1592.260486
Kurtosis	0.091690205
Skewness	0.412115511
Minimum	0
Maximum	265.7454032
Range	265.7454032
Count	10000
Error Count	0
Std. Error	0.399031388
Confidence Level (95%)	0.782181831

Percentiles	
	Total Risk Amount
0.0%	0
2.5%	17.5479784
5.0%	26.69756239
7.5%	32.27334196
10.0%	37.51195735
12.5%	41.76268015
15.0%	45.57603707
17.5%	48.99641319
20.0%	52.32746315
22.5%	55.33304973
25.0%	58.46435163
27.5%	61.19788754
30.0%	64.15174338
32.5%	67.01626298
35.0%	69.63447377
37.5%	71.96873944
40.0%	74.27473497
42.5%	76.56364908
45.0%	79.02360853
47.5%	81.63472384
50.0%	84.04746644
52.5%	86.54536873
55.0%	89.28219329
57.5%	91.98218954
60.0%	94.78877474
62.5%	97.70176171
65.0%	100.7246779
67.5%	103.8270087
70.0%	106.7924589
72.5%	109.876254
75.0%	113.1702802
77.5%	116.2842027
80.0%	120.194415
82.5%	124.183631
85.0%	128.8841381
87.5%	134.3481337
90.0%	139.89886
92.5%	147.275252
95.0%	157.1096771
97.5%	172.1778789
100.0%	265.7454032

Considering the importance of estimating the total risk amount in the implementation of projects, the percentile results are of paramount importance in providing a confident estimate of the possible cost overruns attributed to risk events that can be incurred during the project implementation. For instance, these results can be presented as follows: we are 50% confident that the cost overruns resulting from the occurrence of risk events will not exceed 84% of the total estimated project implementation cost. By analysing these results, we have been able to quantify risk factors into a comprehensive total risk amount, providing valuable information for the investor. This, in turn, addresses the second research question in this study (see section 1.2.1).

Although the initial results provided a quantification of the risk events, they fell short in assessing the specific influence of individual risk factors on the total risk amount. Consequently, additional results are required to provide more information in this regard. In addition to the simulation statistics, the analysis also yielded a tornado diagram as shown in Figure 4.1. It correlates the impact of the identified risk factors on the total risk amount. The length of the bars indicates the degree of influence each risk factor has on the total risk amount. Risk factors with longer bars, such as expropriation or war and corruption and bribery exert a higher influence on the total risk amount. The tornado diagram aids in identifying the risk factors with the most significant influence on the potential negative outcome, specifically cost overruns, thus highlighting risk factors that require heightened attention and adept management in order to limit the negative outcome.

Figure 4.1. *First Simulation Tornado Diagram*



Note. Risk elements in the Tornado diagram corresponds to the risks in the cost overruns impact category (refer to Appendix F)

Based on the results presented, the risk of expropriation or war is identified as a significant risk factor to be considered in the implementation of the project. Its impacts include safety threats to project personnel, damages of infrastructure, facilities, and assets leading to financial losses and project setbacks. Corruption and bribery rank second amongst the most influencing risk factors. Corrupt practices such as misused funds and resources misallocated or diverted for unauthorized purposes, corrupt practices from suppliers and contractors who might deliver substandard materials or services, inflated invoices and payments, and violation of safety and environmental regulations leading to potential legal challenges. These factors can have significant impacts on project implementation thus greatly impacting cost overruns as seen from the results in Figure 4.1. Changes in government policies and regulations, changes in cost of materials, and fluctuating currency exchange rates are seen to have similar impacts on the project costs by having similar correlation coefficients. Risk factors with the least impacts on project's total risk amount include transportation and logistics failure, political instability and civil unrest and climate change and extreme weather events.

In attempting to address the third research question (see section 1.2.1), all host country specific risks are excluded and the simulations are repeated to determine the total risk amount.

We assume that only host country risks are location specific, and will require separate assessments for any chosen geographical location. However, other factors are expected to remain the same irrespective of the geographical location.

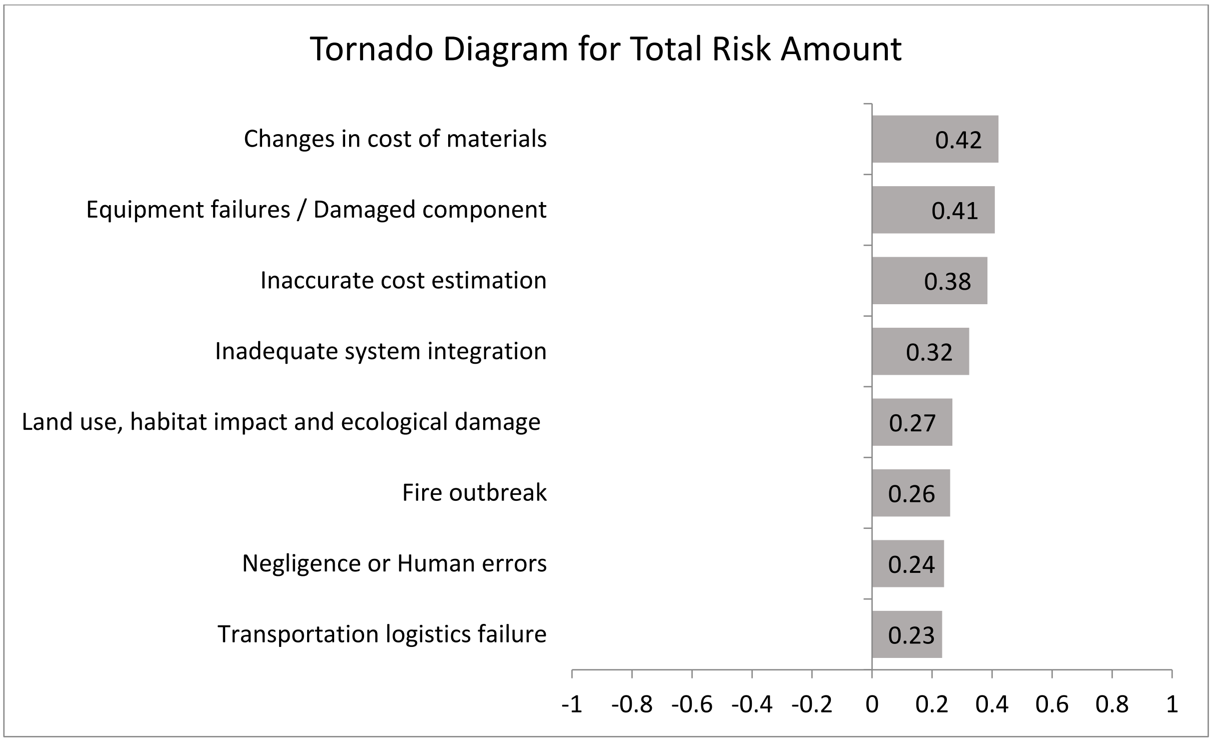
Results of the simulations show a further decrease in the total risk amount as can be observed in Table 4.7. This emphasizes the magnitude of the impact of host country risks on cost overruns as they play a major role in determining how much the projects estimated cost might be exceeded. The tornado diagram in Figure 4.2 indicates that changes in the cost of materials is the most significant risk factor when country-specific risks are factored out. Similar percentiles can be obtained from Table 4.7, as described in page 38.

Table 4.7. Second Simulation Statistics and Percentiles

Simulation Statistics	
	Total Risk Amount
Mean	39.74606172
Median	37.09840478
Mode	0
Std. Deviation	26.42998774
Variance	698.5442519
Kurtosis	0.164547885
Skewness	0.574640979
Minimum	0
Maximum	163.8323268
Range	163.8323268
Count	10000
Error Count	0
Std. Error	0.264299877
Confidence Level (95%)	0.518080954

Percentiles	
	Total Risk Amount
0.0%	0
2.5%	0
5.0%	0
7.5%	0
10.0%	5.190786111
12.5%	9.406365123
15.0%	11.88463782
17.5%	14.18566119
20.0%	16.23989614
22.5%	18.52168381
25.0%	20.40808239
27.5%	22.08215448
30.0%	23.86807104
32.5%	25.77959133
35.0%	27.560286
37.5%	29.25203806
40.0%	30.83573159
42.5%	32.36719926
45.0%	33.87901963
47.5%	35.51260553
50.0%	37.09840478
52.5%	38.66453929
55.0%	40.24102035
57.5%	42.23125816
60.0%	44.20324046
62.5%	46.10739782
65.0%	48.01770349
67.5%	49.6637898
70.0%	51.85061409
72.5%	54.28033811
75.0%	56.43376254
77.5%	58.85238771
80.0%	61.54616446
82.5%	64.57245199
85.0%	67.51531159
87.5%	71.28626834
90.0%	75.21255044
92.5%	79.90328862
95.0%	87.29500193
97.5%	98.94207682
100.0%	163.8323268

Figure 4.2. *Second Simulation Tornado Diagram*



The results obtained addresses the third research question by focusing on risk factors that are common to different geographical locations. Therefore, only host country specific risks will require assessment when applying these results to a different geographical location.

Several studies on the causes of cost overruns have highlighted the following risks as root causes of cost overruns. For example, materials price fluctuations, lack of experience among contractors, incomplete drawings, government delays, incompetence, inaccurate estimates, improper planning, and poor labour productivity.

Generally, the West African region is plagued by varying political issues that can pose a major threat to investments. In addition, corruption and bribery are considered an everyday means of conducting business as their effect encroach into every sphere of business. The prevalence of host country-specific risks as major influencers of cost overruns in the project implementation based on the results obtained comes as no surprise, as other studies have identified government policies, corruption, and host country characteristics as critical risks that warrant attention (United Nations Conference on Trade and Development, 2023). A close examination of studies conducted by (Dick-Sagoe et al., 2023) on the causes of project failures in Ghana points political interference, and change in government; and corruption related risk factors as major causes of cost overruns and project delays.

From the results, this sequence of risks and obstacles has the potential to result in a substantial increase in project implementation costs if left unmanaged.

4.4 Risk Evaluation

Based on the results from the analysis of the three scenarios, certain risk factors have been identified as key influencers resulting in cost overruns. These results guide the assessment process and helps in focusing on specific issues that should be properly managed to ensure the success of the project implementation. These risks are risk of expropriation or war, corruption and bribery, changes in government policies and regulations, changes in the cost of materials, equipment failures/damaged components, and inaccurate cost estimation. It is therefore imperative that attention should be focused on effectively managing these risk factors during project implementation.

4.5 Risk Treatment Strategies

Risk treatment strategies generally involve one or more of the following as documented in: (Chapman & Ward, 2003; Gonen, 2012; International Standard Organization, 2018; Michelez et al., 2011). The strategies are presented in Table 4.8.

Table 4.8. *Risk Treatment Strategies*

Strategy	Description
Avoid	Avoiding sources of uncertainty by modifying the project plan to eliminate risk or protect project objectives e.g., time and cost from the impact of risk
Modify probability/ likelihood	Reducing the probability of an adverse risk to an acceptable level
Modify impact/consequences	Taking early action to reduce the negative impact of a risk event
Contingency plans	Describes particular steps to follow when a possible risk event happens. For instance, the allocation of resources to cover additional costs as a result of risk events is a means of contingency planning
Transfer or Share	Shift the negative impact of a risk to a third party through insurance, guarantees, and warranties
Acceptance	Choosing to accept a known risk without intervening to avert its results or manage its aftermath. Embracing risk is advisable when the potential outcomes are less expensive compared to the endeavour needed to avert the risk or when the risks cannot be eliminated or avoided. Accepting a certain level of risk and focusing on preparedness and response plans can be a more realistic approach.

Sources: (Chapman & Ward, 2003; Gonen, 2012; International Standard Organization, 2018; Michelez et al., 2011)

Note. The modification of probability and/or impact, when combined, is often referred to as risk mitigation.

Through rigorous literature search and expert recommendations, risk treatment options are provided for all risks identified irrespective of whether or not the identified risk was considered for quantitative assessment.

4.5.1 Financial Risks

The first category comprises risks categorized under financial risks likely to result in exceeding costs or project delays, including, inaccurate cost estimation, changes in the cost of materials, economic instability and inflation, fluctuating exchange rates, and budgetary constraints. Table 4.9 outlines the risk treatment options for dealing with financial risks.

Table 4.9. *Financial Risks Treatment Options*

Risk Element	**Risk Treatment Option**
Budgetary constraints **(F1)**	Effective project management, thorough planning, conducting thorough investigations, and meticulous contract management (Gatzert & Kosub, 2016).
Inaccurate cost estimation **(F2)**	Utilizing effective cost analysis tools/methods capable of factoring in all uncertainties identified in project cost estimation (Khodakarami & Abdi, 2014)
Changes in cost of materials **(F3)**	Pay attention to key areas where costs may increase, direct costs. Establish long-term contracts or agreements with suppliers that include price escalation clauses, allowing adjustments to cover inflation over time (Michelez et al., 2011). Diversifying the supplier base can reduce reliance on a single source and mitigate the risk of price increases (Gatzert & Kosub, 2016)
Economic instability and inflation **(F4)**	See risk **(F3)**
Fluctuating currency exchange rates **(F5)**	Execute financial hedging tactics using financial instruments, maintaining substantial cash reserves, or taking loans denominated in the local currency of the execution location (Michelez et al., 2011).

4.5.2 Technical/Technological Risks

In treating technical risks in energy projects, various methods have been identified by various authors. They include guarantees, product guarantee insurance, implementing preventive maintenance, and keeping replacement parts readily available (Gatzert & Kosub, 2016). Additionally, measures involving risk- sharing with contractors can be implemented to create contracts and agreements that allow the sharing of risks between contractual partners to increase their commitment to quality delivery (Michelez et al., 2011). This measure guarantees the active engagement of contractors, motivating them to take all necessary steps to meet the required quality standards. Risks and treatment strategies are summarized in Table 4.10.

Table 4.10. *Technical Risks Treatment Options*

Risk Element	**Risk Treatment Option**
Equipment failures / Damaged component **(T1)**	Guarantee: off take contracts and maintenance agreements between the project implementation team and suppliers, to secure equipment and provide maintenance in the event of damage (Michelez et al., 2011). Performance guarantees from equipment and construction teams Product guarantee insurance: insurance that cover potential failures of suppliers of components and equipment to honour their guarantees, insurance that can also cover equipment breakdowns and component failures (Michelez et al., 2011)
Limited availability of spare parts, equipment, materials, and repair services **(T2)**	Mitigate the risk of delays or interruptions by incorporating design measures, implementing preventive maintenance, and keeping replacement parts readily available (Gatzert & Kosub, 2016).
Introduction of design changes **(T3)**	Effective project management, thorough planning, and conducting thorough investigations (Gatzert & Kosub, 2016). Effective anticipation of design changes in the design stage, standard project management practice can establish design change control procedures that set up criteria for allowable changes (Chapman & Ward, 2003).
Inadequate system integration **(T4)**	Hardware sourcing from reputable suppliers. Obtaining testing and operational data insights from suppliers and involving them in the project's ownership structure (Gatzert & Kosub, 2016)

4.5.3 Political Risks

Several methods have been proposed to address political risks. These measures include Proactive engagement with policymakers, participating in policy-making processes, and building strong relationships with key stakeholders. Risk treatment options are provided in Table 4.11.

Table 4.11. *Political Risks Treatment Options*

Risk Element	**Risk Treatment Option**
Changes in government policies and regulations **(P1)**	Proactive engagement with policymakers, participating in policy-making processes, and building strong relationships with key stakeholders. Partnerships/ Joint Ventures: Risk sharing by involving local partners and local government (Michelez et al., 2011).
Political instability and civil unrest **(P2)**	Political risk insurance (PRI)
Corruption and bribery **(P3)**	Familiarization with local laws and international regulations to ensure full compliance of project activities. Collaboration with local authorities to build relationships and foster trust.
Risk of expropriation, war, or terrorism **(P4)**	Political risk insurance (PRI) provided by multilateral investment guarantee agency e.g. World Bank Group covers risks such as expropriation, and loss in the event of war (Gatzert & Kosub, 2016).

4.5.4 Contractual Risks

Managing contractual risks can be achieved through measures such as clear contract terms, effective dispute resolution mechanisms, and diligent contractor/supplier selection. Conducting thorough due diligence to assess the creditworthiness of potential counterparties is an important step. Risks and treatment strategies are summarized in Table 4.12.

Table 4.12. *Contractual Risks Treatment Options*

Risk Element	Risk Treatment Option
Breach of contracts and disputes with contractors or suppliers **(C1)**	Surety bonds can provide financial guarantee in the event of a breach of contract by any contractual party (Apak et al., 2011; Associated General Contractors of America, 2014). Utilize proficient developers and suppliers who possess a robust credit rating and a proven history of successful performance (Gatzert & Kosub, 2016)
Contract and sub-contract interface risk **(C2)**	Establish contingency agreements with alternate suppliers in the event of an unstable contractor (Gatzert & Kosub, 2016). Utilize reputable contractors (Gatzert & Kosub, 2016) See also risk **(C1)**

4.5.5 Environmental Risks

Risks emanating from extreme weather events are critical factors of importance in project implementation. Recognizing these risks as natural occurrences, often beyond human control, acknowledges the difficulty in mitigating them. Consequently, preparing effective responses in the event of their occurrence are critical step in managing these risks. Methods of treating risks originating from extreme weather events as documented in Ando et al. (2022) include dedicated reserve fund, sovereign risk transfer, insurance of public assets, and catastrophe bonds. Table 4.13 provides a list of the risk treatment strategies for environmental risks.

Table 4.13. *Environmental Risks Treatment Options*

Risk Element	Risk Treatment Option
Land use, habitat impact, and ecological damage **(E1)**	Performing proper environmental impact assessments to identify and manage the potential environmental impacts of the project and provide ways to improve project execution (Michelez et al., 2011). Robust environmental monitoring and reporting systems to help ensure compliance and enable timely corrective actions. Engaging with regulatory bodies, conducting regular audits, and building partnerships with environmental agencies and industry associations to meet environmental requirements (European Investment Bank, 2022; Merck, 2022).
Climate change and extreme weather events **(E2)**	Insurance coverage from large globally diversified insurers (Gatzert & Kosub, 2016). Catastrophe bonds have the potential to provide coverage for losses resulting from catastrophic and severe weather events that cause damage to the project (Ando et al., 2022; Apak et al., 2011). Incorporating climate resilience measures in designs to withstand floods, storms, and other potential natural hazards (Mullan, 2018).

4.5.6 Social Risks

Managing social risks can be achieved through public consultation and participation. These consultations help consider various stakeholder perspectives thereby limiting the risk of stakeholder conflicts community opposition. Risk treatment strategies for the identified social risks are presented in Table 4.14.

Table 4.14. *Social Risks Treatment Options*

Risk Element	Risk Treatment Option
Stakeholder conflicts and community resistance **(S1)**	Proactive stakeholder engagement, including consultations with local communities to identify root causes of opposition and address concerns at the early stages of project development (Noothout et al., 2016). Public consultation and participation (Stakeholder engagement) of civil society both locally and internationally to properly communicate various stakeholder perspectives thus, limiting the risk of community opposition (Michelez et al., 2011).
Cultural and social acceptance challenges **(S2)**	Thorough cultural impact assessments, cultural heritage preservation measures, and inclusive community consultations are essential mitigation measures (World Bank, 2018).
Displacement of local communities and land right issues **(S3)**	Monetary or infrastructural compensation to the host community to foster project acceptance and address the needs of the displaced (Michelez et al., 2011).
Health and safety concerns for workers and nearby communities **(S4)**	Performing health and safety impact assessment, Implementing robust health and safety protocols, providing proper training and protective equipment, and enforcing safety standards (Michelez et al., 2011).

4.5.7 Operation/Administrative Risks

Risks arising from project implementation operations and administration are presented in Table 4.15 alongside their respective risk treatment options.

Table 4.15. Operations/ Administrative Risks Treatment Options

Risk Element	Risk Treatment Option
The prospecting risk **(OA1)**	Before construction, assess weather conditions to evaluate the suitability of the location (Gatzert & Kosub, 2016)
Transportation logistics failure **(OA2)**	Insurance coverage can provide financial protection from accidental damages during construction and transportation.
Lack of cooperating partners to share technical expertise **(OA3)**	Establishing knowledge sharing partnerships, and joint projects to fully engage all necessary partners.
Insufficient management know–how **(OA4)**	Training and development, and selecting experienced management team.
Sabotage, theft, or Vandalism **(OA5)**	Insurance against theft, sabotage, and vandalism are risk transfer mechanisms to effectively transfer the identified risk factors (Apak et al., 2011).
Difficulties in securing skilled labour **(OA6)**	International recruitment. Upskilling initiatives and knowledge transfer.
Scope creep **(OA7)**	See risk **(F1)**
Inadequate infrastructure **(OA8)**	Proper assessment of project location to ensure the availability of the necessary infrastructure
Security risks **(OA9)**	Physical security measures, comprehensive security protocols.
Fire outbreak **(OA10)**	Insurance; see risk **(OA2)**
Negligence or human errors **(OA11)**	Effective internal management monitoring and control
Employee misconduct **(OA12)**	Effective internal management control

CONCLUSION

The importance of risk assessment in project implementation cannot be over-emphasized as every project endeavour is subject to one or more uncertainties that could either present an opportunity or a threat.

In this study, we were able to conduct a thorough risk assessment of the DryHy project with a focus on the implementation phase. The primary input data for the assessment was derived from expert elicitation and a corresponding comparison with insights from the literature. A concise methodology was followed which resulted in a comprehensive risk assessment process. All results were carefully provided and assessed. The quantification of risks into a total risk amount provides a means for the project management team to effectively allocate contingency funds for risk events with confidence levels.

Results showed that country-specific risk factors such as the risk of expropriation or war, changes in government policies and regulations, and corruption and bribery, had the greatest potential to drive cost overruns in the implementation of the project. Excluding country-specific risk factors, changes in the cost of materials, equipment failures and damaged components, and inaccurate cost estimation were key influencers. Although, no quantification was done on the most likely increase in project duration due to a lack of proper estimates from experts, all identified risks likely to result in project delays were meticulously compiled (see Appendix G).

The actual quantitative assessment utilized a probabilistic approach as recommended in varying literature sources as a more accurate method of quantifying risk factors as compared to the deterministic expected value approach. The probabilistic risk quantification was conducted using Monte Carlo simulations (MCSs) on Microsoft Excel with the aid of the XLRisk software. Although the MCS is a well-established method known to produce accurate results, the accuracy of MCSs relies on the robustness of the underlying assumptions/exclusions used in the model and the reliability of the information used to estimate the uncertainty of the model sub-elements. In validating the accuracy of the XLRisk software used in this thesis, similar simulations were conducted using a trial version of the @Risk software by Palisade and the results obtained (see Appendix H) showed similarities with the preliminary results obtained from the XLRisk software. It is important to mention that each time a new iteration is conducted using either the @RISK or XLRisk software, there is a possibility of obtaining slightly varied results and visuals. This variability arises from the inherent nature of Monte Carlo simulations, but does not invalidate the authenticity of the initial results obtained (Herman, 2002).

The major challenge encountered during the course of this research was the unavailability of experts directly involved with the DryHy project to respond to the questionnaire survey. It is therefore pertinent to mention that other experts with knowledge in the field of renewable energy projects implementation especially within West Africa were solicited. The accuracy of the results obtained is solely dependent on the input from experts, and as such, a key assumption is made: all expert inputs are assumed to be provided in good faith.

Suggestions for future work are a more inclusive risk assessment process that takes in the perspectives of all stakeholders involved in the project implementation. Considering that the DryHy project is still in its research and development stage, there is therefore an inherent difficulty in accurately specifying all involved stakeholders. Therefore, there is a need to repeat a quantitative risk assessment of the project prior to project implementation when all stakeholder groups are identified as their inputs and insights will further strengthen the results obtained.

Risk management strategies presented were mainly derived from literature sources. They capture methods adopted in managing similar risk events from other authors and apply to the DryHy project as well. The effective implementation of proper risk treatment strategies based on the identified risks is thus guaranteed to limit the impacts of risk events on the project implementation in the event that they occur.

Finally, this study has thoroughly addressed all research questions. We conducted a comprehensive risk identification process and provided risk management options. Furthermore, identified risks were quantified based on their impact on cost overruns and we were also able to show how the results of the risk quantification could be applicable to a different geographical location.

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Appendices

Appendix A. Semi-Systematic Literature Review Protocol

The semi-systematic literature review process utilized the following combination of search terms: Direct Air Capture AND Risk, Risk AND Risk Management AND Sustainable Energy, Quantitative Assessment AND Renewable Energy, Risk AND Risk Treatment. 97 literary works were reviewed. Among these, 52 were journal articles, 2 were textbooks, and the remaining 43 consisted of a combination of organizational reports and other credible literature sources.

Appendix B. Risks Assessment Questionnaire Spreadsheet Sample

RISK ASSESSMENT – FINANCIAL RISKS							
Risk ID	**Risk Name**	**Risk Description**		**IMPACT**			**Comments**
			LIKELIHOOD	Risk Impact	MIN	MAX	
R1	**Budgetary constraints**	Constraints or restrictions on the project's available funds	10	Project delays	5	10	
R2	**Inaccurate cost estimation**	Underestimation of costs	20	Cost overruns	10	20	
R3	**Changes in cost of materials**	Fluctuations in the prices of raw materials, components, or resources that are required for the project	50	Cost overruns	10	40	
R4	**Economic instability and inflation**	Increase in wages, raw materials, and energy expenses due to inflation	5	Cost overruns	5	10	
R5	**Fluctuating currency exchange rates**	If a project involves transactions in different currencies, fluctuations in exchange rates can affect the cost of import tariffs and wages in Cote d'ivoire	0	Cost overruns	Don’t know	Don’t know	

Appendix C. Expert Input Aggregation Sheet Sample

		IMPACT	
RISK	**LIKELIHOOD**	**MIN**	**MAX**
Inaccurate cost estimation (F2)			
E1	20	10	20
E2	30	5	40
E4	30	30	60
E5	40	5	40
E6	20	10	20
E7	20		30
AGGREGATE	**27**	**10**	**35**
Changes in cost of materials (F3)			
E1	50	5	30
E2	50	5	50
E4	50	40	80
E5	40	5	40
E6	50	10	40
E7	50		40
AGGREGATE	**50**	**5**	**40**
Economic instability and inflation (F4)			
E2	40	5	20
E4	40	30	60
E5	20	5	40
E6	5	5	10
E7	30		20
AGGREGATE	**30**	**5**	**30**

Appendix D. Deterministic Risk Register for Cost Overruns

RISK ID	RISK NAME	LIKELIHOOD	IMPACT MIN %	IMPACT MAX %
F2	Inaccurate cost estimation	27%	10	35
F3	Changes in cost of materials	48%	5	40
F4	Economic instability and inflation	30%	5	20
T1	Equipment failures / Damaged component	22%	10	40
T2	Inadequate system integration	22%	10	30
P1	Changes in government policies and regulations	47%	8	40
P2	Political instability and civil unrest	30%	5	20
P3	Corruption and bribery	43%	13	43
P4	Risk of expropriation or war	23%	20	58
OA2	Transportation logistics failure	25%	5	23
OA5	Sabotage, Theft or Vandalism	22%	7	27
OA8	Inadequate Infrastructure	20%	8	30
OA10	Fire outbreak	13%	7	33
OA11	Negligence or Human errors	25%	5	23
E1	Land use, habitat impact and ecological damage	17%	12	27

Appendix E. Probabilistic Risk Register for Cost Overruns

RISK ID	RISK NAME	LIKELIHOOD	IMPACT MIN %	IMPACT MAX %	SIMULATED IMPACT	SIMULATED OCCURRENCE	DOES RISK THE OCCUR? (YES/NO)	RISK AMOUNT
F2	Inaccurate cost estimation	27%	10	35	22.5	0	No	0
F3	Changes in cost of materials	48%	5	40	22.5	0	No	0
F4	Economic instability and inflation	30%	5	20	12.5	0	No	0
T1	Equipment failures / Damaged component	22%	10	40	25	0	No	0
T2	Inadequate system integration	22%	10	30	20	0	No	0
P1	Changes in government policies and regulations	47%	8	40	24	0	No	0
P2	Political instability and civil unrest	30%	5	20	12.5	0	No	0
P3	Corruption and bribery	43%	13	43	28	0	No	0
P4	Risk of expropriation or war	23%	20	58	39	0	No	0
OA2	Transportation logistics failure	25%	5	23	14	0	No	0
OA5	Sabotage, Theft or Vandalism	22%	7	27	17	0	No	0
OA8	Inadequate Infrastructure	20%	8	30	19	0	No	0
OA10	Fire outbreak	13%	7	33	20	0	No	0
OA11	Negligence or Human errors	25%	5	23	14	0	No	0
E1	Land use, habitat impact and ecological damage	17%	12	27	19.5	0	No	0
					TOTAL RISK AMOUNT			0

Appendix F. Risks Resulting in Cost Overruns

Risk Category	**Risk Element**	**Impact**
	Inaccurate cost estimation	Cost Overruns
	Changes in cost of materials	Cost Overruns
	Economic instability and inflation	Cost Overruns
Technical Risks	Equipment failures / Damaged component	Cost Overruns
	Inadequate system integration	Cost Overruns
Political Risks	Changes in government policies and regulations	Cost Overruns
	Political instability and civil unrest	Cost Overruns
	Corruption and bribery	Cost Overruns
	Risk of expropriation or war	Cost Overruns
Operational / Administrative Risks	Transportation logistics failure	Cost Overruns
	Sabotage, Theft or Vandalism	Cost Overruns
	Inadequate Infrastructure	Cost Overruns
	Fire outbreak	Cost Overruns
	Negligence or Human errors	Cost Overruns
Environmental Risk	Land use, habitat impact and ecological damage (E1)	Cost Overruns

Appendix G. Risks Resulting in Project Delays

Risk Category	**Risk Element**	**Impact**
Financial risks	Budgetary constraints	Project delays
Technical Risks	Equipment failures / Damaged component	Project delays
	Limited availability of spare parts and maintenance services	Project delays
	Inadequate system integration	Project delays
Political Risks	Changes in government policies and regulations	Project delays
	Political instability and civil unrest	Project delays
Operational / Administrative Risks	Transportation logistics failure	Project delays
	Lack of cooperating partners to share technical expertise	Project delays
	Sabotage, Theft or Vandalism	Project delays
	Difficulties in securing skilled labour and technical expertise	Project delays
	Inadequate Infrastructure	Project delays
	Fire outbreak	Project delays
	Negligence or Human errors	Project delays
Environmental Risk	Land use, habitat impact and ecological damage	Project delays

Appendix H. @Risk Monte Carlo Simulations Result -Tornado Diagram