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

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MASTER THESIS

Specialty: Economics/Policies/Infrastructures and Green Hydrogen Technology

Topic :

Exploring the risks associated with renewable energy projects that incorporate green hydrogen production in West Africa

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DECLARATION OF AUTHORSHIP

I, Haddijatou Ceesay, hereby declare that this thesis is the result of my original work and has not been submitted, either in whole or in part, for the award of any other degree or academic qualification. Where the work of others has been used, it has been duly acknowledged and referenced in accordance with academic standards.

I further declare that no part of this thesis was previously published prior to its submission. The writing of this document was carried out independently, with the use of AI-based tools limited solely to grammatical improvements. All ideas, analysis, and conclusions presented in this thesis are entirely my own.

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Date: 08-09-2-25

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ABSTRACT

This study investigates the risks associated with renewable energy (RE) projects incorporating green hydrogen storage in West Africa, with the aim of identifying the most critical threats to project viability and proposing strategies for their management. Even though there is a wealth of research on RE and green hydrogen projects, the majority of these studies have just identified and categorized risks without estimating their financial implications. Majority of risk assessments are qualitative, which creates a critical knowledge gap about how these risks convert into real additional expenses that may have an impact on the feasibility of the project. Without such quantification, technoeconomic evaluations might ignore cost variations, which could result in poor investment choices.

The research combines insights from a comprehensive literature review with primary data gathered through the Delphi method, which included expert interviews and surveys. A risk matrix was applied to evaluate and score identified risks, enabling the prioritization of the three most significant categories: policy/regulatory risk, political instability, and social acceptance risk.

To quantify their potential financial impacts, a 10 MW grid-tied solar PV system with integrated green hydrogen production was modelled for a techno-economic analysis. Risk-adjusted capital expenditure (CAPEX), operational expenditure (OPEX), and discount rates were applied across multiple scenarios to estimate their influence on the levelized cost of electricity (LCOE) and the levelized cost of hydrogen (LCOH). The results showed that scenarios that incoporate political risks led to the most severe increamnet in the LCOE and subcequently LCOH, indicating an increase of over 16%. This increase was primarily due to elevated discount rates and CAPEX escalation, consistent with existing literature on energy investments in politically and institutionally fragile contexts.

The study proposes targeted mitigation measures, such as early policy engagement, inclusive stakeholder consultations, and geographic diversification of assets, alongside risk transfer mechanisms including political risk insurance, construction all-risk coverage, and robust power purchase agreement structuring. By integrating expert consensus with scenario-based financial modelling, this research offers a decision-oriented framework for policymakers, investors, and developers to enhance project viability and resilience, supporting West Africa's RE transition and the integration of green hydrogen into its energy mix.

Key words:

Renewable energy; Green hydrogen; risk assessment; economic viability, risk mitigation.

RESUME

Cette étude examine les risques associés aux projets d'énergies renouvelables (ENR) intégrant le stockage d'hydrogène vert en Afrique de l'Ouest. Elle vise à identifier les menaces les plus critiques pour la viabilité des projets et à proposer des stratégies de gestion. Bien que les recherches sur les projets d'EnR et d'hydrogène vert soient abondantes, la plupart se contentent d'identifier et de catégoriser les risques sans estimer leurs implications financières. De ce fait, la plupart des évaluations des risques sont qualitatives, ce qui crée un manque crucial de connaissances sur la manière dont ces risques se traduisent en dépenses supplémentaires réelles susceptibles d'avoir un impact sur la faisabilité du projet. Sans cette quantification, les évaluations technico-économiques risquent d'ignorer les variations de coûts, ce qui pourrait conduire à de mauvais choix d'investissement.

Cette recherche combine les résultats d'une analyse documentaire exhaustive avec des données primaires recueillies selon la méthode Delphi, impliquant des entretiens avec des experts et des enquêtes. Une matrice de risques a été appliquée pour évaluer et noter les risques identifiés, permettant de hiérarchiser les trois catégories les plus importantes : risque politique/réglementaire, risque d'instabilité politique et risque d'acceptation sociale.

Afin de quantifier leurs impacts financiers potentiels, un système solaire photovoltaïque de 10 MW raccordé au réseau avec production intégrée d'hydrogène vert a été modélisé pour une analyse technico-économique. Les dépenses d'investissement ajustées au risque (CAPEX), les dépenses d'exploitation (OPEX) et les taux d'actualisation ont été appliqués à plusieurs scénarios pour estimer leur influence sur le coût moyen actualisé de l'électricité (LCOE) et le coût moyen actualisé de l'hydrogène (LCOH). Les résultats ont montré que les scénarios intégrant les facteurs politiques et les risques ont conduit à la plus forte augmentation du LCOE et, par la suite, du LCOH, dépassant 16%, principalement en raison de taux d'actualisation élevés et de l'escalade des CAPEX, ce qui est cohérent avec la littérature existante sur les investissements énergétiques dans des contextes politiquement et institutionnellement fragiles.

L'étude propose des mesures d'atténuation ciblées, telles qu'un engagement politique précoce, des consultations inclusives des parties prenantes et une diversification géographique des actifs, ainsi que des mécanismes de transfert de risques, notamment une assurance contre les risques politiques, une couverture tous risques de construction et une structuration robuste des contrats d'achat d'électricité. En intégrant le consensus d'experts à une modélisation financière basée sur des scénarios, cette recherche offre un cadre décisionnel aux décideurs politiques, aux investisseurs et aux développeurs pour améliorer la viabilité et la résilience des projets, soutenant ainsi la transition vers les énergies renouvelables en Afrique de l'Ouest et l'intégration de l'hydrogène vert dans son mix énergétique.

Mots clés :

Énergie renouvelable; Hydrogène vert; évaluation des risques; viabilité économique, atténuation des risques.

ACRONYMS AND ABREVIATIONS

RE: Renewable Energy

CAPEX: Capital Expenditure

OPEX: Operational Expenditure

LCOE: Levelized Cost of Electricity

LCOH: Levlized cost of Hydrogen

SDGs: Sustainable Development Goals

IEA: International Energy Agency

IPCC: International Panel on Climate Change

OGPS: Off Grid Power System

ESMAP: Energy Sector Management Assistance Program

IRENA: International Renewable Energy Agency

SPLAT-W: Planning Test model for West Africa

PV: Photovoltaic

CSP: Concentrated Solar Power

ECOWAS: Economic Community of West African States

WAPP: West African Power Pool

NREAPs: National Renewable Energy Action Plans

NEEAPs: National Energy Efficiency Action Plans

AHP: Analytical Hierarchy Process

FWASPAS: Fuzzy Weighted Aggregated Sum Product Assessment

MCDA: Multi-Criteria Decision Analysis

PEM: . The polymer electrolyte membrane

PPAs: Power Purchase Agreements

WBG: World Bank Group

PRI: Political Risk Insurance

MIGA: Multilateral Investment Guarantee Agency

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1. INTRODUCTION

Access to clean and affordable energy as stated by Sustainable Development Goal 7 (SDG7) promotes social, economic, and environmental development which form the three pillars of sustainable development (Nyarko et al., 2023). According to the International Energy Agency (IEA), Energy access is defined as 'a household having reliable and affordable access to both clean cooking facilities and electricity, which is enough to supply a basic bundle of energy services initially, and then an increasing level of electricity over time to reach the regional average (IEA, 2020)'. The topic of energy access gained international attention following the 2015 introduction of the SDGs, with SDG target 7.1 calling for 'universal energy access for all' by 2030. Achieving the global sustainable future agenda is directly impacted by offering 'universal access to electricity for all' (Alfaro & Miller, 2021). The IEA estimates that nearly 3.5 billion people, mostly in rural developing nations, still lack consistent energy services, rather relying on polluting, expensive sources like wood, kerosene, and diesel (Viteri et al., 2023). This energy poverty hinders human development and contributes to emissions and deforestation. In order to alleviate poverty and safeguard ecosystems, it is crucial that marginalized populations migrate to cleaner and more sustainable energy solutions. West African countries, many of which are rich in renewable resources have much to gain from this transition, particularly in terms of a resilient and affordable low-carbon energy system development and universal access to electricity (IRENA, 2021).

Since the publication of the synthesis report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC Panel, 2014) and the Paris Agreement (UNFCCC, 2015) which aims to achieve carbon neutrality by 2050 and limit global warming to well below 2°C (and if possible, 1.5°C), renewable energy (RE) investment has steadily grown to increase the reliance of economies on low-carbon energy sources. For economies to attain Paris-compatible energy systems, it is necessary to replace conventional fossil fuel energy systems with RE technologies.

Currently, start-up RE Projects are of great interest to investors due to the availability of renewable resources in West Africa (World Bank, 2019). However, there are various investment risks and ucertainties throughout the design, construction, and operational phases of RE projects. Identification and assessment of these uncertainties are paramount to overcome them (Kul et al., 2020). A deeper understanding of the dynamics of RE project risks is a fundamental requirement in designing effective and productive energy policies. In response to the pressing need to address energy poverty while simultaneously attempting to meet climate goals, most West African nations have adopted renewable laws and policies to attract investments for the development of RE projects. The region is blessed with enough renewable resources, particularly solar and wind, that could solve its energy problem (Bhandari, 2022). However, it is crucial to integrate appropriate grid energy storage technologies in order to manage the issue of intermittency offered by solar and wind. This intermittency challenges has led to increased interest in energy storage solutions, such as pumped hydro, compressed air energy storage, lithium-ion batteries, and green hydrogen which is emerging as a particularly promising option for West Africa due to its versatlity, ability to store energy over long periods and potential to decoarbonize hard-to-abate sectors (Tashie-Lewis & Nnabuife, 2021). The role of green hydrogen as both an energy storage medium and a clean fuel makes it uniquely positioned to complement RE technologies such as solar and wind, particularly in West Africa where variability in generation and weak grid infrastrusture presents challenges for large-scale RE dployment.

Furthermore, green hydrogen can also be used to produce chemicals like methanol and ammonia (Arsad et al., 2022), as well as for use in hydro-processing and hydrogenation refinement processes (Bhandari, 2022). These wide-ranging applications highlight its significance not only as an energy carrier but also as an industrial feedstock that can contribute to sustainable development. Building on this potential, this study explores the risks associated with RE projects that incorporate green hydrogen production in West Africa.

1.1 Problem Statement

Despite numerous literature on RE and green hydrogen projects, more than thirty papers that have been reviewed have been limited to identifying and categorizing risks without quantifying their economic impacts, particularly through variations in financial indicators such as the LCOE and LCOH. This makes risk assessments largely qualitative, leaving a critical gap in understanding how these risks translate into actual additional costs that can affect project viability. In many cases, the absence of such quantification may result in techno economic assessments that overlook cost deviations, potentially leading to inaccurate investment decisions (Guindon & Wright, 2020).

Although some studies such as Stargardt et al. (2025) incorporate risk into hydrogen costing through adjusted discounted rates, and others such as Klingle et al. (2024), and Rambo (2013) conduct risks assessments to evaluate their impact on project performance, there is still a lack of systematic integration of risk-related cost adjustments into techno-economic models. For example, Hill et al. (2024) applied Monte Carlo model to assess uncertainties on cost and identify RE and electrolyser CAPEX as the main drivers of LCOH across various scenarios. However, while such approaches capture risks, they do not explicitly account for how they translate into higher system costs in particular. Without a quantitative understanding of how risks impact project costs, investment decisions may be made based on inaccurate or unduly optimistic information.

This study addresses this gap by identifying the most significant risks associated with RE projects that incorporate green hydrogen production in West Africa, estimating their economic costs, and incorporating these costs into a techno-economic assessment to evaluate their impact on the LCOH. Addressing this gap thus offers a more solid basis for decision-making and emphasizes the study's distinctive contribution of directly connecting risk factors to economic outcomes for RE projects.

The study aims to answer the following research questions:

1. What are the key risks associated with implementing RE projects that integrate green hydrogen production in West Africa?
2. How do these risks influence the techno-economic feasibility of such projects, particularly the LCOH?
3. What strategies can be developed to mitigate these risks and enhance the successful implementation of these projects in the region?

1.2 Research objectives.

The main objective of this study is to evaluate the economic impact of key risks associated with RE projects integrating green hydrogen production in West Africa by quantifying their cost implications and assessing their effect on the LCOH.

To fulfil the above objective, the following specific objectives are proposed:

1. To identify and categorize the most significant risks associated RE projects that incorporate green hydrogen production in West Africa.
2. To estimate the costs arising from these risks.

3. To integrate the estimated risk-related costs into a techno-economic model to determine their economic impact.
4. To propose mitigation strategies that help improve the financial viability of such projects.

The paper is organized into four chapters. Chapter 1 introduces the research background, scope and research objectives. Chapter 2 presents the literature review, covering the West African energy context, RE development, green hydrogen production and the RE project risks. Chapter 3 outlines the methodology, including the Delphi survey, risk matrix evaluation, and techno-economic modelling of a solar PV system with integrated hydrogen production. Chapter 4 presents the results and discusses the economic implications of the identified risk factors and highlights some mitigation and risk transfer strategies. Finally, the thesis ends with a conclusion section which summarizes the key findings, highlights the limitations and provides recommendations for future research.

2. LITERATURE REVIEW

In recent years, RE sources have gained significant attention as global energy demand continues to rise. In many African countries, governments are increasingly prioritizing RE to sustainably meet the continent's growing energy demand. As a developing region, West Africa requires substantial investments in the RE sector to address energy access challenges. Solar and wind energy have become popular options among the various renewable sources due to their widespread availability. While RE projects offer promising opportunities for investments, the risk factors stemming from the macro environment as well as project level-risks must be identified. This chapter examines the current state of West Africa's energy lanscape and the region's progress towards RE development. It goes further to outline a systematic review on existing work that has been done in the assessment of risk factors that might hinder the advancement of these projects. Due to limited existing work done exclusively for West Africa, the literature review focuses not only on the region, but also incorporates findings from broader studies on Africa and other developing regions with comparable economic and insfrastructural conditions.

2.1 West Africa's energy context

West Africa is made up of fifteen (15) nations under the Economic Community of West African States (ECOWAS). With over 430 million people (United Nations, 2015), the region is geographically varied, ranging from the more humid coastal regions in the south to the arid and semi-arid Sahelian strip in the north. This geographic diversity is complemented by wide disparities in economic development, infrastructure, and energy access. However, this is accompanied by a shared challenge of meeting rising electricity demand in a sustainable manner.

West Africa's energy industry is essential to the region's economic development and modernization. However, the increasing significance of climate change issues and the need to find ways to reduce greenhouse gas emissions while achieving continuous economic growth have taken center stage in the conversation about energy growth in the region (Maji et al., 2019).

Despite being endowed with abundant renewable and non-renewable resources (Ishaku et al., 2022), (Gueye, 2025), West Africa still suffers from energy poverty, with only about 43% of the population having access to electricity. Furthermore, the region faces some of the highest electricity prices in the world, more than double the rates in East Africa (Ishaku et al., 2022). In addition to high electricity prices, frequent power outages average to about 44 hours per month, which makes electricity highly unreliable. Figure 1 illustrates the electricity access rates of individual West African countries (with the exception of Cape Verde).

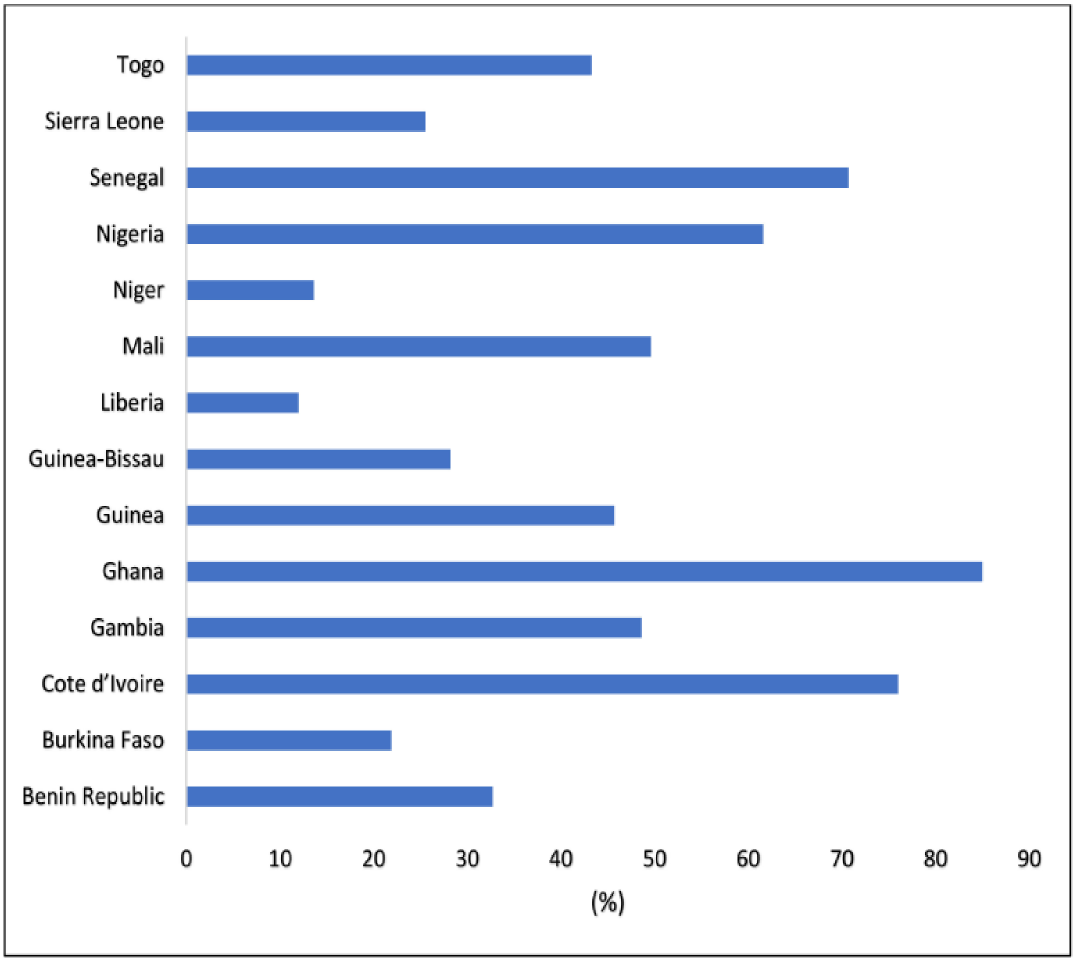

Figure 1: Electricity access rate in West Africa by country

***Source**:* (Ishaku et al., 2022)

It can be seen that only Senegal, Nigeria, Ghana, and Cote d'Ivoire have more than 50% access to electricity, with Ghana having the highest percentage at 85%. Liberia on the other hand has the lowest access rate of 12% at the time, while the other ten nations have less than 50% (Ishaku et al., 2022). However, the picture changes when one considers the rural electrification rates separately from the urban electrification as highlighted in Figure 2. The rural electrification rate is below 50% for all the nations except Ghana (70%) and Cape Verde (95.6) (Nyarko et al., 2023).

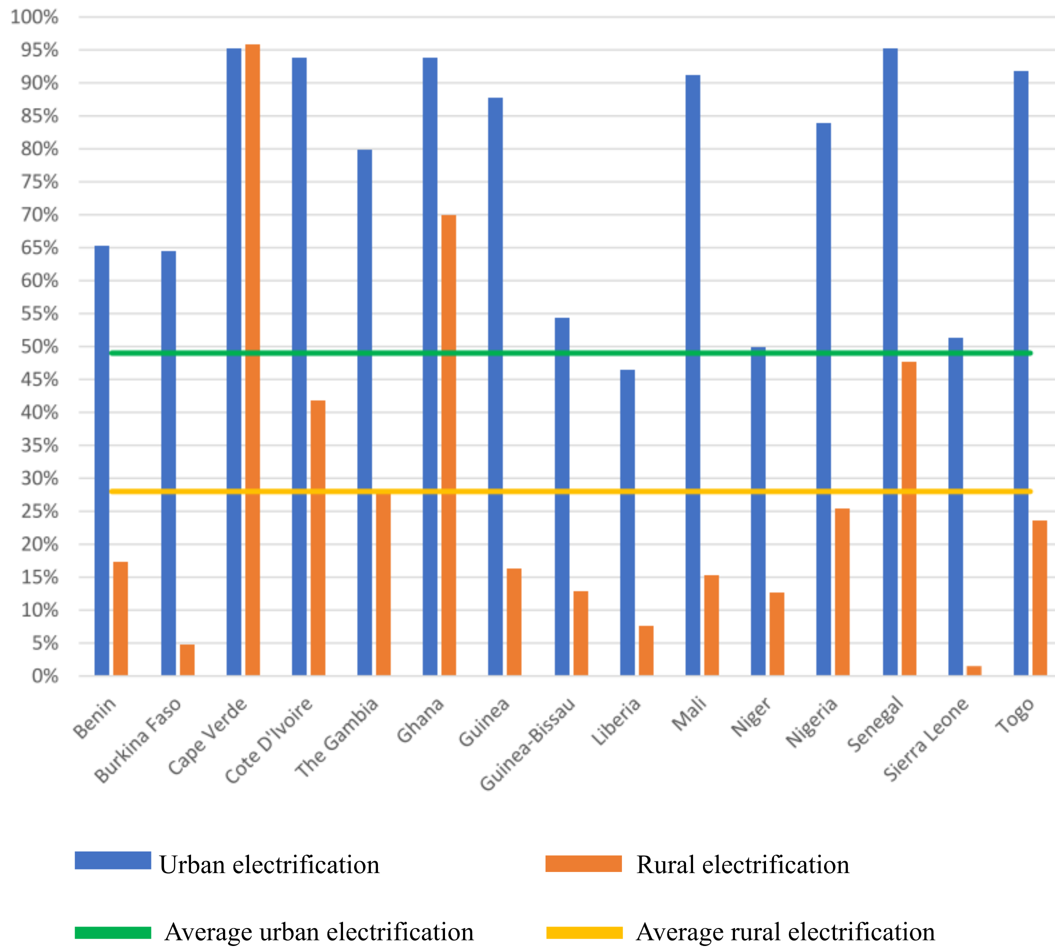

Figure 2: Urban and Rural electrification rates if west Africa

Source: (Nyarko et al., 2023)

In response to the challenges mentioned earlier, West Africa has embraced decentralized systems such as Off-Grid Power system (OGPS) as a solution for rural electrification (Nyarko et al., 2023). A 2019 world bank study on the Energy Sector Management Assistance Program (ESMAP) reported that while atleast 4000 mini-grids have been deployed across Africa between 2014 and 2018, only 385 of these were deployed in West Africa. These mini-grids, which were installed, are either solar photovoltaic-hybrid systems, diesel-fueled systems, or hydro-powered systems (World Bank, 2019), meaning they were still not all renewable-powered yet.

Nevertheless, the International Renewable Energy Agency (IRENA) projected that up to 65% of West Africa's peak demand could be met by renewable sources through the implementation of improved System Planning Test model for West Africa (SPLAT-W) (IRENA, 2017). The region benefits from abundant solar radiation, typically receiving an average of 6–8 kWh/m^2/day of solar radiation, which is excellent for both photovoltaic and Concentrated Solar Power (CSP) applications (globalsolaratlas.com, 2025). Nigeria, Burkina Faso, Niger, and Mali receive the higher values due to their location along the Sahel Savannah. The Sahel Savannah region also has the greatest potential for wind energy, the second-highest RE resource in WestAfrica. Hydro power on the other hand has the least potential in the region. However, small hydro dams can still supply rural communities with enough electricity to meet their basic needs (Nyarko et al., 2023).

Nyarko et al. (2023a), in their study titled 'Drivers and challenges of off-grid RE based projects in West Africa' also revealed that most West African governments provide incentives for producing renewable power but yet these resources remain largely undertapped. According to (Gueye, 2025), barely 20% of installed capacity in the region comes from RE sources like hydropower, found primarily in countries like Nigeria, Cote d'Ivoire, Guinea-Bissau, Senegal, Ghana and Togo. While countries like Senegal and the Gambia have recently began to explore their solar and wind potentials, the abundant solar potential in places like Burkina Faso, Niger, and Mali remains largely under explored (IEA, 2019). If utilized well, the vast RE potential can position the region as a key contributor to global efforts in reducing GHG emissions. The Africa Energy Outlook 2019 report (IEA, 2019) highlights that while Africa as a whole is rich in RE, West Africa in particular is uniquely positioned to adopt a low-carbon development pathway due to abundant solar and wind resurces. Harnessing these resources effectively presents a valuable opportunity for sustainable economic growth, energy security, and regional integration in West Africa.

At the policy level, significant progress has been made. The first evaluation of the potential for RE in the ECOWAS nations was conducted in 2013 by IRENA (ECREEE, 2013). The assessment presented two significant regional policy developments namely: The official adoption of the 2011/12 West African Power Pool (WAPP) Master Plan and the ECOWAS Renewable Energy Policy (EREP). The EREP adopted in 2012, aims to increase the region's share of renewable electricity to 48% by 2030. The National Renewable Energy Action Plans (NREAPs) was also adapted and this aims to develop country level NREAPs that align with EREP goals. These were followed by the National Energy Efficiency Action Plans (NEEAPs) which came to complement NREAPs by targeting reduction in energy intensity and improving energy use across sectors. All policies sought to raise the proportion of RE in the region's overall electricity generation mix to 23% in 2020 and 31% in 2030 (ECREEE, 2013).

The utilization of RE is undoubtedly the most effective path to a future with reduced carbon emissions. However, grid management becomes challenging as intermittent RE source continue to grow in capacities (Bhandari, 2022). Integrating high shares of intermittent renewables present challenges for grid management and stability. As these technologies grow in capacity, so must the ability of national grids to handle these imbalances. In order to effectively handle the problem, efforts are being made to incorporate suitable grid energy storage technologies. It is notable to also discuss how modern energy technology may be able to solve the problem of the mismatch between the demand and the energy supply from renewable sources (Sun et al., 2023). The solution to these issues is the incorporation of modern energy storage technologies. Among the promising solutions is green hydrogen production, an emerging energy technology that offers long-term storage potential and supports decarbonization sources (Sun et al., 2023).

On the other hand, green hydrogen's potential as a sustainable energy vector is becoming more widely recognised. Although different studies use terms such as green hydrogen, renewable hydrogen, sustainable hydrogen and clean hydrogen interchangably, in this study green hydrogen specifically refers to hydrogen produced through water electrolysis powered entirely by RE sources (Bhandari, 2022). Hydrogen produced using renewable electricity can be converted to heat and even back to electricity, making it an integral component of the energy transition process. It can also be distributed locally and internationally, and can be stored for seasonal or daily needs (Maestre et al., 2021). Hydrogen can be integrated into RE sources in a variety of ways, including power-to-power, power-to-gas, power-to-fuel, and power-to-feedstock (Maestre et al., 2021). These applications are particularly essential in the decarbonisation of hard-to-abate sectors such as transportation and industrial heating.

The applications of green hydrogen are extensive, ranging from fuel cell vehicles to energy storage systems that balance supply and demand in power grids (Sun et al., 2023). Its integration into existing energy infrastructure can lead to the development of hybrid systems that optimize resource utilization and enhance system resilience. Additionally, hydrogen's ability to store excess energy addresses intermittency issues associated with solar and wind power, positioning it as a key component in the transition to a sustainable energy future (Roucham et al., 2025) However, the sector faces significant challenges, particularly in hydrogen storage, economic feasibility, and the need for supportive policy frameworks. Addressing these barriers is crucial for advancing the development and commercialization of green hydrogen technologies (Roucham et al., 2025).

2.2 Renewable Energy Project Risks

2.2.1 Risk Identification and Categorization

Numerous studies have documented the risks that hinder RE development. A study conducted by (Ouedraogo, 2019) on 'Opportunities, Barriers and Issues with RE Development in Africa' examined the conditions affecting its deployment in Africa. The review highlighted key barriers such as weak institutional frameworks, high upfront cost, limited technical capacity, poor infrastructure and inadequate maintenance & information systems. Ouedraogo's findings emphasized the need for both improved existing strategies and new approaches to effectively scale RE and close the financing gap across the continent (Ouedraogo, 2019). Ouedraogo's research, however, is primarily descriptive and provides little insights on how these risks may be systematically grouped or converted into quantifiable financial variables on projects.

A more systemic approache is provided by Kul et al. (2020) through a structured decision-making model (Delphi, AHP, and FWASPAS) for the assessment and prioritization of investment risks. Their work identified six risk factors, namely: Economic and Business risks, Market risks, Social risks, Political and Policy risks, Technical risks, and Environmental risks. They went further to categorize each risk by several sub-risk factors. The paper assessed the RE investment risk factors for sustainable development in Turkey using the AHP to assess the identified risks, followed by the evaluation and prioritization of strategies to overcome risk factors of RE development projects by using FWASPAS. The Delphi method unveiled 6 major risk factors with 23 sub-risk factors. Results of AHP analysis revealed economic & business risk as a major risk factor, followed by Market risks and third on the rank was Political and policy risks. Although this framework is rigorous, its reliance on expert judgement without empirical validation limits its capacity to quantify the real techno-economic impacts of these risks on project outcomes and project cost parameters such as the LCOE.

In a related study, Ioannou et al. (2017) provided a thorough analysis of risk-based approaches to sustainable energy planning. Although their risk categories were quite similar to those described by Kul et al. (2020), they made a significant advance by mapping risks across several project stages, which were the planning, construction and the operation stages of the project. This temporal framework demonstrates how risks' characteristics and intensity evolve over the project lifecycle. Their study went further by providing a state-of-the-art literature review of the quantitative and semi-quantitative methods that have been used to model risks and uncertainties in sustainable energy system planning and feasibility studies. They found that in quantitative methods, risks are mainly measured by means of the variance or probability density distributions of technical and economical parameters; while semi quantitative methods such as scenario analysis and multi-criteria decision analysis (MCDA) allow the inclusion of softer, non-statical variables like public acceptance. Compared to Kul’s (Kul et al., 2020) framework, this approach is more dynamic and holistic but might also prove challenging in data-scarce regions like West Africa.

Other researchers have highlighted additional risk dimensions. A study by Nuriyev et al. (2019) stated that corruption and foreign exchange volatility are also important risk factors, arguing that large-scale RE projects can be inherently complex and uncertain, and therefore require well-grounded combination of different strategies and resources. They proposed life cycle-based framework that integrates scenario analysis, life cycle assessment, life cycle costing, social sustainability assessment and MCDA. A study published in the International Journal of Business and Finance Management Research by Charles M. Rambo (Rambo, 2013) explores the financing risks associated with RE projects in developing countries by examining secondary data. The paper identified common investment risks such as political instability, weak carbon policies, currency fluctuations, monopolized control over energy production and distribution, and limited community engagement as the major risks faced by such projects. Rambo concluded with recommendations aimed at nations to foster a more secure and attractive investment environment for RE development by putting in place strong policies and mitigation strategies.

Another study (Akçay, 2018), investigated the risk factors and impacts related to solar power investments by using a three-step approach: first by performing an extensive literature review, secondly identifying the techno-economic parameters for solar power investments, and finally identifying the impacts and probability of occurrence of the risk factors. His methodology used a survey questionnaire to gather expert opinions and insights from three different investment companies. 18 risk factors were identified grouped into two main categories as Technical and External Risk factors. After a thorough examination of existing feasibility reports on solar investment, the cash flow parameters were identified to be income, cost of expropriation, operation cost, interest rate, construction cost, operation period and construction period. The resulting information from the survey outlined the probability of occurrence and the impact of each risk factor on each cash flow parameter.

In a different perspective, Egli (2020) focused on RE Sources Development Risk Analysis and Evaluation, taking into consideration renewables risk-related statistical data limitation. Experts' opinion survey approach was chosen as an information collection tool. A group of experts was composed of twelve specialists in the fields of economics, business administration and energy systems. They identified the five most relevant RE investment risk types as curtailment, policy, price, resource and technology, and showed their relative importance over time using a network analysis of interview transcripts to identify the drivers behind the observed changes.

2.2.2 Risk Assessment Methods

Identification of risks must be complemented by appropriate methods for their assessment. Kul et al. (2020) used the Delphi technique, which refines risk identification by iterative expert agreement, particularly useful in situations with little empirical data. Although Delphi minimizes individual bias by combining the opinions of other experts, it still depends on the choice and representativeness of experts, which may restrict its applicability.

The AHP, often used alongside Delphi, enables the ranking of risks by relative importance. However, AHP necessitates unambiguous pairwise comparisons, which may generate discrepancies when working with subjective assessments or huge lists of criteria.

Similarly, MCDA methods, as described by Ioannou et al. (2017) and Nuriyev et al. (2019), provide a structured means of weighing multiple, often conflicting criteria such as economic performance, environmental sustainability, and social acceptance. MCDA's strength lies in its flexibility, allowing both quantitative and qualitative dimensions to be incorporated. Its results, however, are extremely dependent on the weighting scheme used, which could be controversial in real-world scenarios.

Beyond decision analysis methods, other scholars have turned to expert interviews and network analysis. Egli (2020), for instance, convened twelve experts in economics, business, and energy systems to identify the most relevant risks in RE development and used network analysis to trace the drivers behind these risks and their changing relevance over time. This longitudinal perspective reveals how risks evolve in response to technological maturity and policy developments, but the small expert sample raises concerns about external validity.

The three-step approach adopted by Akçay (2018) combined literature review, expert surveys, and feasibility report analysis to identify risk factors for solar power investments, categorized into technical and external risks. Notably, Akçay went beyond identification by linking risks directly to cash flow parameters such as income, interest rates, construction costs, and operating periods. This step bridges the gap between qualitative assessments and project economics, but his method failed to evaluate the monetary value of the risk impacts.

Literature generally demonstrates a wide range of methodological approaches, each with distinct strengths and limitations. In the context of West Africa, where empirical project data is scarce and institutional contexts are fluid, expert-driven approaches like Delphi are particularly suitable. This study builds on that strength, employing Delphi for risk identification and a risk matrix for their prioritization. It also extends the analysis through quantitative integration of risks using scenario-based evaluations by incorporating risk adjustments into a techno-economic model to assess their impact on the LCOH.

2.2.3 Risk Quantification Attempts

Despite the rich literature on identification and categorization, relatively few studies have attempted to quantify the economic impact of risks on RE projects. Akçay (2018) is one of the few exceptions, explicitly linking identified risks to project cash flow parameters. By assessing the probability and impact of risk factors on revenues, operating costs, interest rates, and construction periods, his study provided a pathway to evaluating how risks shape financial outcomes. However, the study was limited to the solar sector in Turkey.

More recently, Kigle et al. (2024) examined the effect of country-specific risks on the levelized cost of hydrogen (LCOH). Their study revealed that while countries with abundant renewable resources have the technical potential to produce cheaper hydrogen, high financing costs due to higher interest rates can offset this advantage. In other words, risk premiums embedded in financial markets directly translate into higher LCOH, undermining competitiveness. This work illustrates the direct techno-economic implications of risks, but its focus remains at the macro (country) level rather than project-level feasibility.

These quantification attempts highlight the potential of integrating risk into economic modeling but also reveal significant gaps. Most approaches either remain qualitative or stop short of fully embedding risks into techno-economic parameters such as LCOE or LCOH. Without risk quantification, project feasibility studies risk underestimating cost escalations, mischaracterizing economic viability and weakening investment decisions.

2.2.4 Green Hydrogen-Specific Considerations

Currently, no major green hydrogen projects have been identified in West Africa, and literature on the risks of green hydrogen production projects risks in the region remain scarce. However, global studies have identified critical risks in hydrogen project deployment. For instance, Kigle et al. (2024) conducted study titled ‘The impact of country-specific investment risks on the levelized costs of green hydrogen production”. It was realized that countries with higher RE resources to produce green hydrogen had higher interest rates. This higher interest rates can lead to significant increase in the LCOH, diminishing the relative competitiveness of countries with abundant RE resources compared to countries with fewer resources but fewer investment risks (Kigle et al., 2024). The country-specific risks depicted political risks mentioned for other RE projects like solar and wind. Furthermore, technology risks, business risks, regulatory risks, and market & supply chain risks were also found to be fundamental in the implementation of green hydrogen projects (McGregor et al., 2025).

In the West African context, several hydrogen-specific risks warrant emphasis. First, water dependency is a critical concern. Electrolysis requires significant volumes of purified water, but many regions in West Africa face water scarcity, raising both environmental and social risks. Second, storage and safety risks are heightened given hydrogen’s low volumetric density and high flammability, necessitating advanced and costly infrastructure. Third, the absence of policy frameworks is a major barrier. While some countries in North and South Africa have launched national hydrogen strategies, West African nations still lack dedicated regulations. This creates uncertainty for investors. Finally, market immaturity raises the risk of stranded assets, as domestic demand for hydrogen is limited.

From the literature, it could be seen that RE projects, including green hydrogen production, have numerous similar or related project risks which necessitate strategic mitigation measures from all relevant stakeholders. Ioannou et al. (2017) pointed out that the medium and long-term success of RE projects depend on the identification, mitigation, and management of their risk factors. Wing (2015) outline several strategies that governments can adopt to minimize the impact of risks in RE projects and improve their economic viability. These include capital subsidies, grants or rebates which could directly reduce LCOE, investment tax credits which help lower upfront capital requirements, and preferential loan schemes which improve access to project financing and reduce the cost of capital.

3. METHODOLOGY

This study adopts a mixed methods approach as illustrated in Figure 3 , integrating both qualitative and quantitative methods to identify, evaluate and analyze risks associated with RE projects that incorporate green hydrogen production in West Africa. The methodology is defined by a combination of literature, expert surveys and interviews as well as techno economic analysis.

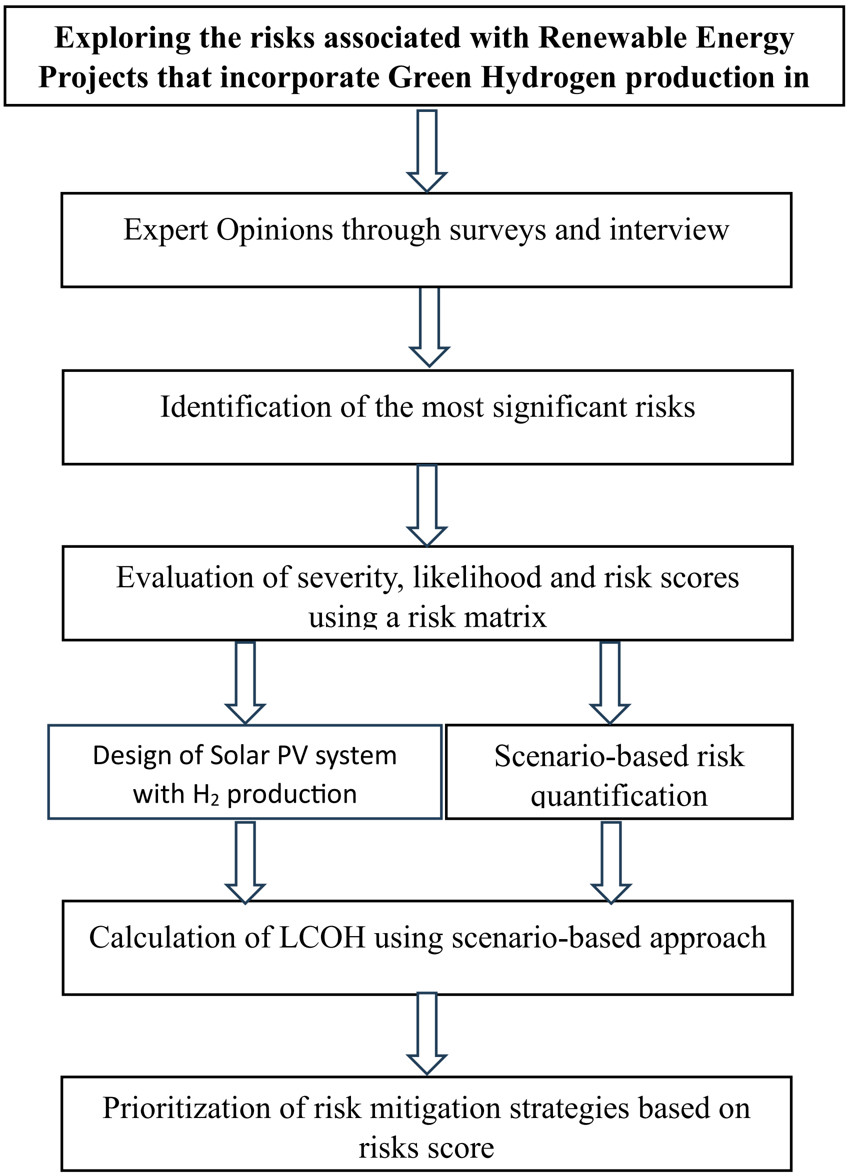

Figure 3: Flow chart of proposed Methodology

***Source**: Author*

3.1 Risk categorization

Firstly, an extensive literature review was conducted to understand the current state of knowledge on risks associated with RE projects, particularly those incorporating green hydrogen production. There was however limited research focusing on West Africa and for this reason, the literature review focused on Africa and other developing regions with similar economic and insfrastructural conditions. After the identification of numerous risk categories from the literature, these risk categories were then rigorously examined based on their frequent appearance in literature, to determine the risk factors that were most significant in the West African context. Eight risk categories that were deemed highly significant and selected for further analysis were Financial(Kul et al., 2020), Technical (Komendantova et al., 2012), Social (Kul et al., 2020), Political (Gatzert & Kosub, 2016), Supply Chain & Logistics (Klingle et al., 2024) (McGregor et al., 2025), Policy & Regulatory(Gatzert & Kosub, 2016) (Egli, 2020), Environmental(Klingle et al., 2024), Safety, and Market risks (McGregor et al., 2025) (NenPower, 2025). Table 1, adopted from Kul et al. (2020) presents a list of the main risk factors and the sub-risk factors that are related to them, along with a brief description of how they could affect the development, implementation, and sustainability of a project.

Table 1: Risk Categorization

Risk Factor	**Sub-risk factor**	**Description**
Financial Risk	Access to Finance	Perceived project risks make it difficult to have access to investments or other project financing facilities such as loans. Lack of sufficient financing capital scarcity.(Mazzucato & Semieniuk, 2018)
	Capital cost overruns	Actual project costs exceed estimates due to inflation, logistics, etc.

	Exchange Rate fluctuations	Effects of local currency devaluation on internationally funded projects
Technical Risk	Technology Maturity	The readiness level of certain technologies is still low, particularly that of hydrogen production.
	Equipment reliability	Risk of underperformance or failure of system components
	Local Capacity Shortage	Lack of skilled local contractors and technicians
	Grid access	Integrating hydrogen systems with other RE sources or the national grid might be challenging. (Kul et al., 2020)
Political Risk	Political instability	Coups, conflicts, or policy shifts may have negative impact on project success or continuity
	Corruption and bad governance	Fund mismanagement or non-transparent processes may pose high project risks.(Komendantova et al., 2012)
Environmental Risk	Water resource scarcity	Limited water resource availability for electrolysis and even for panel cleaning in solar energy projects
	Extreme weather conditions	Sever weather events such as storms, floods, draughts, heatwaves, etc. that can damage

		infrastructure or disruption energy generation (Klingle et al., 2024)
Social Risk	Community acceptance	Resistance from local communities due to social and cultural concerns or lack of awareness. (Gatzert & Kosub, 2016)
	Land acquisition	Having access to land and getting the required permits from local communities might also pose project risks. (Kul et al., 2020)
Policy and Regulatory Risk	Policy uncertainty	Lack of clearly defined policies on RE and Hydrogen production
	Licensing delays	Delays in obtaining necessary permits and approval due to bureaucracy
	Tariff and taxation issues	Unfavorable tax regimes, feed-in tariffs, or lack of incentives for green hydrogen production
Supply Chain & Logistics	Material/equipment import delays	West Africa lacks the required materials and equipment and therefore heavily rely on importation of key components like solar panels and electrolyzer for implementing RE projects. Delays due to customs or other logistics may always happen
	Poor transportation infrastructure	Poor Road networks or port infrastructure may limit access to production sites. This poses a risk for both material delivery at the project site

		as well as product distribution from project sites.(AfDB, 2022)
	Supplier dependency	Over reliance on limited international suppliers increases vulnerability to disruptions
Market Risk	Market access barriers	Challenges in entering or growing within the energy market that may arise from market monopolization, or poor market structures.(Kul et al., 2020)
	Demand uncertainty	Risks may arise from uncertainty regarding future renewable energy projects due to inadequate feasibility studies or resource assessment. Such case may result in lower-than-expected revenues.(Gatzert & Kosub, 2016)
	Price volatility	Fluctuation in energy prices or feedstock can pose significant economic risks

***Source**: Author*

3.2 Risk Prioritization

The second step in the methodology was to conduct a round of surveys and a series of expert interviews to gather insights and opinions from experts in the RE sector using Delphi (survey link provided in appendix B). The Delphi Method is a survey technique used to gain a consensus of a panel of experts in the field through several rounds of questioning (Sablatzky, 2022). During a

Delphi study, selected experts respond to several rounds of questionnaires, and the responses are aggregated and shared with the group after each round. A Delphi study relies on the idea that collective group responses are superior to individual responses. For this study, twenty-eight (28) respondents (see appendix B), including twenty-two (22) engineers, two (2) energy analysts, three (3) economists and one (1)energy planner, with at least five years of experience in their various fields of expertise participated in the survey. The questionnaires investigated the types of RE projects, storage techniques used, experts' perspective about the incorporation of green hydrogen production in West Africa and most importantly, the risks involved in such projects. Furthermore, the respondents were able to rate these risks in terms of severity and probability of occurrence based on their knowledge and experience from existing projects. Another round of expert consultation was conducted, this time in the form of semi-structured interviews to give the experts a chance to elaborate on their decisions. Lastly, the survey and interviews also allowed experts to give suggestions on mitigation strategies that could be adapted to enhance project success in the region. Table 2 is an extraction from the survey questionnaires that shows the perception of experts on how significant each risk is and how likely they are to occur.

Table 2: Questionnaire format

Risk Type	Evaluate risk occurrence probability and risk impact (severity)									
	Likelihood of occurrence					Severity of risk				
	5	4	3	2	1	5	4	3	2	1
Financial risks										
Technical risks										
Social risks										
Environmental risks										
Regulatory and Policy risks										
Political risks										
Supply chain & Logistics risks										
Market risks										

***Source**: Author*

After collecting and analyzing expert responses, the risks were evaluated using a risk matrix. Each risk was assigned a probability score which indicates the likelihood of occurrence on a scale of 1-

5 where 5 is almost certain and 1 is rare. Likewise, a severity score was also assigned to each risk on a scale of 1-5 where 5 is catastrophic and 1 is negligible. This scale was selected for its simplicity, ease of interpretation, and widespread use in risk assessment studies. The 5-point scale allows experts to clearly differentiate between slight variations in risk severity while avoiding excessive complexity that may reduce consistency. The risk scores were given by the product of severity and likelihood. (**Risk Score = Likelihood x Severity**) (Lu et al., 2015)

The risk scores were evaluated using the averages of the probability and severity scores from the Delphi. Based on the calculated risk scores, the three most significant risks were further analyzed through a scenario-based techno-economic assessment. The potential impact of each risk on important financial parameters including CAPEX, OPEX and discount rates were considered by incorporating each into different scenarios.

3.3 Techno-economic analysis with risk adjustments

The next stage of the methodology was to perform a techno-economic analysis using Microsoft Excel. The techno-economic assessment used cost structure approaches to evaluate some key economic indicators. This study focused on the LCOE and LCOH given by Equations 1 and 2 respectively, with risk adjustment for a solar PV plant that incorporates green hydrogen productions. This was done by first modeling a 10MWp solar PV plant coupled with a 5MW PEM electrolyzer system for green hydrogen production as shown in Figure 4. All calculations were carried out using Microsoft excel. (an extract is shown in appendix A).

The PEM electrolyzer was chosen because of its fast response and quick start-up times (Lai & McCulloch, 2017). The PEM is also known for operational flexibility and therefore most appropriate to be considered in configurations with the integration of intermittent RE sources like solar PV (Bhandari & Shah, 2021). In comparison to traditional alkaline units, PEM electrolyzer can be reversible devices and can operate at higher current densities, lower cell voltages, and higher temperatures and pressures, leading to higher efficiency (Carmo et al., 2013). However, compared to alkaline technology, PEM technology is still less developed, more expensive, and has a shorter lifespan (Bhandari & Shah, 2021).

$$LCOE = \frac{I_0 + \sum_{t=1}^{N} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{E_t}{(1+r)^t}} \qquad \text{Equation 1}$$

Source: (Lai & McCulloch, 2017)

LCOE- Levelized Cost of Electricity in €/kWh

I_0- Total initial investment in €

A_t- total annual cost in year t in €

t- year of operation (1,2,3…)

N- project lifetime in years (20 years)

E_t- Total Electricity Generated in year t in kWh

r- discount rate (10%)

$$LCOH = \frac{I_0 + \sum_{t=1}^{N} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{H2_t}{(1+r)^t}} \qquad \text{Equation 2}$$

Source: (Kigle et al., 2024)

LCOH- Levelized cost of Hydrogen in €/kgH_2

I_0- Total initial investment in €

A_t- total annual cost in year t in €

t- year of operation (1,2,3…)

N- project lifetime in years (20 years)

H_{2t}- Total Hydrogen Generated in year t in kgH_2

r- discount rate (10%)

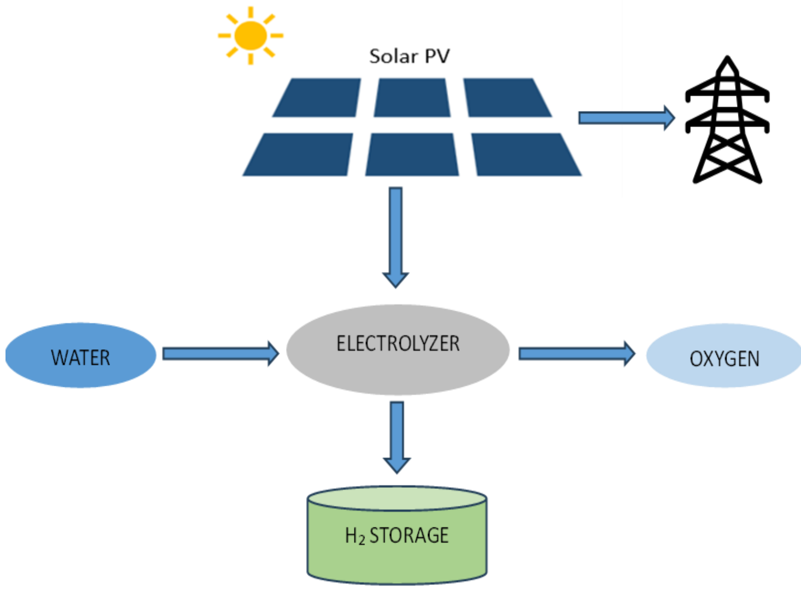

Figure 4: PV system with integrated hydrogen production

Source*: Author*

The chosen location is the Northern Region of Ghana, precisely Tamale. This choice was based on a combination of technical, environmental, and political factors that make the region highly suitable for RE deployment. As soon in Figure 4, Northern Ghana benefits from some of the highest solar irradiation levels in the country, with Global Horizontal Irradiance (GHI) values of 5.5-6.0 kWh/m^2/day (Global solar Atlas) and an average of 7.4 sun hours (Worlddata, 2025), making it an ideal location for solar energy generation. Comparable solar resources are found across the region including Burkina Fasso, Mali, Niger and Northern Nigeria, where solar irradiation often exceeds 5.5 kWh/m^2/day. This suggests that system designs optimized for Tamale could be readily adapted to other parts of West Africa.

Tamale enjoys relatively flat land (Tahiru et al., 2024) and the low population density (only about 319 persons per square kilometer) (Tahiru et al., 2024) makes large scale solar PV installations even more feasible. These characteristics are likewise present in countries like Gambia, Senegal, Mali and other regions, where rural settlements characterized by low population density present favorable conditions such as land availability for large scale RE projects.

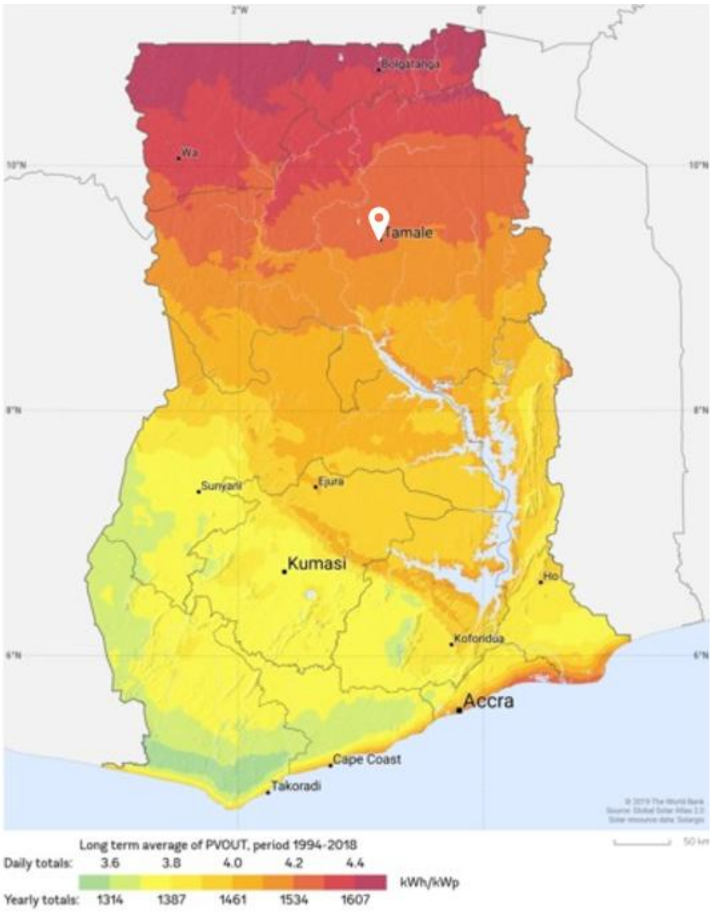

Figure 5: Photovoltaic Power potential of Ghana

***Source**: (Global Solar Atlas, 2021)*

Despite being in the savannah zone, Northern Ghana including areas around Tamale has access to surface ground water bodies and groundwater reserves, particularly from the White Volta River basin. The region also benefits from borehole water systems developed under various rural water access programs like the Sustainable Rural Water and Sanitation Project funded by the World Bank (The World Bank, 2010). Comparable water resource availability patterns exist across the West African sub-region, particularly in area with river basins like the Volta, Niger, Senegal, Gambia, and Guinea. These water resources make it technically feasible to support electrolysis for hydrogen production provided proper water treatment systems are in place.

In terms of infrastructure and policy support, Ghana, like many West African countries, does not currently have a dedicated national hydrogen strategy. However, the country is increasingly prioritizing clean energy technologies through its National Energy Transition Framework which outlines an approach to transitioning from fossil fuels to RE sources including hydrogen (Ghana Ministry of Energy, 2022) . Similar policy gaps but growing RE ambitions can be observed in other West African countries where governments are increasingly exploring low-carbon pathways to decarbonize their energy systems. In addition, Northern Ghana has also seen recent investments in grid extension and several RE mini grid pilot projects (The World Bank, 2017) which lay the foundation for integrating new systems like hydrogen production.

Overall, the choice of Tamale is not only relevant for Ghana but also enhances the regional relevance of the study. This is because the climatic and infrastructural conditions of Northern Ghana closely resemble those of neighboring countries in Shahel zone and other West African countries. Therefore, the findings and system design are likely to be replicable in other West African countries for similar analysis.

Table 3: System Costs

Cost type	Value	Unit	Source
PV system CAPEX	678	€/ KW	(IRENA, 2024)
PV system OPEX	1	% of CAPEX per year	(IRENA, 2024)
PV system lifetime	25	years	
Electrolyzer Capex	800	€/kW	(European Hydrogen Obsevatory, 2024)
Electrolyzer OPEX	2	% of CAPEX per year	(Bhandari & Shah, 2021)
Stack replacement	340	€/ KW	(Bhandari & Shah, 2021)
Electrolyzer lifetime	10	years	(Bhandari & Shah, 2021)
Hydrogen Storage	460	€/kgH_2	(Lai & McCulloch, 2017)
Water supply	1.21	€/m^3	(PURC, 2023)
Discount rate	10	%	(Asante et al., 2024), (IRENA, 2024)

Source *: Author*

Table 4: PV specifications

Description	**Value**	**Unit**	(Eastman World, 2024)
Maximum power	450	W	(Eastman World, 2024)
Efficiency	20.7	%	(Eastman World, 2024)
Maximum voltage	41.47	V	(Eastman World, 2024)
Maximum current	10.85	A	(Eastman World, 2024)
Open circuit voltage	49.51	V	(Eastman World, 2024)
Open circuit current	11.78	A	(Eastman World, 2024)
Power tolerance	From 0 to +5	W	(Eastman World, 2024)
Maximum system voltage Nominal	1500	V	(Eastman World, 2024)
Operating cell temperature	-40~+85	ºC	(Eastman World, 2024)
Maximum series fuse Rating	20	A	(Eastman World, 2024)

***Source**: Author*

Table 5: Electrolyzer specifications

Description	**Value**	**Unit**	**Source**
Electrolyzer capacity	5000	kW	VERDE HYDROGEN
Daily production	2136	kgH_2/day	VERDE HYDROGEN
annual H2 production	240389	kgH_2	Calculated
Water consumption	1	m^3/h	VERDE HYDROGEN
Daily water consumption (m3)	7.4	m^3	Calculated
Annual water consumption	2701	m^3	calculated
Electricity consumption	53	kwh/kgH_2	H-TECH systems
Annual Electricity consumption	12740617	kWh	Calculated
Daily electricity consumption	34905.80	kWh	Calculated

***Source**: Author*

3.3.1 Scenario-based risk quantification with assumptions

The results from the risk scoring matrix indicate that Social, Policy & Regulatory, and Political risks are the most significant risks for renewable energy projects that incorporate green hydrogen production. This study adapted a scenario-based risk quantification approach to evaluate how these risks affect the LCOE and LCOH by adjusting specific cost parameters. The baseline scenario was evaluated with no project risks. Apart from the baseline scenario, 7 scenarios were assumed. Scenario 1 assumed that the project encountered social risks which reflect land acquisition challenges and resistance from local stakeholders. Most investors are mandated to ensure fair and equitable compensation for land that belongs to people of the affected communities. However, there is no fixed, pre-determined amount for land compensation in West Africa or any other region. Therefore, compensation amounts are determined on a case-by-case basis, depending on various factors related to the specific project and the affected land and people. The estimated amount for cost of land compensation used in this study was based on the case of the Ghana Petroleum Hub, which was found in a report by the Ghana Broadcasting Corporation (gbcghanaonline, 2025) on April 3 2025. It was reported that the Ghana government compensated over 1.2 billion Ghana Cedis for 20000 acres of land which amounted to about 150000 Cedis per hectare of land. Furthermore, the cost of public awareness campaigns and community educational initiatives, which can be between 1-4% of total investment (Development Bank of Southern Africa (DBSA)., 2021) must be accounted for to increase stakeholder involvement and reduce the risk of community resistance and unwillingness to pay. Scenario 2 assumed policy and regulatory risk caused by licensing and administrative bottlenecks as well as other policy-related impediments. These risks are reflected in the CAPEX by adding licensing and project delay costs. Scenario 3 reflects political instability-related risks, which presumed changes in government and the risk of renegotiating Power Purchase Agreements (PPAs). The first two scenarios did not assume any political disruptions and therefore used the 10% discount rate as used in the baseline scenario. However, scenario 3 increased the discount rate to 12% to reflect higher political uncertainties (Afful-Dadzie et al., 2022). Furthermore, a political risk premium was also added to the CAPEX. Apart from the single risk scenarios, the study went further to assume multiple risk scenarios to capture the complex nature of real-world projects where these risks often rather occur concurrently as shown in Table 6. Scenario 7 reflects the worst-case scenario, presenting all three major risks simultaneously allowing for an evaluation of project sensitivity to multiple unmitigated risks. The additional costs, due to the cost of risks from the scenario assumptions, are also indicated in Table 7.

Table 6: Scenario Description

Scenario	Description	Risk adjustment	Discount rate
S0	Baseline (no risk)	No Adjustment	10% - Base discount rate (Asante et al., 2024), (IRENA, 2024)
S1	Social risk only	Adjusted CAPEX for land compensation and community education	10% (Asante et al., 2024), (IRENA, 2024)
S2	Policy & Regulatory risk	Add licensing and delay costs to CAPEX	10% (Asante et al., 2024), (IRENA, 2024)
S3	Political risk only	Add political instability risk premium to CAPEX	Adjusted discount rate 12% (Afful-Dadzie et al., 2022)
S4 (S1+S2)	Social risk + Policy & Regulatory risk	Adjusted CAPEX to cater for land compensation, community awareness, licensing and delay costs	10% (Asante et al., 2024), (IRENA, 2024)
S5 (S1+S3)	Social risk + political risk	Adjusted CAPEX to cater for land compensation, community awareness, and political instability premium	12% (Afful-Dadzie et al., 2022)
S6 (S2+S3)	Policy & Regulatory risk + Political risk	Adjusted CAPEX to cater for political instability risk premium, licensing and delay costs,	12% (Afful-Dadzie et al., 2022)

S7 (S1+S2+S3)	Social + Political + Policy &Regulatory risk	Adjusted CAPEX to cater for land compensation, community awareness, political instability risk premium, licensing and delay costs	12% (Afful-Dadzie et al., 2022)

***Source**: Author*

Table 7: Risk adjustment cost

Risk adjustment	Cost in €	Source
Land compensation	12000 per hectare	Calculated based on the land compensation cost of the Ghana Petroleum Hub reported by gbcghanaonline (2025)
Community awareness	4% of CAPEX	(Development Bank of Southern Africa (DBSA)., 2021)
Licensing fees	Initial: 8552 Annual: 31643	(Energy Commission, 2025)
Political risk premium	1.5% of total investment	(NenPower, 2025)

***Source**: Author*

The direct costs from Table 7 above were used in the techno economic analysis framework by adjusting some cash flow parameters such as CAPEX and OPEX and discount rate in some instances to calculate their impact on levelized cost of hydrogen. Equation 3 was used with an additional parameter to account for the additional CAPEX.

$$LCOH_R = \frac{I_0 + I_R + \sum_{t=1}^{N} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{H2_t}{(1+r)^t}} \qquad \text{Equation 3}$$

I_R in equation 3 represents the additional investment due to risks.

4. RESULTS AND DISCUSSIONS

The analysis of expert opinions, combined with the scenario-based LCOH evaluations, provides a comprehensive picture of how the identified risks interact to influence the techno-economic parameters of RE projects incorporating green hydrogen production. The insights gathered from the surveys and interviews together lead to the selection of political, policy & regulatory, and social risks as the most relevant for further analysis to assess their impact on project viability. The findings provided the qualitative justification for the risk prioritization framework and the scenario-based impact assessment that follows in the next sections of this chapter.

4.1 Risk Identification and scoring.

Through the survey, the respondents were able to determine the three most significant risk categories by ranking the risks according to their likelihood of occurrence and severity. Risks such as Political, Policy & Regulations, and Social were continuously listed as the main barriers. Results of the severity and probability ratings are shown in Table 7.

Table 8: Severity and probability ratings from survey

	Risk Category								
Respondent	**Respondent ratings (out of 5)**	**Financial**	**Technical**	**Supply chain & Logistics**	**Political**	**Regulatory & Policy**	**Environmental**	**Social**	**Market**
1	severity	3	4	2	3	3	2	3	2
	likelihood	1	2	4	3	3	2	2	2
2	Severity	4	4	3	3	3	2	2	4
	Likelihood	4	4	4	3	3	4	2	3
3	Severity	3	1	1	4	3	1	3	2
	Likelihood	3	2	2	3	4	3	3	4
4	Severity	1	3	2	5	4	1	1	2
	Likelihood	1	2	2	2	2	3	3	4
5	Severity	2	3	3	2	4	5	5	3
	Likelihood	2	3	3	2	4	5	5	3

6	Severity	1	1	4	5	2	3	4	4
	Likelihood	1	1	3	5	4	2	5	5
7	Severity	5	3	2	5	3	3	4	2
	Likelihood	5	3	4	3	3	4	5	2
8	Severity	1	2	4	3	2	3	4	5
	Likelihood	1	2	4	3	4	3	4	5
9	Severity	2	4	1	2	5	3	4	5
	Likelihood	4	3	4	2	5	3	3	2
10	Severity	3	4	3	4	3	3	3	2
	likelihood	3	2	3	3	2	3	3	2
11	severity	4	5	4	5	4	3	4	3
	likelihood	4	4	4	5	3	3	3	3
12	Severity	5	2	4	4	3	2	3	2
	Likelihood	5	5	4	2	3	4	2	2
13	Severity	5	3	3	4	4	4	3	1
	Likelihood	5	3	4	4	4	4	3	1
14	severity	4	4	3	4	3	3	3	3
		4	3	2	3	3	3	3	3
15	severity	5	5	5	3	5	5	4	5
	likelihood	5	4	4	5	3	3	3	3
Average	**Severity**	3.2	3.2	2.933	3.733	3.4	2.867	3.267	2.733
	likelihood	3.2	2.867	3.4	3.2	3.333	3.2667	3.2	2.86
Risk	**Scores**	**10.24**	**9.173**	**9.973**	**11.947**	**11.333**	**9.364**	**10.45**	**7.836**
%	**Scores**	**40.96**	**36.693**	**39.893**	**47.786**	**45.333**	**37.457**	**41.81**	**31.342**

***Source**: Author*

As illustrated in Figure 7, participants identified Political risk (47.787%), Policy & Regulatory risk (45.33%) and social risk (41.813%) as the three most significant risks associated with RE projects in West Africa. These findings underscore the dominant influence political stability, good governance practices and community engagement on project success. These were followed in order of significance by financial risk (40.96%), supply chain & logistics (39.893%), Environmental risk (37.457%), and technical risk (36.693%). Market risk, with the lowest score of 31.342%, was perceived least significant. This, according to most experts, was due to growing long-term demand for RE. In addition, several experts emphasized the relevance of safety risks for the RE projects that incorporate green hydrogen production, commenting on flammability and high-pressure requirements of hydrogen systems which may increase the risk of explosion.

Figure 6: Risk scores calculated based on expert opinions

***Source**: Author*

For further interpretation, a 5x5 risk matrix was adopted from (Lu et al., 2015), as shown in Figure 7 to categorize each risk based on their scores. The matrix enabled a more intricate prioritization beyond raw expert scoring. High-severity high-probability risks such as political, policy & regulation, social and financial risks fall within the upper part of orange (high) approaching the red (extremely high) zone, indicating high economic impact. Technical, Environmental and Supply Chain & Logistics risks, on the other hand, are found in the lower orange approaching the yellow (medium) zone. Despite these risks having a high impact, they reflected a somewhat lower probability of occurrence. Meanwhile, market risk lying in the lower yellow zone suggested a rather lower criticality.

		Probability				
		1	**2**	**3**	**4**	**5**
Severity	**5**					
	4			Political, Policy & Reg. Social financial		
	3			Supply Chain, Environmental, Technical		
	2			Market		
	1					

Low Risk Medium Risk High Risk Extremely High Risk

Figure 7: 5x5 Risk Matrix

***Source**: Author*

4.2 Techno economic analysis

A techno-economic model was developed for a RE system comprising a 10 MWp solar PV plant integrated with a 5MW PEM electrolyzer for green hydrogen production. This configuration was selected to reflect the technology mix feasible for Northern Ghana and aligns with the system design parameters previously outlined in chapter 3.

The system costs and performance were evaluated over the projects lifetime of 20 years using the levelized cost approach. As summarized in Table 9 , the 10MWp solar PV plant requires an initial investment of €6.78 million, yielding LCOE of €0.0539 per kWh. Part of this electricity is then used to operate the 5MW electrolyzer, whose performance is detailed in Table 10. The electrolyzer system requires €4.3 million in upfront investment and generates 2.05 million kg of hydrogen discounted over the project lifetime, resulting in LCOH of €5.63 per kgH_2 under risk free conditions. The LCOH value form the base case reference model for subsequent risk-adjusted scenario analyses, where variations in cash flows and discount rates are applied to reflect the influence of social, political and regulatory risks identified in previous sections.

Table 9: 10MW peak solar system

Description	Value	Monetary unit
Initial investment	6780000	€
Total discounted annual costs	577219.6202	€
Total discounted Elec. produced	136479237.3	kWh
LCOE	0.053907245	€/kWh

Table 10: 5MW electrolyzer system for hydrogen production

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs	7211546.752	€
Total discounted H2 produced	2046567.069	kgH_2
LCOH	5.626252336	€/kgH_2

4.3 Scenario-Base Risk analysis

The scenarios S1 to S7 incorporate individual and combined effects of Social, Policy & regulatory, and Political risks while S0, the base-line scenario assumes a non-risk environment, yielding the lowest LCOH at approximately 5.61 €/kgH_2. This was taken as a reference point for assessing the impact of the subsequent risk adjusted scenarios. Tables 10 to 16 present the deviations in cash flow parameters leading to different LCOH under different risk scenarios. As outlined in chapter 3, risk-adjusted CAPEX and OPEX values were applied to calculate the LCOE for each scenario. The corresponding values of the LCOE were evaluated as part of the operational cost component in the calculation of the LCOH under each scenario. In most cases only the discounted annual costs varied between the scenarios. However, scenarios that reflected political risk also showed an increase in the total discounted hydrogen production. This deviation is due to the increased discount rates associated with political risk, which also reduces the present value of the future hydrogen production.

Scenario 1 (S1): Social risks only, reflecting adjustments for land compensation and community education

Table 11: Scenario 1

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	7474770.818	€
Total discounted H2 produced	2046567.069	kgH_2
LCOH	**5.754869702**	€/kgH_2

Scenario 2 (S2): Policy & Regulatory risk only, reflecting licensing and delay costs

Table 12: Scenario 2

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	7432447.294	€
Total discounted H2 produced	2046567.069	kgH_2
LCOH	**5.734189449**	€/kgH_2

Scenario 3 (S3): Political risks only, reflecting political risk premium and increased discount rate

Table 13: Scenario 3

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	6960273.619	€

Total discounted H2 produced	1795572.083	kgH_2
LCOH	**6.272780538**	€/kgH_2

Scenario 4 (S4): Social risk combined with Policy & Regulatory risk, reflecting adjustment for land compensation, community awareness and licensing costs.

Table 14: Scenario 4

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	7695671.36	€
Total discounted H2 produced	2046567.069	kgH_2
LCOH	**5.862806815**	€/kgH_2

Scenario 5 (S5): Social risk combined with political risk, reflecting Adjustment for land compensation, community awareness, political instability premium and increased discount rate.

Table 15: Scenario 5

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	7555597.773	€
Total discounted H2 produced	2046567.069	kgH_2
LCOH	**5.794363621**	€/kgH_2

Scenario 6 (S6): Policy & Regulatory risk combined with Political risk, reflecting adjustment cater for political instability risk premium, licensing costs, and increased discount rate.

Table 16: Scenario 6

Description	Value	Monetary unit
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	7235743.012	€
Total discounted H2 produced	1795572.083	kgH_2
LCOH	**6.426196485**	€/kgH_2

Scenario 7 (S7): All three risk factors combined (Social Political + Policy &Regulatory risk), reflecting adjustments for land compensation, community awareness, political instability risk premium, licensing costs and increased discount rate.

Table 17: Scenario 7

Description	**Value**	**Monetary unit**
Initial investment	4302956	€
Total discounted annual costs + risk adjustment	7498967.077	€
Total discounted H2 produced	1795572.083	kgH_2
LCOH	**6.572792697**	€/kgH_2

Figure 8 presents the LCOH under different risk scenarios. S3 (Political risks only) has the highest LCOH of approximately 6.24€/kgH_2 among the single risk cases, followed by S1 (Social risks only) and then S2 (policy & regulatory risks) 5.74€/kgH_2 and 5.72€/kgH_2 respectively. When the risks were combined, S6 (Policy & Regulatory + Political risks) and S7 (all three risk types combined), resulting in significantly higher hydrogen costs of approximately 6.42€/$kgH_2$and 6.57€/kgH_2, respectively.

The additional LCOH values shown by the red graph indicate the effects of the different risk factors on the various cost parameters of the system which in turn is directly reflected on the LCOH.

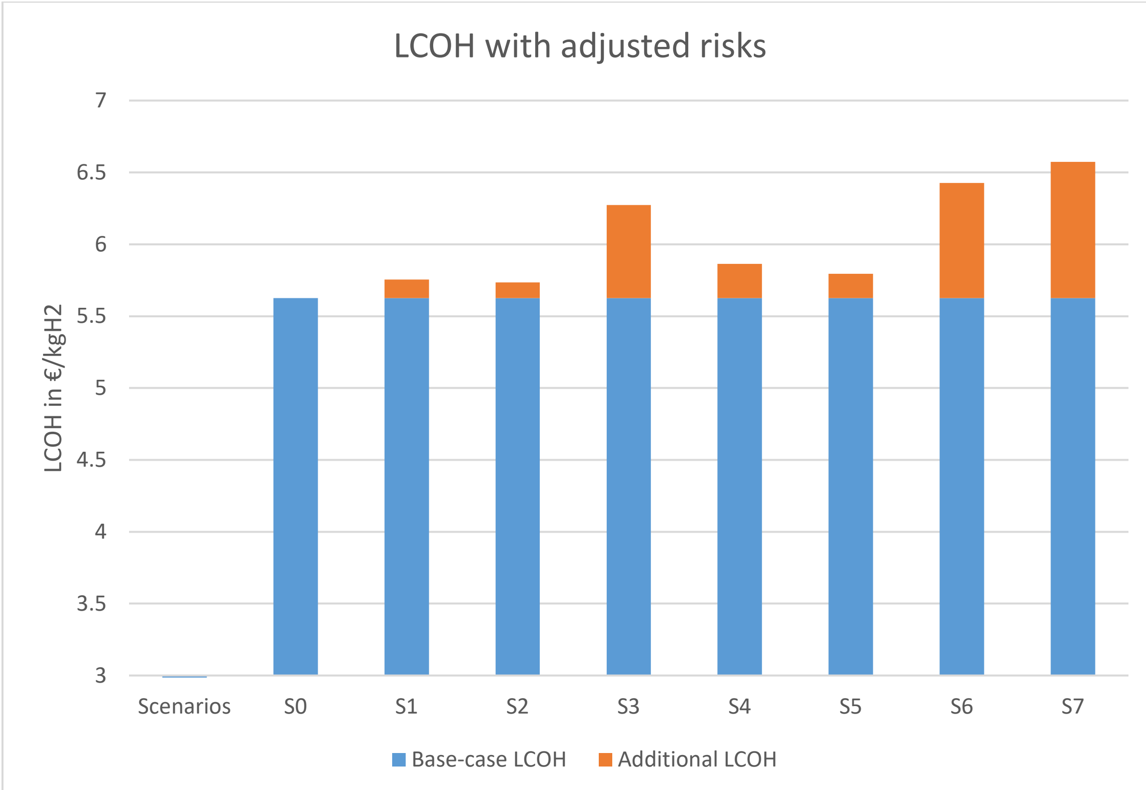

Figure 8: LCOH of the different scenarios

***Source**: Author*

4.4 Discussion

The findings from the DELPHI survey and interviews reveal a high degree of consensus among experts regarding the most significant risk categories. Majority of the participants had direct experience with solar PV systems, followed by wind and bioenergy with over 60% having worked on grid-tied or Mini grid renewable projects that ranged from 100s of kW to over 20MW. Most respondents cited battery storage systems as the primary choice for RE storage. However, a smaller group, notably from Ghana and Senegal mentioned pumped hydro. Emerging storage solutions such as hydrogen-based systems seemed not to have been part of current storage choice. This may be attributed to the relatively early stages of hydrogen technology development in West Africa.

In terms of familiarity with green hydrogen, only about 60% reported moderate knowledge with less than 30% having practical implementation experience of this emerging technology. However, several of the participants outlined the lack of technical capacity, high capital cost, safety issues, limited infrastructure and government policies as well as inadequate regulatory standards as the key potential barriers to adoption. This aligns with (Ahlborg & Hammar, 2014), who emphasized that weak institutional framework significantly undermine energy infrastructure investment in Africa. The interviewees emphasized the need for capacity building, small pilot projects and international collaboration to enable knowledge transfer and reduce potential risks.

The respondents, through the survey, were able to rank the risks using severity and likelihood of occurrence to identify the three most impactful risk categories. Political, Policy & regulatory uncertainties, and social acceptance issues were consistently ranked among the top concerns. These responses highlighted governance and institutional challenges in the region, ranging from frequent policy reversals, regulatory delays, community-level resistance to large-scale energy infrastructure as highlighted by (Nuriyev et al., 2019). Experts also pointed out the fragmented nature of permitting processes and weak enforcement of energy policies, which exacerbate investor uncertainty. This analysis concords with (Kigle et al., 2024) stating that country specific risks directly affect the LCOH.

From a social perspective, land acquisition emerged as a recurring issue, with respondents citing disputes over land ownership and inadequate community engagement strategies as common pitfalls. One of the interviewees from the World Bank Group emphasized that without early and transparent stakeholder consultations, even well-financed projects risk long delays or community rejection.

On the part of policy and regulatory, just as highlighted by (Gatzert & Kosub, 2016) in their study on Risks and Risk Management of Renewable Energy projects, experts highlighted inefficiencies in licensing procedures, lack of harmonized standards for RE systems and vague tariff structures. Many of them expressed concern over unclear government positions on green hydrogen, especially regarding its role in national energy strategies and its integration into existing infrastructure.

On the other hand, political risks were mostly associated with changes in government leadership, politicization of energy contracts and absence of long-term guarantees for private sector investors.

Political risks were perceived as the most impactful, especially for capital-intensive projects with long payback periods, such as those involving hydrogen production technologies.

Interestingly, although safety risks were not listed as a predefined category in the structured survey as those gathered from literature, several experts independently raised concerns about operational safety risks associated with hydrogen. Issues mentioned included hydrogen's flammability, the risk of leakage in high-pressure storage systems and the lack of skilled technicians for hydrogen-specific operations.

The findings from the scenario-based analysis show a clear visualization of the economic impacts of the three most significant risks identified in the study. Among the single risk scenarios, Political risks have the highest LCOH of approximately 6.24€/kgH_2 , reflecting the cost implications of increased discount rates and risk premiums due to political instability. These findings are identical to those of Rambo (2013) and Kul et al. (2020), stating that low democracy and contentious government transitions reduce investment opportunities for developing countries. Political instability reflects high tendency of increased interest and discount rates as indicated in a study on the Effects of Political Instability on Private Investment by (Ibrahim & Ngahane, 2024).

Social and policy & regulatory risks on the other hand have a more moderate effect, raising the LCOH to around 5.74€/kgH_2 and 5.72€/kgH_2 respectively. This suggests that while land acquisition, community engagement, and licensing issues may introduce cost increases, their financial impact is less severe than political uncertainty.

Furthermore, the combined risk scenarios demonstrated a compounding effect Policy & Regulatory combined with Political risks, and all three risk types combined, came out with significantly higher hydrogen costs of approximately 6.42€/kg$H_2$and 6.57€/kgH_2, respectively. A similar analysis given by (Gatzert & Kosub, 2016) indicates substantial erosion of cost-effectiveness when multiple risk dimensions interact, particularly under unstable political and regulatory environments.

The analysis confirms that political risk has the most pronounced effect on hydrogen production costs, whether as an isolated or a compounding factor. The increase in LCOH observed in scenarios reflecting political risk is primarily driven by the higher discount rates associated with unstable political environments. This demonstrates the critical role of financing costs in determining project viability as a slight increase in the discount rate significantly raises the price of hydrogen. The impact on CAPEX and OPEX was more noticeable in the regulatory/policy and social risk scenarios, indicating that community opposition, land disputes, uncertainty in permitting and other legal procedures directly result in greater upfront and operational delays. The findings, consistent with Nyarko et al. (2023), highlighted the importance of political stability, streamlining regulatory processes and proactive community engagement in reducing the LCOH.

Overall, these findings imply that while technology risks are manageable through engineering solutions, institutional and governance related risks present a more significant barrier to investment in RE and green hydrogen in West Africa.

4.5 Risk Transfer and Mitigation Strategies

As mentioned in the discussion section, through the expert consultations, the study identified the main risks influencing the viability of RE projects with green hydrogen production in West Africa. The next step is to examine some of the available risk management tools applicable to these risks, followed by targeted risk mitigation strategies derived from both literature and expert insights. These measures are intended not only to reduce the probability or severity of risk events but also to improve project viability by transferring certain economic exposures to third parties.

Risk transfer mechanisms are essential in managing project uncertainties, especially when it comes to risks that cannot be fully mitigated through operational or design solutions. (Gatzert & Kosub, 2016) mention Insurance as a major risk management instrument essential to ensuring sustainable growth of RE by reducing cash flow risks, which is particularly important for investors. Political risk insurance (PRI), for instance, may provide partial cover if a change in policy constitutes an unjustified violation of the investors rights.

The Multilateral Investment Guarantee Agency (MIGA) by the WBG (World Bank, 2024) offers Political risk insurance for developing economies and emerging markets gives regions such as West Africa and other developing regions. The African Insurance Agency also provides coverage against expropriation, currency inconvertibility, political violence and breach of contract by public entities (AFBD, 2015). This is especially relevant for the scenarios in the study where political instability led to higher discount rates and significant increase in the discounted annual costs of the project. Other risk transfer instruments include PPAs, Construction All-risk and Operational All-risk insurance, which covers physical damage to assets such as electrolysis systems, solar PV panels or hydrogen storage tanks (Schwab et al., 2020).

Despite risk transfer mechanisms offering protection against the financial consequences from risk events, proactive risk mitigation is still necessary. Based on the findings from experts, the most significant risks identified require tailored mitigation approaches.

To address regulatory and policy risks, experts recommended early and sustained engagement with government agencies to advocate for stable policy frameworks, transparent permitting processes, and clear hydrogen development roadmaps. Such engagement should be supported by intensified communication with policy makers, regulators, and relevant stakeholders, as emphasized by (Gatzert & Kosub, 2016), to ensure that developers are actively involved in shaping regulatory environments. Additionally, investing in local capacity building and knowledge transfer can strengthen institutional capabilities and enable smoother policy implementation and regulatory compliance over the projects lifecycle.

Furthermore, mitigating social risks requires proactive measures to foster community acceptance and minimize the likelihood of project delays due to social resistance. A key approach proposed by the experts in this study is to conduct comprehensive feasibility studies early in the project life cycle to identify potential risks before significant investments are made. Inclusive stakeholder consultations should be undertaken to ensure that local communities are engaged in decision-making and that their concerns are addressed transparently (Gatzert & Kosub, 2016). Furthermore, securing long-term PPAs reduces project risks by providing both financial stability and assurance to local stakeholders, demonstrating the projects long-term commitment to the region (Egli, 2020).

When it comes to political risks, experts opinions coincides with that of (Ouedraogo, 2019), stating that political risks can be mitigated through strategic geographic diversification of project assets across multiple jurisdictions. Geographic diversification, as emphasized by (Gatzert & Kosub, 2016), significantly reduces the impact of localized political instability on the overall project portfolio by avoiding overreliance on single jurisdictions, thus safeguarding operations against abrupt policy changes or political unrest in one location.

CONCLUSION

This study revealed the most significant risks associated with RE projects that integrate green hydrogen production in West Africa, drawing insights from both existing literature and expert opinions gathered through the Delphi method. The literature revealed that while technology, financial, environmental, supply chain and market risks are considerably important, non-technical factors such as policy/regulatory uncertainty, political instability and social acceptance pose some of the most significant risks to RE project development in the region. These findings were echoed in the expert surveys and semi-structured interviews, where consensus emerged around these risk categories as the most critical to address.

The methodology, which combined the Delphi technique with scenario-based analysis, proved effective in evaluating the economic implications of these risks. The modelling of a 10MW solar PV system with integrated hydrogen production showed that risk adjusted cash flows significantly affect the LCOE and consequently, the LCOH. Across the different scenarios, LCOH values varied according to the risk factors applied. The highest LCOH values were observed in scenarios incorporating political risks, where increased discount rates significantly increased the present value of annual costs and hence inflated the cost per kilogram of hydrogen. In these cases, LCOH exceeded 6.50 €/kgH_2 compared to 5.63 €/kgH_2 in the base line scenario.

Given that changes in the discount rate have a greater impact on cost increase than social or regulatory risks when considered individually, the findings highlight the disproportionate impact of political instability on project viability. The result is consistent with existing literature, which emphasizes that the cost of capital is a determining factor in RE infrastructure investments, particularly in politically unstable environments.

The relevance of this study lies in its ability to inform both policymakers and stakeholders. For decision-makers, the findings underscore the importance of establishing stable regulatory environments, reducing political uncertainties and encouraging community involvements as preconditions for unlocking the potential of RE and green hydrogen production in West Africa's energy mix.

Limitations

The limitation of this study lies in the composition of the expert panel used in the Delphi survey. Most respondents were engineers, whose professional background and practical experience may lead to risk perceptions that differ from those of investors, policymakers or community representatives. This potential bias means that some risk categories, particularly those related to financial structures, may be underrepresented in the results.

Another limitation is the unavailability of direct, variable cost data for the various risks assessed. As a result, financial modelling relied on a combination of secondary data, expert opinions and reasonable assumptions. While such an approach may work in early-stage feasibility assessments, it unavoidably introduces uncertainties into the quantitative analysis of the adjusted cost parameters for each scenario.

Recommendation for future research

Future studies should broaden the scope of expert consultation to include a more balanced representation of stakeholders, such as policy makers, investors, regulators, community representatives, alongside technical experts. This would help capture a more diverse comprehension of risk perception to enhance the applicability of findings to real world decision-making contexts. Additionally, future research should focus on specific types of RE technologies, such as wind, solar, or even bioenergy systems that integrate hydrogen production, rather than just considering RE projects in general. This would enable a more tailored approach in accounting for the distinct risk factors peculiar to each technology. Furthermore, studies could also extend the scope beyond West Africa to include North, East, South and Central Africa. A comparative analysis across regions would provide deeper understanding of how different policy and regulatory frameworks, political environments and resource availability influence RE project risks and their economic impacts.

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APPENDIX

A. System design and calculations

Discription	Unit	Value	Source
PV system CAPEX	€	6780000	IRENA, 2024
pv system OPEX	€ per annum	67800	IRENA, 2024
Land Compensation	€	60000	
comm. education	€	271200	
Electrolyser CAPEX	€	4000000	Bhandari & Shah, 2021
Electrolyzer OPEX	€	80000	Bhandari & Shah, 2021
Stack replacement	€	1700000	Bhandari & Shah, 2021
Hydrogen Storage	€ per kgH2	302956	Bhandari & Shah, 2021
Cost of Water	€ per m3	1.21	GhanaWeb
Total cost of water	€ per annum	3268.21	Calculated
Discout rate	%	10%	IRENA, 2024
Capacity factor	%	18.30%	Calculated
Annual electricity production	kWh	16030800	Calculated
Annual Hydrogen production	kgH2	240389	Calculated

Electrolyser Capacity	5000	kW	VERDE HYDROGEN
H2 Production	2136	kgH2/day	VERDE HYDROGEN
daily production hours	7.4	hours	World Data
Daily H2 production	658.6	kgH2	Calculated
annual H2 production	240389	kgH2	Calculated
Water consumption	1	m3/h	VERDE HYDROGEN
Daily water consumption (m3)	7.4	m3	Calculated
Annual water consumption	2701	m3	Calcukated
Electricity consumption	53	kwh/kgH2	H-TECH systems
Annual Eleecrity consumption	12740.617	MWh	Calcualeted
Daily electricity consumption	34.9058	MWh	Calculated

Total PV system CAPEX	7111200	€
PV system annual OPEX	67800	€
Electrolyser system CAPEX	4302956	€
Electrolyser system OPEX	800997.9663	€
Stack replacement cost	1700000	€
System power peak =	10000	kW

$$E(kWh) = Ppeak(kW) \times Cf \times Ah(hours)$$

E(kWh) = annual electricity production	
Ppeak(kW) = installed solar PV capacity	
cf = capacity factor of the pv system	
Ah(hours) = Total hours in a year = 8760	

year	PV OPEX (€)	cost_replacement (€)	annual cost_(€)	Discounted annual cost (€)	Annual Elec. produced (kWh)	P.Value Elec. produced (kWh)
1	67800		67800	61636.36364	16030800	14573454.55
2	67800		67800	56033.05785	16030800	13248595.04
3	67800		67800	50939.1435	16030800	12044177.31
4	67800		67800	46308.31227	16030800	10949252.1
5	67800		67800	42098.4657	16030800	9953865.546
6	67800		67800	38271.33246	16030800	9048968.678
7	67800		67800	34792.12042	16030800	8226335.162
8	67800		67800	31629.20038	16030800	7478486.511
9	67800		67800	28753.81853	16030800	6798624.101
10	67800		67800	26139.83502	16030800	6180567.364
11	67800		67800	23763.48638	16030800	5618697.604
12	67800		67800	21603.16944	16030800	5107906.913
13	67800		67800	19639.24495	16030800	4643551.739
14	67800		67800	17853.85904	16030800	4221410.672
15	67800		67800	16230.78095	16030800	3837646.065
16	67800		67800	14755.25541	16030800	3488769.15
17	67800		67800	13413.86855	16030800	3171608.318
18	67800		67800	12194.42596	16030800	2883280.289
19	67800		67800	11085.84178	16030800	2621163.899
20	67800		67800	10078.03798	16030800	2382876.272
			1356000	**577219.6202**	**320616000**	**136479237.3**

$$LCOE = \frac{I_0 + \sum_{t=1}^{N} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{E_t}{(1+r)^t}}$$

Initial investment	7111200	€
Total discounted annual costs	577219.6202	€
Total discounted Elec. produce	136479237.3	€
LCOE	**0.056333987**	€

year	Electrolyser OP	cost_replacement (€)	annual cost_(€)	Discounted annual cost (€)	Annual H2 produced (kgH2)	P.Value H2 produced (kgH2)
1	800997.9663		800997.9663	728179.9694	240389	218535.4545
2	800997.9663		800997.9663	661981.7904	240389	198668.595
3	800997.9663		800997.9663	601801.6276	240389	180607.8137
4	800997.9663		800997.9663	547092.3887	240389	164188.9215
5	800997.9663		800997.9663	497356.717	240389	149262.6559
6	800997.9663		800997.9663	452142.47	240389	135693.3236
7	800997.9663		800997.9663	411038.6091	240389	123357.5669
8	800997.9663		800997.9663	373671.4628	240389	112143.2426
9	800997.9663		800997.9663	339701.3298	240389	101948.4024
10	800997.9663	1700000	2500997.966	964242.9828	240389	92680.3658
11	800997.9663		800997.9663	280744.9007	240389	84254.878
12	800997.9663		800997.9663	255222.637	240389	76595.34364
13	800997.9663		800997.9663	232020.5791	240389	69632.13058
14	800997.9663		800997.9663	210927.7992	240389	63301.93689
15	800997.9663		800997.9663	191752.5447	240389	57547.21536
16	800997.9663		800997.9663	174320.4952	240389	52315.65032
17	800997.9663		800997.9663	158473.1774	240389	47559.68211
18	800997.9663		800997.9663	144066.5249	240389	43236.07465
19	800997.9663		800997.9663	130969.5681	240389	39305.52241
20	800997.9663		800997.9663	119063.2438	240389	35732.2931
			17719959.33	**7474770.818**	**4807780**	**2046567.069**

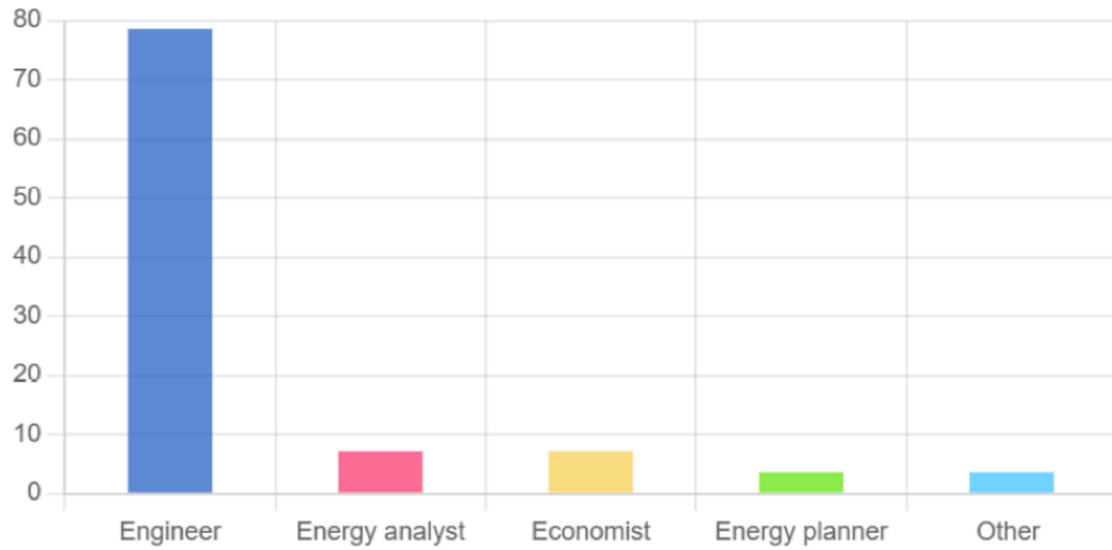
$$LCOH = \frac{I_0 + \sum_{t=1}^{N} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{N} \frac{H2_t}{(1+r)^t}}$$

Initial investment	4302956	€
Total discounted annual costs	7474770.818	€
Total discounted H2 produced	2046567.069	€
LCOH	**5.754869702**	€

B. Reports

1. What is your profession or job title?

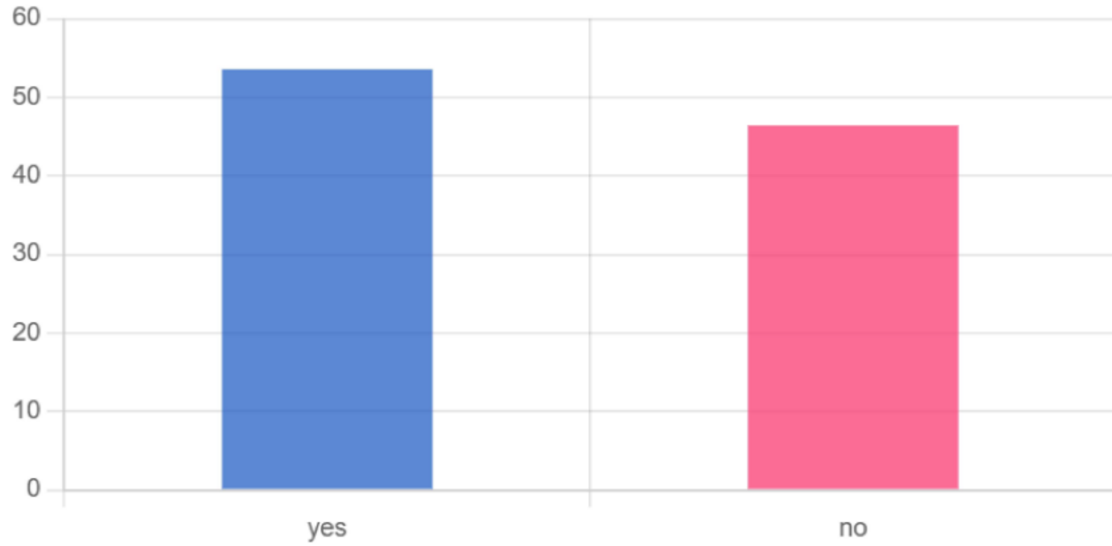
TYPE: SELECT_ONE. 28 out of 28 respondents answered this question. (0 were without data.)



Value	Frequency	Percentage
Engineer	22	78.57
Energy analyst	2	7.14
Economist	2	7.14
Energy planner	1	3.57
Other	1	3.57

4. Have you been involved in renewable energy projects in any West African country?

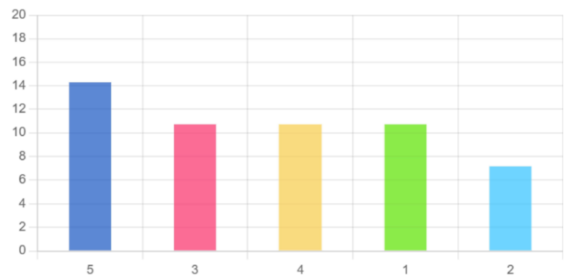
TYPE: SELECT_ONE. 28 out of 28 respondents answered this question. (0 were without data.)



Value	Frequency	Percentage
yes	15	53.57
no	13	46.43

Financial

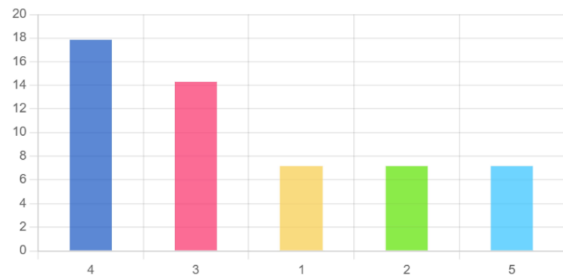
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
5	4	14.29
3	3	10.71
4	3	10.71
1	3	10.71
2	2	7.14

Technical

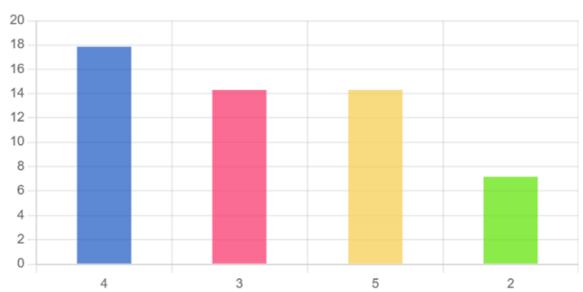
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
4	5	17.86
3	4	14.29
1	2	7.14
2	2	7.14
5	2	7.14

Political

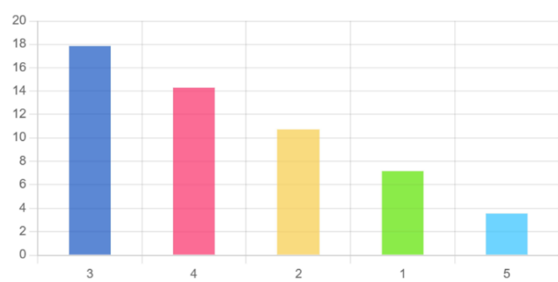
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
4	5	17.86
3	4	14.29
5	4	14.29
2	2	7.14

Supply Chain/Logistics

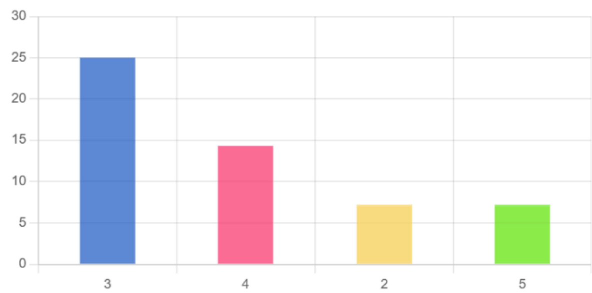
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
3	5	17.86
4	4	14.29
2	3	10.71
1	2	7.14
5	1	3.57

Regulatory and Policy

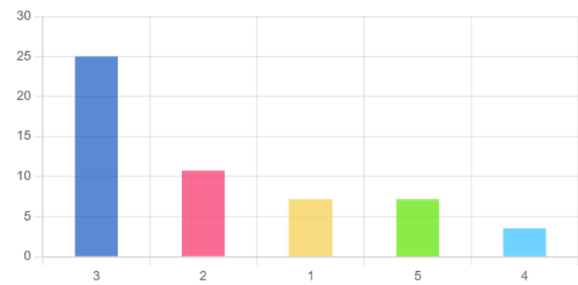
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
3	7	25
4	4	14.29
2	2	7.14
5	2	7.14

Environmental

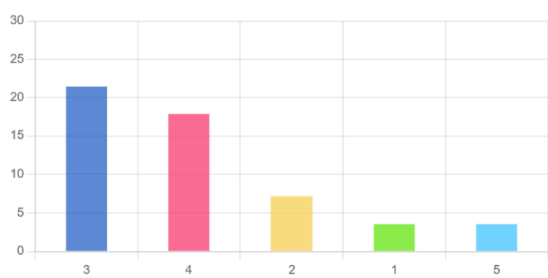
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
3	7	25
2	3	10.71
1	2	7.14
5	2	7.14
4	1	3.57

Social

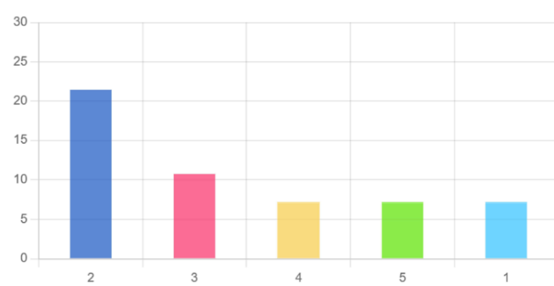
TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
3	6	21.43
4	5	17.86
2	2	7.14
1	1	3.57
5	1	3.57

Market

TYPE: SELECT_ONE. 15 out of 28 respondents answered this question. (13 were without data.)



Value	Frequency	Percentage
2	6	21.43
3	3	10.71
4	2	7.14
5	2	7.14
1	2	7.14

9. From ex	Financial	Technical	Supply Ch	Political	Regulatory	Environme	Social	Market	10. On a s	Financial	Technical	Supply Ch	Political	Regulatory	Environme	Social	Market
	3	4	2	3	3	2	3	2		1	2	4	3	3	2	2	2
	4	4	3	3	3	2	2	4		4	4	4	3	3	4	2	3
	3	1	1	4	3	1	3	2		3	2	2	3	4	3	3	4
	1	3	2	5	4	1	1	2		1	2	2	2	2	3	3	4
	2	3	3	2	4	5	5	3		2	3	3	2	4	5	5	3
	1	1	4	5	2	3	4	4		1	1	3	5	4	2	5	5
	5	3	2	5	3	3	4	2		5	3	4	3	3	4	5	2
	1	2	4	3	2	3	4	5		1	2	4	3	4	3	4	5
	2	4	1	2	5	3	3	1		4	3	4	2	5	3	2	1
	3	4	3	4	3	3	3	2		3	2	3	3	2	3	3	2
	4	5	4	5	4	3	4	3		4	4	4	5	3	3	3	3
	5	2	4	4	3	2	3	2		5	5	4	2	3	4	2	2
	5	3	3	4	4	4	3	1		5	3	4	4	4	4	3	1
	4	4	3	4	3	3	3	3		4	3	2	3	3	3	3	3
	5	5	5	3	5	5	4	5		5	4	4	5	3	3	3	3
	3.2	3.2	2.933333	3.733333	3.4	2.866667	3.266667	2.733333		3.2	2.866667	3.4	3.2	3.333333	3.266667	3.2	2.866667
scores	10.24	9.173333	9.973333	11.94667	11.33333	9.364444	10.45333	7.835556									
percentag	40.96	36.69333	39.89333	47.78667	45.33333	37.45778	41.81333	31.34222									

Survey Questionnaire : https://ee.kobotoolbox.org/x/ilr2V7Qc