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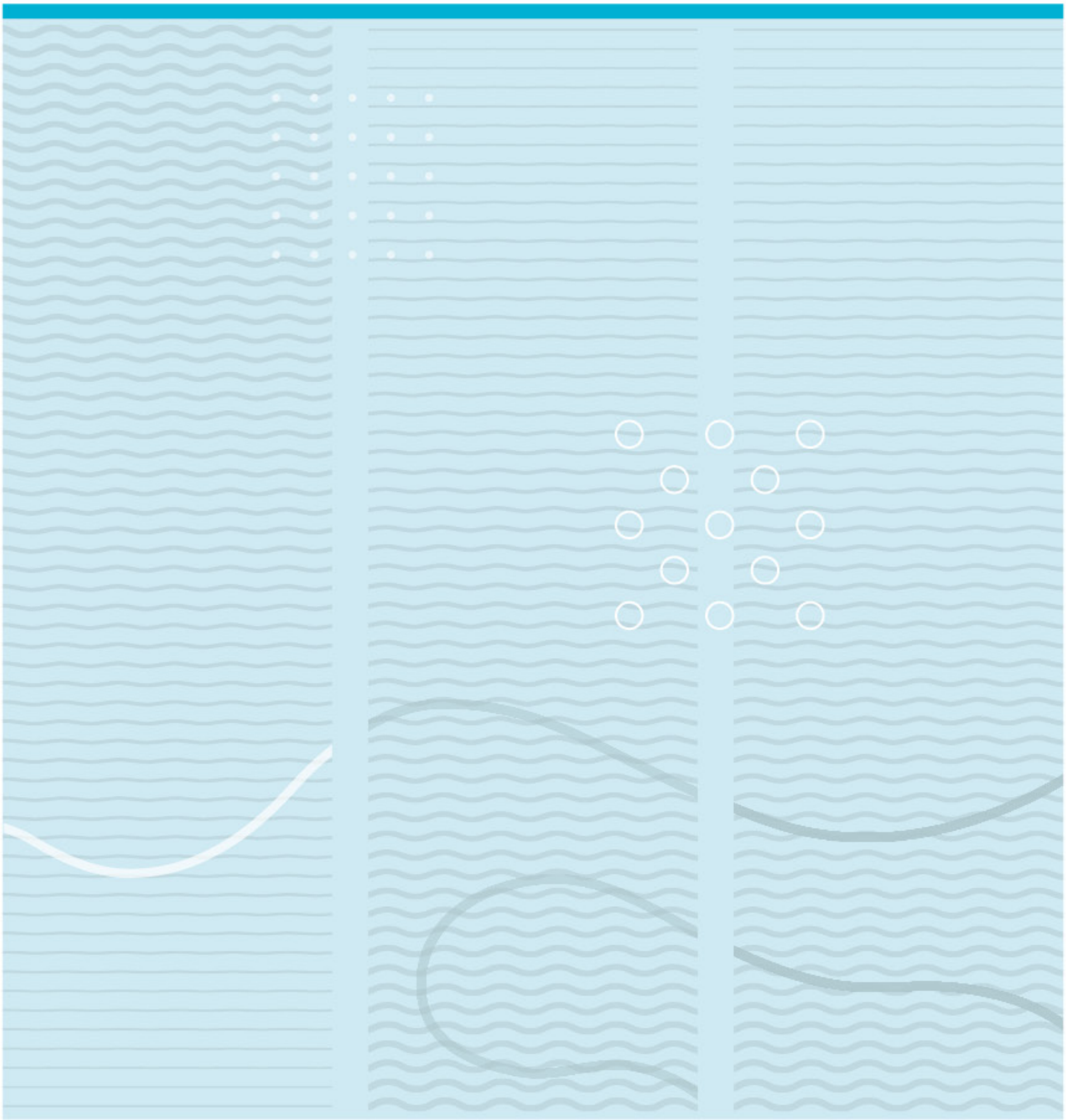
# Modelling the Financial Impacts of Renewable Energy Certificates (RECs) on Rooftop Solar Photovoltaic (PV) Project Investments in Ghana



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This thesis is worth 30 study points.

# ABSTRACT

This thesis evaluates the impact of Renewable Energy Certificates (RECs) on the financial viability of a hypothetical medium-scale 1 MWp rooftop solar photovoltaic (PV) project in Kumasi, Ghana. The objective is to analyse how RECs impact key financial metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and payback period, and to provide strategic insights into managing renewable energy investments under varying economic conditions. Using SolarGis for energy yield simulations and Microsoft Excel for financial modelling, this study creates two situations: one without the inclusion of REC income and one with REC income. The financial performance of these situations is compared to assess the potential improvement in profitability provided by RECs. A sensitivity and scenario analysis is then conducted to further explore the resilience of the project's financial metrics against fluctuations in key variables such as REC prices and their contract durations, discount rates, and electricity tariffs. Employing Real Options Theory, the research offers qualitative strategic decision-making insights for potential investors based on the modelled financial outcomes.

The findings indicate that incorporating RECs significantly improves the project's NPV and IRR, suggesting that RECs can be a critical factor in promoting the economic success of solar energy projects in emerging markets like Ghana. The study also highlights the need for robust policy frameworks to support the integration of renewable energy incentives such as RECs, which could lead to increased adoption of renewable technologies in Ghana and similar regions where renewable energy development is still emerging.

# FOREWORD

It is with great pleasure that I present this thesis, which explores the impact of Renewable Energy Certificates (RECs) on the financial viability of solar PV projects in Ghana. This research intends to bridge the knowledge gap in renewable energy financing, particularly in emerging markets, and provides an in-depth analysis of how innovative mechanisms like RECs can promote sustainable energy development.

The journey of this research project has been intellectually stimulating and immensely rewarding. I am deeply grateful to my supervisor, Prof. Niklas Valter Kreander, whose expertise in sustainable finance and guidance have been invaluable throughout the five (5) months spent on the project. His insight and support have not only shaped this work but have also profoundly influenced my personal and professional growth in the field of sustainable finance.

I also extend my thanks to the various experts and professionals who contributed their time and knowledge to validate the assumptions and findings of this study. Special thanks go out to Daniel Arnesson of Veyt AS in Oslo Norway, whose extensive knowledge and expertise in the Energy Attribute Certificate industry have greatly benefited this work. Additional thanks also go out to Lode, a PhD holder in Renewable Energy Management from Belgium, brought in by my supervisor, whose perspectives and critiques have enriched this work immeasurably. I am also grateful to Engineer Mark Wopicho (a.k.a Wops), the current Chief Technical Officer of Empower New Energy AS, for providing an engineering perspective that has significantly improved the quality of this research.

This thesis is dedicated to the hardworking people of Ghana, whose resilience and commitment to sustainable practices continue to inspire. It is my hope that this research will contribute to the ongoing efforts to harness renewable energy resources in Ghana and similar regions, providing a roadmap for future initiatives like RECs and others.

**Felix Sarfo Agyapong, BA, MA, MSc, MSc.**
**13th May, 2024**

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## LIST OF ABBREVIATIONS

CAPEX – Capital Expenditure
CIT – Corporate Income Tax
D-REC - Distributed Renewable Energy Certificates
FIT - Feed-in Tariff
GO - Guarantees of Origin (GO)
IEA – International Energy Agency
IMF - International Monetary Fund
IREC - International Renewable Energy Certificate
IRENA - International Renewable Energy Agency
IRR - Internal Rate of Return
kWh – Kilowatt-hour
kWp – Kilowatt-peak
MW - Megawatt
MWh – Megawatt hour
MWp – Megawatt peak
NPV - Net Present Value
NZECS - New Zealand Energy Certificate System
OPEX – Operational Expenditure
PPA - Power Purchase Agreement
PURC - Public Utilities Regulatory Commission
PV – Photovoltaic
RECs - Renewable Energy Certificates
REMP - Renewable Energy Master Plan
RPS - Renewable Portfolio Standards
SDGs - Sustainable Development Goals
TIGRs - Tradable Instruments for Global Renewables
WMO - World Meteorological Organization

# CHAPTER ONE

# INTRODUCTION

## 1.1.Background of the study

The global energy landscape is at a crucial stage transitioning from one source (fossil fuels) to another source (renewables), driven by the urgent need to mitigate the devastating impacts of climate change (Mentel et al., 2023). This urgency is underscored by international commitments such as the Paris Agreement and the Sustainable Development Goals (SDGs), which call for deep, rapid, and sustained cuts to carbon emissions. The World Meteorological Organization (WMO) emphasises this need by revealing that 2023 was the hottest year on record, highlighting the accelerating effects of climate change and underscoring the imperative for immediate action towards renewables (World Meteorological Organization, 2024).

As part of the transition, renewable energy sources such as solar have gained prominence due to their scalability and the declining cost of technology. Solar energy can be scaled up or down easily depending on the energy needs of an individual or a community (Cui et al., 2023). Moreover, compared to the cost of other technologies, solar photovoltaics (PV) currently offer one of the most cost-effective solutions. Gerarden (2023) notes a substantial reduction in solar panel costs over the last ten years, enhancing their affordability and accessibility for both residential and commercial users. Complementing this, the World Meteorological Organization report brings a glimmer of hope, stating that in 2023, renewable energy capacity surged by almost 50% from the previous year, marking the highest growth rate in two decades (World Meteorological Organization, 2024), a testament to the increasing feasibility and pivotal role of renewables like solar in combating climate change.

The International Renewable Energy Agency (IRENA) highlights the promising growth of the global renewable energy landscape, particularly in solar installations, with Asia (604 GW) and Europe (225 GW) leading in solar energy development as of the end of 2022 (IRENA, 2024). Despite this global momentum, Ghana's solar energy sector faces challenges. As of the end of 2022, Ghana's contribution to Africa's solar capacity was about 109 MW (IRENA, 2024), less than 1% of the continent's total. The country's energy mix remains heavily reliant on thermal sources (Gyamfi et al., 2018), even as it grapples with rising energy demands driven by economic growth and a growing population of around 30.8 million (Ghana Statistical Service, 2021). The challenges of power outages, known locally as "dumsor" (Dye, 2023), and significant increases in electricity tariffs partly due to economic pressures (Amoako et al., 2023), with the latest ones in 2023 coming from the International Monetary Fund (IMF, 2023) further complicate the energy landscape. These challenges underscore the need for Ghana to diversify and strengthen its energy portfolio through renewable sources.

Recognising the potential of renewable energy, the government of Ghana has enacted some regulatory frameworks. This includes the likes of the country's "Renewable Energy Act" introduced in 2011 and its subsequent version amended in 2020 (Public Utilities Regulatory Commission Ghana, 2021), and the more recent "Renewable Energy Master Plan" introduced in 2019 (Energy Commission Ghana, 2019). These regulatory and policy frameworks aim to increase renewables' share in the country's energy mix and offer incentives like VAT exemptions on imported solar panels and off-grid system components. Despite these efforts to create a supportive regulatory environment, Ghana's shift to solar energy has progressed more slowly than expected. As highlighted by Mahama et al. (2021), financing emerges as the most significant challenge. In one of the many studies about the renewables sector in the country, Agyapong (2022) and Mahama et al. (2021) note that traditional financing models are often inadequate for the needs of renewable energy projects, largely due to the considerable upfront costs involved and the perceived risk of repayment default. But these concerns are not limited to Ghana, they resonate across the global south where similar financial challenges present significant hurdles to the development of renewable energy. Studies by Appiah et al., (2023) and Dagnachew et al., (2020) share this same sentiment noting that the financing issues for renewable projects stem from a combination of high initial investments and sometimes the risks associated with repayment default stemming occasionally from economic instability which are characteristic of emerging economies.

Overcoming this financial hurdle that traditional financing models struggle to cover has brought what is now called third-party financing. Typically provided by foreign investors, this model involves supplying the necessary capital for renewable energy projects up front, under a mutually agreed arrangement (Li et al., 2019). While investors mostly have the capacity to cater for the significant initial investments required, their main concern usually has been the risk of inconsistent repayment by off-takers when investments are finally made (Steffen, 2018). Investments in infrastructure projects like renewable energy can have long payback periods, during which the cash flow can be uncertain, thus impacting revenue. So, investors normally worry about having a steady and reliable cash flow to give them a sort of security for their financial interests. To address these cashflow and revenue concerns and complement the third-party financing model, Renewable Energy Certificates (RECs) have been identified as a strategic alternative solution.

RECs offer a way to monetise the environmental benefits of renewable energy generation which creates an additional revenue stream that can be factored into renewable energy projects' cash flows (Shrivats & Jaimungal, 2020). This secondary income not only stands the chance to improve projects' financial attractiveness but also provides a layer of security for investors worried about the risks of fluctuating payments in their revenue models (Holt et al., 2011). It is therefore envisaged that by integrating RECs into the financing structure for solar PV investments, Ghana could offer a more compelling case to foreign investors. The assurance of an alternative revenue source from selling RECs, aside from the revenues derived from selling solar electricity to off-takers, could mitigate some perceived off-taker risks, making the upfront provision of capital and subsequent investments in solar energy projects less daunting in the country.

## 1.2.Research Problem

Internationally, Renewable Energy Certificates (RECs) have been the subject of extensive research, underscoring their potential to transform the renewable energy market. Studies conducted in regions such as Europe, North America, and parts of Asia have demonstrated the multifaceted benefits of RECs, ranging from incentivising renewable energy production to contributing to the financial sustainability of renewable energy projects. For instance, studies like those by Falconett and Nagasaka (2010) used probabilistic models leveraging Monte Carlo methods to assess the financial viability of renewable energy projects under various support mechanisms, including RECs. Their findings revealed that RECs significantly enhance the profitability of competitive renewable technologies, even though Feed-in Tariffs are more effective at boosting less mature technologies. A similar study by Klabjan & Arinez (2015) in the United States shows that changes in REC prices can greatly influence the financial side of solar energy investments, affecting when it's best to agree to buy back solar panels and providing strong financial reasons for investors to engage. Further studies, such as those by Holt et al. (2011), who explored the varied impacts of RECs on the economics of renewable energy projects, and Wimmers & Madlener (2023) who studied the market for Guarantees of Origin (GoOs), a similar REC type in Europe, acknowledge the financial benefit of these certificates although they point out that the certificates need to be priced higher than current support schemes to have a stronger effect. These studies from various places around the world demonstrate the widespread benefit of RECs and similar systems in boosting the renewable energy sector.

However, this promising global narrative around RECs finds a stark contrast in Ghana. The country's renewable energy sector, although rich in potential, clearly lacks empirical research on the impact of the revenues from RECs on the traditional financial metrics of solar projects. Traditional financial metrics here refer to the Net Present Value (NPV), Internal Rate of Return (IRR), and Payback period which investors commonly use to gauge the profitability and attractiveness of projects. Studies like those by Asumadu-Sarkodie and Owusu (2016), Agyekum (2021), and Peprah et al. (2023) emphasise the importance of financial metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR) in solar projects in Ghana but fail to delve deeply into the financial role of RECs. To the best of the knowledge of this study's author, no studies or research paper investigates the inclusion of RECs in solar PV project investments in Ghana. Hence, little is known about how RECs could financially impact the financial metrics of solar investments in the Ghanaian solar space. This significant gap hinders Ghanaian stakeholders' ability to effectively leverage RECs to advance renewable energy projects. Although the theoretical financial benefits of RECs—such as providing additional revenue streams, enhancing project attractiveness to investors, and the potential to improve investment returns—are known in academia and industry, kind courtesy of research studies from the global north, the absence of localised empirical evidence in the Ghanaian context limits the practical understanding and application of RECs.

Therefore, this study bridges this critical gap by examining the actual financial impact that RECs could have on the financial metrics and the subsequent economic viability of such solar projects in the context of the Ghanaian solar energy space. To do this, a hypothetical medium-scale rooftop solar photovoltaic (PV) project of about 1 MWp is modelled with the intention to finance the project using an equity financing model under a third-party Power Purchase Agreement (PPA) arrangement with a potential future off-taker. It is important to note that while debt financing is a common method in funding renewable energy projects, this study assumes equity as the sole form of financing and does not consider any debt financing elements. This is done so to help simplify the financial analysis and focus on assessing the viability of the project from an equity investor's perspective, which is consistent with the author's direct experience and expertise in solar project financing. The modelling of the project first starts with the simulation of energy generation for the project using a reputable simulation system called SolarGis. Next, a financial model is constructed in Microsoft Excel to analyse the project's financial viability without including income from the sale of RECs, focusing on key financial metrics like the NPV, IRR, and Payback Period. The model then evaluates the impact of RECs by incorporating revenues from them and comparing the results with the base model to identify how RECs influence the project's financial outcomes. Finally, a sensitivity and scenario analysis is conducted to understand how variations in key financial variables affect the solar project's financial metrics. The study also draws on the Real Options Theory, famously used in industries like oil and gas and real estate, to offer qualitative strategic decisions on what an investor potentially could take based on the outcomes of the project's financial analysis.

### 1.3.Research Objective

The main goal of this study is to assess how RECs impact the finances of medium-scale solar PV projects in Ghana, focusing on key financial metrics such as NPV, IRR, and the payback period. It also aims to provide strategic insights into managing such investments in the Ghanaian renewable energy sector. The study compares the financial performance of the solar project with and without RECs to determine their effect on profitability while exploring the sensitivity and scenario analysis of key variables. The strategic insights for investment management are analysed using the Real Options Theory, which helps in understanding the flexibility and decision-making processes in managing these investments under various economic conditions.

### 1.4.Research Question

Given the broad goal, the main research question is framed as "How do revenues from Renewable Energy Certificates (RECs) influence the financial metrics and attractiveness of a 1 MWp rooftop solar PV project in Ghana, under a third-party financed Power Purchase Agreement (PPA) model? This research question is further broken into three (3) specific research questions that together address the overarching main research goal:

1. What do the financial metrics for a 1 MWp rooftop solar PV project in Ghana under a third-party financed Power Purchase Agreement (PPA) model look like, excluding the impact of Renewable Energy Certificates (RECs)?
2. How does the inclusion of RECs in the financial model of the project influence the key financial metrics: Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period?

3. How do changes in key variables such as REC prices and contract duration, solar electricity tariffs, CAPEX, OPEX, and discount rates impact the key financial metrics of the project through sensitivity and scenario analysis?

## 1.5.Contributions of the Study to Literature

This study makes two key contributions to the literature. First, it addresses a crucial gap by providing empirical evidence on the financial impact of RECs on solar PV project investments in the context of an emerging market from the African continent. This context differs markedly from developed markets. To the best of this study's author's knowledge, this study is the first to examine a pilot solar PV project in Ghana that incorporates revenues from the sale of RECs into its financing model. The findings, therefore, from this study, grounded in real-world data, can serve as a compelling argument for the broader adoption of RECs in similar emerging markets on the African continent, offering a blueprint for stakeholders to leverage RECs to overcome financial barriers and enhance the attractiveness of renewable energy investments.

Secondly, the study, through its sensitivity and scenario analysis, contributes to enriching the understanding of how solar PV projects' financial viability is affected by fluctuating market and economic factors such as REC prices and their contract durations, different discount rates and solar electricity tariffs. These potential simulating sensitivities are crucial for investors and developers for strategizing effectively and preparing for adverse conditions that potentially could rock projects at any time.

## 1.6.Overview of the Study

The study from here is organised into six more chapters. Chapters Two and Three delve into a comprehensive review of existing literature on solar energy, project financing, and RECs, and point out the gaps in those existing studies. The theoretical framework guiding the study is also discussed in the third chapter. Chapter Four describes the research design and methods used to investigate the study. The findings of the study are presented in Chapter Five followed by the interpretation and discussion of the findings in Chapter Six. The Final Chapter, Seven, summarises the key findings of the study and their implications for theory, policy, and industry. The study limitations are also elaborated on in this chapter with possible recommendations for future research.

# CHAPTER TWO

# LITERATURE REVIEW [I]

## 2.0.Introduction

This chapter looks into what's already known about renewable energy, focusing on how solar power is used around the world and in Ghana. The review covers topics like the growth and development of solar energy, the policies that have been implemented in the past in Ghana to support the sector, and the specific opportunities and challenges that hinder the growth and development of the sector.

## 2.1.The Growth, Significance, and Technological Advancements of Solar Power

Renewable energy, encompassing sources like sunlight, wind, rain, tides, and geothermal heat, represents the foundation of the global transition towards sustainable energy systems. Among these sources, solar power, derived from the sun's rays, is particularly notable for its potential to significantly contribute to meeting the world's energy demand (Kannan & Vakeesan, 2016). Its importance extends beyond energy production, playing a pivotal role in mitigating climate change by reducing emissions that harm the global environment (Jacobson et al., 2011).

Beyond environmental benefits, solar energy is increasingly recognised for its contribution to enhancing energy security. Its decentralised nature offers a reliable alternative to conventional energy sources, reducing dependence on imported fuels and bolstering national energy sovereignty (Hiremath et al., 2009). This aspect underscores the strategic value of solar power in diversifying energy portfolios and ensuring a stable energy supply.

Solar power has transitioned from a niche technology to a dominant force in the renewable energy sector. This transformation is marked by a significant increase in solar PV systems, which accounted for approximately 75% of the global renewable energy capacity expansion in 2023 (IEA, 2024). The drive behind this exponential growth is attributed to ongoing technological advancements and a dramatic reduction in the cost of photovoltaic (PV) systems, making solar energy more accessible and cost-effective (Apeh et al., 2022; Vartiainen et al., 2020).

The decline in prices for solar PV modules—by over 90%—and the overall cost reduction of systems—by nearly 80% in real terms over the past decade—illustrate the significant economic strides made in solar technology (Vartiainen et al., 2020). These trends are expected to persist, aligning with efforts to achieve global climate goals. Concurrently, solar panel efficiency has seen remarkable improvements, with multijunction III-V concentrator cells achieving conversion efficiencies above 40%, a testament to the progress in enhancing solar cell efficiency (King et al., 2011). These developments not only underscore solar power's potential as a mainstream energy source but also highlight the role of continued research and development in advancing solar technology towards greater efficiency and sustainability.

## 2.2.Issues Around the Solar Energy Transition and the Way Forward

### a. The Intermittency of Solar Power

The transition to solar energy, while promising, encounters several significant barriers. One such barrier with solar power is its intermittent nature. (Rowe et al., 2016). Unlike traditional energy sources that can provide constant power, solar energy production is directly dependent on sunlight, varying with the time of day, weather conditions, and seasons. This variability can lead to mismatches between energy supply and demand, necessitating robust solutions to ensure reliability and stability in the energy system (Shivashankar et al., 2016).

To address this intermittency issue, developing and implementing efficient energy storage solutions are critical. Technologies like batteries enable the storage of surplus energy generated during peak sunlight periods. This stored energy can then be used during times when solar output is reduced, helping to maintain a consistent energy supply (Dimitriev et al., 2020; Hasan et al., 2023). One such battery storage system that has gained ground is the lithium-ion battery. Khan et al. (2023) share that lithium-ion batteries have emerged as a focal point because of their superior energy density. The batteries work by converting surplus solar energy into chemical energy for storage and later converting it back to electrical energy as required (Chen et al., 2020). Research conducted by Vieira et al. (2017) demonstrated that integrating lithium-ion batteries with solar PV systems can enhance the self-use of solar power from 30% to 60%, thereby decreasing dependence on electricity from the grid. However, inasmuch as using battery storage systems alongside solar PV systems helps to mitigate intermittency issues and enhance the self-consumption of solar energy, the high costs and technological limitations of current storage solutions remain barriers to widespread adoption (Olabi et al. 2021). Advances in battery technology, including reductions in cost and improvements in capacity and durability, are therefore essential for making solar energy a more viable and reliable energy source.

### b. The Issue of Integrating Solar Systems into Existing Power Grids

Another major hurdle in the transition to solar energy is incorporating solar systems into current power grids. This challenge arises primarily from the fundamental differences in how traditional power grids and solar energy systems operate (Oyekale et al., 2020). Traditional power grids are built around the concept of centralised energy production, and rely on a relatively small number of large power plants which can be precisely controlled to match energy production with demand. The power output from these conventional plants is stable and predictable, allowing for straightforward planning and management of electricity flow across the grid (Kubik et al, 2012). Solar power, on the other hand, is inherently decentralised. It is usually generated by a vast number of small-scale installations spread across a wide area, such as residential rooftops, commercial buildings, and dedicated solar farms. This decentralisation challenges the centralised model of traditional power grids. Again, solar energy production is variable and less predictable than traditional energy sources (Basit et al., 2020). It depends on factors like the time of day, weather conditions, and seasonal changes. This variability can lead to fluctuations in electricity supply, making it harder to maintain a stable and reliable power grid together with the traditional grid.

Integrating solar energy into existing power grids requires upgrades to grid infrastructure to handle the variable energy inputs and to ensure that electricity distribution remains stable and efficient. This involves developing smart grids that employ digital technology to oversee and control the energy flow from various sources, thereby increasing the system's flexibility and resilience (Ahmas & Zhang, 2021). The digital technologies here normally simply involve installing meters that are smart, fixing sensors, and putting up automated control systems to manage the flow of energy in real time.

### c. Outdated Policy and Regulatory Systems

Policy and regulatory frameworks also play a crucial role in the solar energy transition. They can either significantly accelerate the adoption of solar technology or, conversely, become a substantial impediment to its progress. In many regions, outdated policies and regulatory barriers hinder the growth of solar energy (Agyapong, 2022; Wyllie et al., 2018). Specifically, in Ghana, Asante et al. (2020) find regulatory barriers and issues related to political will to be the most significant among six factors impeding the development of renewable energy. Even though Ghana has introduced legislative instruments and policies aimed at promoting renewable energy, such as the Renewable Energy Act, 2011 (Act 832) and the Ghana

Renewable Energy Master Plan (2019), these measures have fallen short of expectations. Several authors, including Sakah et al. (2017) and Obeng-Darko (2019), highlight the sector's challenges. For example, Sakah et al. (2017) criticise the policies in Ghana for focusing heavily on on-grid solutions and neglecting off-grid solutions, despite some communities in Ghana lacking electricity access. Furthermore, while recognising the benefits of government incentives like the Feed-In Tariffs, Sakah et al. (2017) suggest that market-driven incentives, such as tradable Renewable Energy Certificates (RECs), could offer better outcomes. This is because reliance on government incentives can pose sustainability and efficiency challenges.

An effective blend of policies, including both government-dependent incentives like feed-in tariffs and tax incentives, as well as market-driven approaches like auctions and tradable RECs, is seen as vital for fostering the development and investment in solar energy in Ghana. This perspective is supported by the findings of Timilsina et al. (2012), Sakah et al. (2017), Solangi et al. (2011), and Yaqoot et al. (2016), who highlight the importance of a diversified approach to incentives in encouraging renewable energy advancements in various jurisdictions.

### d. Economic Barriers

The initial cost of solar installations is a crucial factor that influences the adoption rate of solar energy technologies. Even though the literature review, earlier in this study, mentions that the prices of solar panels and related components have decreased significantly over the past decade due to technological advancements and increased manufacturing scale, the upfront cost of installing a solar energy system still remains a considerable barrier for many countries today. A significant portion of the cost of acquiring a solar system is attributed to capital expenditure which is seen as the initial required investment (Yao et al., 2021). This expenditure typically includes the cost of system equipment such as panels, inverters, mounting systems, and occasionally, batteries for storing excess energy. In addition to equipment costs, installing a solar system also involves expenses related to labour, site preparation, and potentially obtaining necessary permits and inspections. It is important to note that these costs vary widely based on the location, system size, and local regulations. Despite the variety of cost components, the purchase of system equipment and construction work accounts for a major part of the capital expenditure involved in setting up a solar system (Yao et al., 2021). Given the capital expenses incurred during the initial stages of system installation, particularly the substantial outlay required at the outset compared to the relatively low immediate costs of continuing with conventional energy sources, many businesses and residential consumers end up being daunted by the prospect of transitioning.

Access to affordable financing options, such as loans, leases, and power purchase agreements (PPAs) can significantly alleviate concerns regarding the high costs of solar systems and thus encourage adoption (Feldham & Bolinger, 2016; Keshavadasu, 2023; Tongsopit et al., 2016). These financial products can make solar energy more accessible by spreading the cost over time, making the initial financial barrier less daunting. However, in regions where such financial products are scarce or the terms are unfavourable, the barrier to adopting solar energy remains high. This lack of favourable financing options can deter potential users, maintaining the perception of solar systems as prohibitively expensive and hindering their widespread adoption. In Ghana, for example, Agyapong (2022) underscores that a key challenge in solar financing is the limited availability of funds, with not enough private sector players having readily accessible funds for investment. Similarly, Mahama et al. (2021) point out that, even where financing is available, it is often accompanied by high interest rates. This situation exacerbates the cost of financing, making it even more challenging for potential adopters to invest in solar energy solutions.

In explaining the reasons behind the high-interest rates on financing for solar energy projects in Ghana, Pueyo (2018) observes that local banks view these investments as riskier than traditional investments, though the specific factors contributing to this perceived risk are not explicitly detailed. This perception of risk mirrors the general apprehension people have towards new technologies, including green technologies like solar, as discussed by Yoshino et al. (2019). The novelty of a technology often brings with it uncertainties about its reliability and longevity. When a technology is in its budding stages, with limited information available about its performance, there is a higher risk of it failing, which could lead to significant financial losses for investors. Taghizadeh-Hesary & Yoshino (2020) emphasise that this fear of potential breakdowns and the consequent financial implications contribute to the cautious stance of financial institutions towards funding such projects, often resulting in higher interest rates to mitigate these perceived risks.

To overcome these economic hurdles pointed out above, financial mechanisms and incentives including but not limited to RECs that help lower the upfront costs and demonstrate the long-term savings of solar energy are essential (Heeter et al., 2021; Painuly & Wohlgemuth, 2021).

### e. Social Barriers

Social barriers play a crucial role in the adoption of solar technology. Factors entrenched within society, such as public awareness and acceptance, can facilitate or hinder the decision-making process. The way society perceives new technologies plays a crucial role in individuals' decisions to embrace them, a concept echoed by Ajzen's (2020) theory of planned behaviour, which examines the impact of attitudes and societal norms on decision-making. Public awareness and acceptance are key because perceptions and understandings directly affect people's readiness to adopt innovative technologies, including renewable energy systems (Lucas et al., 2021). Misinformation or misconceptions about the cost or efficiency of renewable systems can discourage potential users from considering solar energy options (Lucas et al., 2021).

In Ghana, the research titled "Decoding the Shift: Assessing Household Energy Transition and Unravelling the Reasons for Resistance or Adoption of Solar Photovoltaic" by Kyere et al., (2024) highlights these challenges. Conducting interviews with more than 20 households, including both users and non-users of PV systems, the research reveals that several key factors act as barriers to the adoption of solar PV. These include household values, attitudes, cost and others. Agyapong (2022) also in his study on the barriers to solar energy transition in Ghana underscores the challenge of low public awareness. Through interviews, he discovers that awareness among Ghanaians is significantly lacking, especially within residential sectors. Many Ghanaians perceive solar panels as a luxury only affordable to the wealthy. This poor perception also extends to households with sufficient income who could afford solar technologies but choose not to, believing these solutions cannot fully power their homes or deem them unnecessary since they expect the government to provide electricity. Drawing from the findings of Kyere et al. (2024) and Agyapong (2022), it becomes evident that the transition to solar photovoltaic systems in Ghana faces multifaceted challenges rooted not only in technical and economic factors but also in social and perceptual barriers. The essence of these insights points to a pressing need for targeted educational and awareness campaigns that clarify solar technology and its benefits.

To overcome these social barriers and make it essential for wider adoption of solar technology, efforts should aim to correct misconceptions about the affordability and efficiency of solar systems, emphasising the role of renewable energy in ensuring energy security and environmental sustainability (Kyere et al., 2024). Additionally, addressing the identified barriers requires a holistic approach that encompasses policy reforms, incentive structures, and the development of robust market mechanisms to make solar energy solutions more accessible and appealing to a broader segment of the Ghanaian population (Agyapong, 2022).

## 2.3.The Regulatory Environment Around Renewable Energy in Ghana

The current regulatory environment for renewable energy in Ghana showcases the country's commitment to sustainable development and its efforts to protect the environment. Like many nations, Ghana is navigating the transition towards greener energy sources to fight climate change and ensure energy security. To date, Ghana has taken bold steps by introducing a number of comprehensive frameworks. These include laws and policies designed to promote the adoption of renewable energy technologies. The following subsection outlines some of these initiatives.

### 2.3.1. The Renewable Energy Act (Act 832), 2011, and its Amendment Act (Act 1045), 2020

The foundation of Ghana's renewable energy legislation is the Renewable Energy Act of 2011 (Act 832). This Act 832 represents a significant headway towards creating a conducive environment for developing and using renewable energy resources in Ghana (Public Utilities Regulatory Commission Ghana, 2012). It encompasses support programmes like feed-in tariffs and among others, aimed at promoting the efficient and environmentally sustainable management, development, and use of renewable energy sources for heat and power. The Act 832 explicitly covers a variety of energy sources, including solar, wind, hydro, biomass, and biofuels.

Overall, the Act 832 contains 53 provisions structured into eight sections. These sections address initial provisions, define the roles of various institutions, outline licensing requirements, detail specific obligations related to licenses, establish and govern the Renewable Energy Fund, regulate biofuel and wood fuel, and cover other miscellaneous topics. Below is a little detail on some of the key sections in the Act 832 worthy of discussion in our study:

- Regulatory Licensing Regime: It sets up a framework for the licensing of renewable energy projects, ensuring that these projects meet specific standards and regulations to operate within Ghana.

- Obligation for Utilities and Bulk Customers: The Act 832 mandates that utilities and bulk consumers of electricity source a portion of their power from renewables. This requirement is designed to expand the demand for renewable power and integrate it into the national energy mix.
- Feed-in Tariff Scheme: A significant feature of the Act 832 is the establishment of a Feed-in Tariff (FIT) scheme. This scheme guarantees investors in the renewable energy sector a favourable rate of return. The FIT is particularly important for compensating for the high initial costs associated with renewable energy technologies and the comparatively higher cost per unit of electricity generated, particularly by PV systems.

The Act 832 assigns roles and responsibilities to various governmental bodies and institutions. The apex of the shared responsibilities sits with the country's Minister at the Ministry of Energy, with clear support works from state institutions like the Energy Commission and Public Utilities Regulatory Commission. The Minister is responsible for providing policy direction, while the Energy Commission is given a wide range of duties from advising on renewable energy matters to promoting local manufacturing and training in the renewable energy sector. The Public Utilities Regulatory Commission plays a critical role in setting financial parameters for renewable energy, such as rates and charges related to electricity from renewable sources and grid connections. Also, the Act 832 emphasises collaboration among a broad spectrum of institutions, highlighting the multi-faceted approach needed to effectively develop, promote, manage, and utilise renewable energy resources.

Building on the foundation laid by the Act 832 since its inception in 2011, Ghana has recognised the need to adapt to the rapidly evolving landscape of renewable energy technologies. Since the enactment of the Act, the price of renewable energy technologies, particularly solar PV systems, has fallen due to technological advancements, as highlighted in the earlier sections of this study's literature review. In some countries, including even the likes of Italy, electricity generated from PV systems has reached grid parity, becoming as affordable as or even cheaper than electricity generated from fossil fuels (Poponi et al., 2021). This global cost reduction and the changing dynamics of the renewable energy market made the original feed-in-tariff regime, a cornerstone of Ghana's Act 832, less effective and increasingly burdensome for consumers. Under the feed-in-tariff system, consumers were required to pay for solar PV power at rates that, due to technological advancements and cost reductions, have become higher than what could be achieved through competitive bidding (Parliament of Ghana, 2020). In response to these developments, the Ghanaian Parliament amended the Renewable

Energy Act in 2020 to introduce measures that align with the new realities of renewable energy production and consumption. So, currently, the amendment is designed to allow consumers to take advantage of lower electricity generation costs from renewable sources through a competitive procurement system, moving away from the earlier feed-in-tariff scheme (Parliament of Ghana, 2020).

The amended Act, called Act 1045, now includes provisions for competitive 'procurement' and 'net-metering' schemes for power produced from renewable sources (Public Utilities Regulatory Commission Ghana, 2021). It also grants the Energy Minister to appoint a body or unit to oversee certain tasks related to renewable energy and other green power projects (Public Utilities Regulatory Commission Ghana, 2021). The competitive procurement regime introduced by the amendment is expected to attract market-competitive rates for electricity from renewable sources, thereby preventing expensive power procurement agreements that have previously burdened the country. Another thing worthy of highlighting in the new Act 1045 is that, the amendment encourages distribution utilities to buy power from consumer-generators, thereby stimulating entities to produce their own electricity (Parliament of Ghana, 2020). It also further mandates entities contributing to greenhouse gas emissions, such as fossil fuel-based electricity suppliers and producers, to invest in renewable energy technologies beyond utility-scale projects (Parliament of Ghana, 2020).

### 2.3.2. Critical Evaluation and Future Directions for the Renewable Energy Acts

Following the amendment of the Renewable Energy Act in 2020 (Act 1045), it is imperative to reflect on the critiques and suggestions for further refining the legislation to better meet Ghana's energy security and sustainability goals. Some of these critiques worth noting come from a study by Mohammed and Ackah (2015) which highlights the original Act 832's limitations and areas for improvement, emphasising the lessons learned from global practices and the necessity for policy instruments that ensure a successful renewable energy regime.

In their study, Mohammed and Ackah (2015) draw parallels with South Africa's experience with Feed-in Tariffs (FIT), pointing out the dynamic nature of renewable energy technology costs and the implications for electricity pricing. They underscore the need for Ghana to adapt its policies to reflect the rapid technological advancements that have made renewable energy, particularly solar PV, more cost-effective. The authors argue that the initial FIT regime, while instrumental in promoting renewable energy investment, became a financial burden on consumers as the cost of solar PV power outpaced the rates set by the feed-in-tariff, making a case for the transition to competitive bidding as enacted in the 2020 amendment (Act 1045). Further in the study, the authors highlight some key factors that is believed to be crucial for a successful renewable energy policy framework, as outlined by a certain Karl Mallon, and this includes transparency, well-defined objectives, appropriate incentives, and energy market reform. The authors assess the Act 832 against these success factors, suggesting that while the Act makes strides towards a comprehensive renewable energy policy, there are areas for further enhancement to align with these critical success factors fully.

Another critical observation from a different study, conducted by Aboagye et al. (2021), also shares that Act 832 lacked an enduring strategy with a defined roadmap for promoting and developing renewables throughout the country. It is this absence of long-term planning that resulted in many renewable energy initiatives being implemented on a pilot or temporary basis, potentially limiting their impact and scalability (Aboagye et al., 2021).

In light of these critiques, the amendment Act 1045 represents a step forward in addressing some of the challenges identified. By shifting towards competitive procurement and net metering, the amendment aims to leverage market forces to reduce costs for consumers and encourage broader adoption of renewable energy.

### 2.3.3. The Renewable Energy Master Plan (REMP) 2019

The Renewable Energy Master Plan (REMP) of Ghana was introduced in 2019. It serves as a strategic blueprint designed to support the development and promotion of renewable energy resources within the country (Energy Commission Ghana, 2019). Its introduction was primarily motivated by the Ghanaian Government's commitment to augmenting the renewable energy sector's contribution to the nation’s electricity mix to 10% by 2030, as stipulated in the country’s Renewable Energy Act (882) of 2011. This 10% target might seem little especially when compared to regions like Northern Europe which are nearly 100% renewable energy. But it is essential to understand that this target reflects a realistic approach given Ghana's significant challenges in financing and infrastructure.

As reiterated by some authors, Aboagye et al. (2021), in the critical evaluation of Ghana’s Renewable Energy Act 832 in the preceding section up till this point, it was noted that despite the ambitious goals set by the Act 832, there was a notable absence of an integrated, comprehensive plan and dedicated financial mechanisms to ensure the sustainable growth of the renewable energy sector in the country. Many initiatives, as a result, were initiated on a provisional or short-term basis, lacking the continuity and scope required for substantial impact. The REMP therefore emerged as a critical response to these challenges, aiming to provide a robust framework for investment in renewable energy. By setting specific targets (as shown in Table 1) and outlining a clear path for attracting investments, the REMP seeks to advance and support renewable energy technologies, fostering economic development and environmental sustainability (Energy Commission Ghana, 2019). Its implementation schedule spans from 2019 and it is expected to end in 2030 (Energy Commission Ghana, 2019).

The Renewable Energy Master Plan outlines several strategic approaches to ensure its successful execution, focusing on stimulating the local renewable energy (RE) sector. Key strategies include advocating for tax exemptions on components and materials used in assembling renewable energy systems (Energy Commission Ghana, 2019). It proposes significant incentives for companies engaged in the manufacturing and assembly of renewable energy technologies, such as considerable tax reductions and the removal of import duties and taxes on raw materials and components. The plan also emphasises reducing dependence on imported renewable energy technologies by supporting local manufacturing and assembly efforts (Energy Commission Ghana, 2019). This support is envisioned through various incentives like tax breaks, capital subsidies, and loan guarantees. Further to these exemptions, the import of plants and their parts for electricity generation from renewable resources is also proposed to be exempt from import duty and VAT, aiming to encourage the adoption and development of renewable energy within the country (Energy Commission Ghana, 2019).

**Table 1: Targets for solar technologies from the REMP 2019 policy document**

| Technology/Intervention | Unit | Reference (2015) | 2020 | 2025 | 2030 | Progress (2022) |
|---|---|---:|---:|---:|---:|---|
| 1. Utility-scale | MW | 22.5 | 152.5 | 347.5 | 447.5 | 109.7** |
| 2. Distributed PV | MW | 2 | 20 | 100 | 200 | |
| 3. Stand-alone PV | MW | 2 | 10 | 15 | 20 | |
| 4. Street/Community lighting | MW | 3 | 7 | 11 | 25 | N/A |
| 5. Solar Traffic signals | %* | 14 | 25 | 40 | 60 | N/A |
| 6. Lanterns | Units | 72,000 | 200,000 | 500,000 | 1,000,000 | N/A |
| 7. Irrigation | ha | 150 | 6150 | 26,150 | 46,150 | N/A |
| 8. Crop Dryers | Units | 70 | 150 | 400 | 700 | N/A |
| 9. Water Heaters | Units | 4700 | 20,000 | 70,000 | 135,000 | N/A |

Source: (Energy Commission Ghana, 2019; IRENA, 2024)

**Percentage of total installed traffic signals. Targets are cumulative.*

*** 109.7 MWp is the total for all first three (3) technologies (Utility-scale, Distributed PV, and Standalone PV) and this is taken from IRENA's database.*

# CHAPTER THREE

# LITERATURE REVIEW [II]

## 3.0.Introduction

This chapter extends the review of literature to cover other areas such as the concept of Renewable Energy Certificates (RECs) and what role they play in making solar projects work better financially, project finance, and the theoretical framework employed in the study. At the end of the chapter, the study points out the gap which forms the foundation for this research, preparing the ground for the investigation ahead and the findings in the subsequent chapters.

## 3.1.The Concept of Renewable Energy Certificates (RECs)

The concept of Renewable Energy Certificates (RECs) emerged as an innovative solution to a complex problem: how to incentivise renewable energy production and use, even when the green power isn't consumed directly by the purchaser. They are more like instruments or documents used in the market for renewable electricity. They keep track of renewable electricity and its qualities, regardless of whether it is generated on-site at an organisation's facility or bought from another source (U.S. Environmental Protection Agency, 2018). At its core, a REC represents a unit of electricity generated and delivered to the grid from a renewable energy source, such as wind or solar power (Hardison et al., 2020). The idea of the REC mechanism is to allow the environmental or green attributes of renewable electricity to be commodified and traded (U.S. Environmental Protection Agency, 2018).

The journey of RECs began in the late 1990s, primarily in the United States, as part of efforts to deregulate and increase competition in the electricity market (Wiser et al., 2008). The goal was to provide a flexible way for businesses and individuals to support renewable energy development, regardless of their geographical location or the capacity to directly source renewable energy. It offered a transparent method for claiming renewable energy use, thus encouraging the growth of the renewable sector by providing an additional revenue stream to renewable energy producers (Wiser et al., 2008).

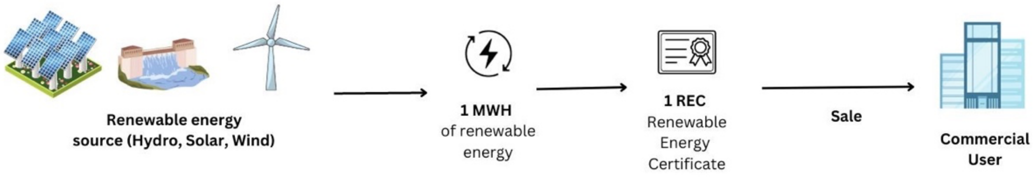
RECs play a crucial role in tracking renewable energy generation and ensuring that the claims of renewable energy use are accurately accounted for and not double-counted (Holt et al., 2011). When a renewable energy facility generates electricity, it produces both physical electricity and RECs. While the electricity can be fed into the grid and mixed with electricity from other sources, the RECs can be sold or traded separately. This separation allows RECs to be purchased by individuals or organisations wishing to support renewable energy beyond what their local utility might offer (Holt et al., 2011).

The creation of RECs introduced a market-driven approach to accelerating renewable energy adoption. By turning the environmental benefits of green power into a tradable commodity, RECs provide a way to finance and expand renewable energy projects, contribute to reducing greenhouse gas emissions, and enable purchasers to meet sustainability goals, even if their local grid mix is predominantly fossil-based (Holt et al., 2011).

## 3.2.The Mechanism of RECs

RECs function through a simple but effective system that encourages the production and consumption of renewable energy. This system encompasses several processes, including the creation, trading, and eventual use of RECs, all aimed at supporting a more sustainable energy landscape. An illustration of how the REC value chain works is shown in Figure 1.

**Figure 1: A basic pictorial display of the value chain of RECs**



**Source: (Redex, n.d.)**

### a. Creation and Certification

The process begins when a renewable energy facility generates electricity. For each unit of renewable electricity produced, an equivalent REC is created (Ferdous et al., 2023). These certificates are then certified by a regulatory body or a trusted third party to ensure their authenticity and prevent double counting (Ferdous et al., 2023). Once verified, a REC is issued. It's crucial to understand that managing the issuance and the subsequent activities, including the trading of the REC and its acquisition by an end buyer, involves a comprehensive system to track these transactions. According to Ferdous et al. (2023), these tracking systems maintain transparency and integrity within the REC market, offering a trustworthy record of each certificate's creation, sale, and final use or cancellation.

### b. Trading and Use

The REC market comprises various stakeholders, including renewable energy producers, utilities, businesses, and individual consumers. Producers sell RECs to earn additional revenue, while buyers purchase RECs to meet regulatory obligations or voluntary sustainability goals (Hardison et al., 2020; Senturk & Ozcan, 2023). RECs can be traded in open markets or through bilateral contracts (Hardison et al., 2020). The price of RECs is determined by supply and demand dynamics, influenced by factors such as renewable energy targets, the availability of renewable resources, and market participant objectives (Liu et al., 2024).

### c. Retirement and Claims

Once a REC is used to assert the environmental benefits of the renewable electricity it signifies, it is removed from circulation, as noted by Cali et al. (2022). This process guarantees that the environmental advantages associated with a certain quantity of renewable energy are acknowledged only once. Organisations that purchase RECs can then claim their support for the generation of renewable energy. This aspect is particularly significant for entities aiming to diminish their carbon emissions, report reduced greenhouse gas emissions, or achieve sustainability objectives. However, it's important to note that the actual electricity consumed by the buyer of a REC may still originate from non-renewable sources, as highlighted by Hardison et al. (2020).

## 3.3.Global Implementation and Variations of RECs

The concept of Renewable Energy Certificates (RECs) is recognised and implemented worldwide, though the specifics of its adoption and the regulatory frameworks governing it differ markedly from one country or region to another. These variations mirror the distinct energy policies, market conditions, and renewable energy targets characteristic of each locale. Moreover, the terminology used to describe RECs also changes across different geographies. In North America, the term "Renewable Energy Certificates" (RECs) is used, likely reflecting its origins in that region (U.S. Environmental Protection Agency, n.d.). In contrast, Europe refers to them as Guarantees of Origin (GOs), as noted by the Association of Issuing Bodies (n.d.). New Zealand adopts the term “New Zealand Energy Certificate System (NZECS)”, according to Brave Trace (n.d.), while Japan uses J-Credits, as per the J-Credit Registry (n.d.). In Asia and Central America, they are known as Tradable Instruments for Global Renewables (TIGRs), according to APX (n.d.), and I-RECs serve as the designation in many countries across various regions (The International Renewable Energy Certificate Standard Foundation, n.d.).

Regarding the adoption specifics and regulatory frameworks of RECs, there is some variation in governance. In the United States, RECs are crucial for state-level Renewable Portfolio Standards (RPS), mandating utilities to procure a certain proportion of their electricity from renewable sources, as described by Wiser et al. (2008). Conversely, in Europe, the Guarantees of Origin (GOs) system is governed by the EU's Renewable Energy Directive, as outlined by the European Commission (n.d.), which aims to enable cross-border trade and support the EU’s renewable energy objectives.

Globally, the REC market is segmented into voluntary and compliance sectors. Entities in the voluntary market purchase RECs to fulfil corporate sustainability goals, whereas in the compliance market, entities are compelled by regulatory mandates to acquire RECs, as outlined by Hardison et al. (2020) and Senturk & Ozcan (2023). Market dynamics are subject to a range of influences, including local policy frameworks, the availability of renewable resources, and buyer demand (European Commission, n.d.; Liu et al., 2024; Wiser et al., 2008). Due to the influences of policy frameworks and the degree of market saturation, the value of RECs is prone to significant shifts in different areas and over periods of time. Such variability creates a range of opportunities and challenges for those participating in the market.

### 3.4.The Role of RECs in Promoting Renewable Energy

RECs play a pivotal role in fostering the growth of the renewable energy sector. For energy producers, RECs are not merely a symbol of energy generated, they represent a tangible asset that can be sold or traded (Holt et al., 2011). This creates an additional revenue stream, over and above the sale of the generated power. The financial gains from selling RECs can significantly lower the cost barrier for new renewable energy projects, making them more economically competitive with traditional fossil fuel sources (Holt et al., 2011).

On the consumer side, when companies and individuals purchase RECs, they directly support the production of renewable energy. This market demand for RECs incentivises the development of more renewable energy facilities.

By linking financial incentives to the production and consumption of renewable energy, RECs effectively create a market-driven approach to promoting clean energy. This market encourages the expansion of renewable energy capacity, helps reduce harmful gas releases, and accelerates the transition to a more green and eco-friendly energy landscape.

### 3.5.Challenges and Criticisms of RECs

While RECs play a significant role in promoting renewable energy, they are not without their challenges and criticisms. One of the key challenges with RECs is ensuring accurate tracking and verification to prevent double counting or fraud. While tracking systems exist, the diversity of these systems across different regions can complicate cross-border trades of RECs and the overall transparency of the market (Zuo, 2022). A single unit of renewable energy could be accounted for more than once, for instance, if it's claimed by two different parties in the energy market, thus inflating the actual impact of renewable energy production. Though tracking systems have been established to curb this issue, the complexity arises from the fact that different regions (eg. North America and Asia) use distinct tracking systems, and these systems might not always be compatible or able to communicate with one another effectively.

Another challenge with RECs has to do with the market and regulatory environment. The REC market, like any other market, faces the challenge of price volatility and inconsistent policies (Coulon et al., 2015). Several studies have looked into this and explain that the prices of RECs fluctuate due to a variety of factors including imbalances in the production and supply of renewable energy at a given time (Baamonde-Seoane & Vázquez, 2023; Coulon et al., 2015; Hustveit et al., 2017). When the production of renewable energy increases rapidly, it can lead to an oversupply of RECs, driving prices down. Conversely, if demand surges or production falls due to policy changes or natural fluctuations, REC prices can spike. This uncertainty can be problematic for renewable energy developers who rely on the sale of RECs as part of their financial planning. The unpredictability of revenue streams makes it difficult to secure financing and plan for the future, potentially stifling the growth of renewable energy projects.

### 3.6.Financial Modelling in Project Finance

Project Finance focuses on funding projects independently, with a clear emphasis on the allocation of risks and the distribution of benefits (Finnerty, 2013). Implementing this normally involves using a tool called the financial model. At its core, financial modelling involves creating a comprehensive representation of a project's financial performance, including expected revenues, costs, and profitability over time (Benninga, 2014). Today, in the implementation of projects, including renewable energy projects, this tool has become very essential for stakeholders, and various authors provide several reasons for this.

Primarily, financial modelling aids in project planning by providing a detailed forecast of a project's financial health (Benninga, 2014; Bodmer, 2014). Financial health here refers to the overall condition of a project’s finances, indicating the returns that a project can potentially reap and the risk conditions under which those returns can be achieved. In the case of solar projects, developers and investors can, using a financial model, assess the economic viability of a project before committing substantial resources. Benninga (2014) highlights that by estimating financial returns and identifying potential financial risks, stakeholders can make informed decisions that align with their investment criteria and risk tolerance.

Again, financial models play a critical role in the investment decision-making process by providing a quantitative basis for comparing different projects or investment opportunities (Benninga, 2014; Bodmer, 2014). Investors typically evaluate key financial metrics to determine the attractiveness of an investment. These include the Return on Investment (ROI), which measures expected financial returns; the Payback Period, which indicates the time needed to recoup the initial investment; and the Internal Rate of Return (IRR), which assesses the profitability of the investment (Benninga, 2014). So in the case of solar projects, using financial models enables developers and investors to calculate these metrics, allowing them to quantitatively compare their project or investment opportunity against others to determine its viability.

## 3.7.Key Components of a Project Financial Model

A project financial model typically includes several key components that collectively influence the project's financial outcomes. Below is a highlight of these components:

### a. Capital Costs

These are the upfront expenditures required to develop and construct a project (Benninga, 2014; Bodmer, 2014). The industry normally uses the abbreviation “CAPEX”. In a solar project, these capital costs can include the cost of solar panels, inverters, mounting systems, and installation. Bodmer (2014) mentions that capital costs always represent a significant portion of total project expenses and are critical for determining the initial investment required.

### b. Operating Expenses

These are the expenses required to manage the operation of a project once it is up and running (Benninga, 2014; Bodmer, 2014). It is commonly referred to as “OPEX” during industry engagements. In the context of solar project implementation, when a solar asset is finally mounted and begins operating and delivering power, it incurs ongoing expenses such as maintenance, repairs, insurance, and administrative costs. It is these kinds of expenses that are categorised under OPEX.

### c. Revenue Streams

Typical project revenue refers to the total amount of money generated from its investments (Bodmer, 2014). In a solar project, the primary source of revenue comes from the sale of electricity. Additionally, as highlighted by several authors earlier in this literature review, Renewable Energy Certificates (RECs) can also provide an alternative revenue stream, offering financial returns for the environmental attributes of the generated renewable energy.

### d. Financing Structures

Financing structure here refers to the financing arrangements for the project, and this can include either one or a mix of equity, debt, and grants (Bodmer, 2014). It is important to note that the cost of using any of these financing options must be assessed thoroughly before deciding because of the varying cost implications and repayment schedules (Bodmer, 2014; Finnerty, 2013).

## 3.8. Traditional Metrics from Project Finance Modelling (NPV, IRR, Payback Period)

The traditional metrics from project finance modelling are Net Present Value (NPV), Internal Rate of Return (IRR), and payback period (Delapedra-Silva et al., 2022). These are fundamental tools used to assess the financial viability of projects, including investments in sectors like solar PV. Unlike other approaches to assessing the viability of solar projects which include the real options approach and the levelized cost of electricity approach, these traditional metrics offer a straightforward way to assess the financial performance and risk of projects (Delapedra-Silva et al., 2022). They are widely used due to their simplicity and effectiveness in providing quick, valuable insights into the potential profitability and financial health of investments (Delapedra-Silva et al., 2022). A brief explanation of each can be found in the appendices section of this study.

### 3.9.Theoretical Framework for the Study: Real Options Theory

Real Options is a financial modelling framework that evaluates investment opportunities under uncertainty. It offers a way to assess the value of managerial flexibility in strategic decision-making (Schoenmaker & Schramade, 2023). Derived from financial options theory, Real Options captures the value of strategic actions such as waiting, expanding, scaling down, or abandoning projects in reaction to market shifts, technological progress, or changes in policy amidst uncertainties (Li & Rugman, 2007; Trigeorgis et al., 2017). This approach is particularly relevant in the renewable energy sector where projects face numerous uncertainties and dynamic external factors.

Koller et al. (2020), as discussed by Schoenmaker & Schramade (2023), describe different strategic decisions, termed real options, that businesses can capitalise on to navigate uncertain environments effectively:

- **Defer Option:** This is an option that allows a business to wait before making a decision, like launching a new product when the time seems right.
- **Abandonment Option:** This is an option that gives a company the choice to stop doing something, like closing a part of or full operations to avoid bigger losses.
- **Expand or Contract Option:** This strategy offers the ability to adjust project scale in response to changing conditions, like altering production levels based on market demand.

While most studies that employ the Real Options framework incorporate quantitative modelling as part of their methodology to elaborate on strategic options available, this study chooses not to engage in quantitative modelling. Instead, it goes the qualitative route and focuses on situating the 1MW project's analysis within the Real Options framework to enhance understanding. This approach opens avenues for future research in Ghana to build upon, possibly adopting Real Options as a primary methodological lens. This study concentrates exclusively on modelling the financial metrics of the project, offering a foundation for further exploration in this domain.

### 3.10. A Review of Previous Empirical Studies on Solar PV Investments and RECs

The practicality and strategic deployment of solar PV have become a hot topic worldwide, as more people look into using renewable energy to fulfil their energy needs in a clean way. This part of the literature review synthesises findings from empirical studies focusing on financial modelling and the potential impact of Renewable Energy Certificates (RECs) on solar PV projects, with an emphasis on identifying gaps and opportunities for further research.

Studies such as Bustos et al. (2016) and Asumadu-Sarkodie and Owusu (2016) underscore the importance of financial metrics like Net Present Value (NPV) and Internal Rate of Return (IRR) in assessing the financial feasibility of solar PV projects. These studies highlight the critical challenge of high initial costs and the potential for policy mechanisms, such as RECs, to enhance project attractiveness. However, they also reveal a significant gap: the lack of comprehensive analysis of the influence of RECs on the economic viability of solar projects, particularly in emerging markets like Ghana.

Further, research by Assereto and Byrne (2021) and Zhang et al. (2023) delves into the strategic valuation of solar investments under policy-driven financial mechanisms in developed markets. These studies employ the Real Options approach to account for investment uncertainties, emphasising the strategic advantage of deferring investments in mature solar markets. However, their focus on developed countries points to a gap in understanding how similar policy supports, specifically RECs, could impact solar PV investments in emerging economies.

The works of Datta et al. (2020), Umar et al. (2021), and Ramírez-Sagner et al. (2017) contribute valuable insights into the direct economic benefits and sensitivity analyses of solar PV systems, employing tools like RETScreen for comprehensive financial simulations. While these studies provide a foundational understanding of solar PV system viability across various climatic conditions, they fall short in exploring the dynamic impacts of instruments like RECs on enhancing the economic appeal of solar PV investments.

Agyekum (2021) and Peprah et al. (2023) extend the discussion by evaluating the economic viability and prosumption benefits of solar PV systems in Ghana. Their findings affirm the financial attractiveness of solar PV investments and the potential of specific prosumer configurations. However, an analysis of the broader influence of mechanisms such as RECs remains absent, marking a crucial area for further investigation.

All the studies reviewed so far up till this point collectively demonstrate the economic potential of solar PV projects across diverse geographic and regulatory landscapes. However, a clear gap persists in the examination of mechanism supports—particularly RECs—and their capacity to further augment the financial viability of solar PV investments in emerging markets like Ghana. This gap suggests a crucial area of contribution, which this current research aims to explicitly fill, that is, to model the impacts of RECs on solar PV project investments in

Ghana. By incorporating RECs into financial analyses, this study attempts to provide an understanding of how financial support mechanisms can enhance the attractiveness and feasibility of renewable energy projects, thereby contributing valuable insights into effective policy design and renewable energy financing strategies.

Moreover, the incorporation of traditional financial metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and payback period, alongside the Real Options Analysis framework, presents a more robust method for evaluating the economic viability of solar PV projects. This dual approach not only highlights the immediate financial attractiveness of solar PV investments, as evidenced by straightforward financial evaluations but also introduces a strategic dimension that accounts for the flexibility and array of decision-making options available to investors amidst market and policy uncertainties. Such an integrated analytical perspective is essential for acknowledging the dynamic nature of the renewable energy sector, where future electricity prices, technological advancements, and policy changes, particularly those related to Renewable Energy Certificates (RECs), can significantly influence project outcomes.

# CHAPTER FOUR

# METHODOLOGY

## 4.0.Introduction

This chapter outlines the methodological framework adopted to carry out the study. Emphasising a quantitative research strategy, it outlines the processes for data collection, the construction of a financial model, and the analytical techniques deployed to thoroughly investigate the study's posed research questions outlined in Chapter One.

## 4.1.Research Strategy

This study employs a quantitative research strategy mainly because of the nature of the research questions the study seeks to address. The choice of the quantitative research strategy is deemed suitable for several key reasons. First, this approach is precise in managing and analysing numbers (Bryman, 2012). Since adding RECs to solar PV projects requires detailed math and predictions, a method that can accurately work with variables like costs, earnings, and possible savings is crucial. This way, then it can be possible to closely examine financial measures such as Net Present Value (NPV), Internal Rate of Return (IRR), and payback periods. These are vital for figuring out if investing in solar projects makes sense financially. Second, this study involves looking ahead and predicting the impact of RECs on financial figures. The quantitative method is perfect here because it uses numbers to give us clear insights.

## 4.2.Data Collection

The data collected for this study is in two folds: primary and secondary. The primary data comes from the data used in modelling the energy generation yield for the project, and this is taken from SolarGis, a premier solar resource assessment tool renowned for its accuracy in solar yield predictions. The secondary data is compiled from a plethora of industry reports, scholarly articles, and policy documents pertinent to the Ghanaian solar energy domain. Noteworthy references include the International Renewable Energy Agency (IRENA) for CAPEX and OPEX, the International Energy Agency (IEA) for discount rate pricing, the D-REC Initiative for REC market pricing and trends, and a host of other data sources, all of which are elaborated in Table 2.

**Table 2: Inputs and Assumptions for the SolarGis System and Financial Model**

| Item | Units | Inputs | Sources |
|---|---|---|---|
| PV System Size | kWp | 1000 | |
| System Yield (Annual) | kWh/KWp | 1374.1 | SolarGis |
| Hours in a period | hours in month | 730 | |
| First year Degradation | %/ Annum | 2% | (Jinko Solar, n.d.) |
| Degradation post year 1 | %/ Annum | 0.55% | (Jinko Solar, n.d.) |
| Power Purchasing Agreement Tenor | years | 25 | |
| PV module type | | c-Si - crystalline silicon (mono or polycrystalline) | (Jinko Solar, n.d.) |
| Geometry of PV modules | | Azimuth: 180° • Tilt: 8° | Default values from the SolarGIS system |
| Inverter Type | | String inverter [98.4% Euro efficiency] | (Huawei Smart Photovoltaics, n.d.) |
| Solar Energy Tariff (USD) | $ | 0.11 | |
| Solar Energy Tariff Escalation Rate | % | 3.0% | (Public Utilities Regulatory Commission, 2020) |
| Conventional Tariff (Local Currency) | GHC | 1.58 | (Public Utilities Regulatory Commission, 2024) |
| Conventional Tariff (USD) | $ | 0.12 | |
| Conventional Tariff Escalation Rate | % | 3.0% | (Public Utilities Regulatory Commission, 2024) |
| CAPEX | $/kWp | 1257 | (International Renewable Energy Agency, 2023) |
| OPEX | $/kWp/Annum | 7.7 | (International Renewable Energy Agency, 2023) |
| Corporate Income Tax in Ghana | % | 25% | (Ghana Revenue Authority, n.d.) |
| Discount Rate | % | 9% | (Erdogan & Sarasota, 2023) |
| D-REC Pricing Range | $/MWh | 10 - 30 | (Powertrust, 2023, November 9) |
| Financing Structure | 100% | Equity | |

### 4.3.Energy Generation Modelling using SolarGis

After gathering all necessary inputs and making essential assumptions, the study commenced by simulating the energy yield needed for the project. As part of the simulation, the study used a simulation tool called SolarGis - a system renowned for its precision and reliability in the solar industry for over a decade (Cebecauer & Suri, 2015). Interface of the system is shown in

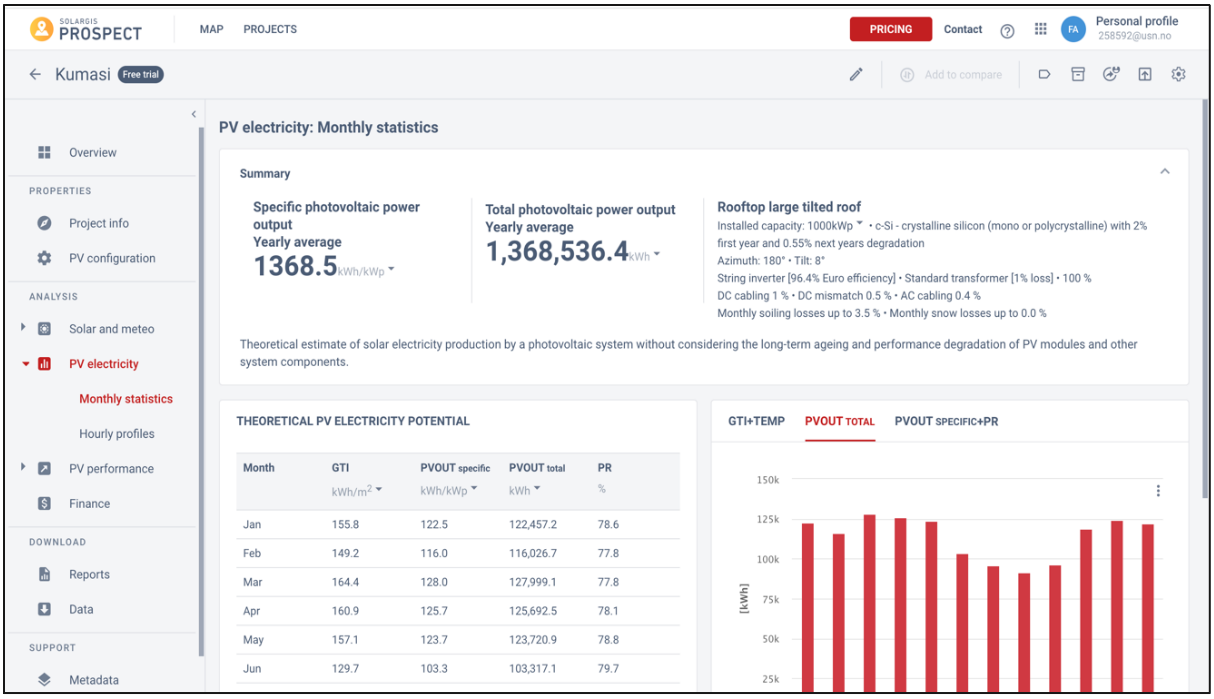
Figure 2. SolarGis offers comprehensive features to effectively simulate a solar project, including default values for certain data points where specific user data may not be available.

The simulation process began by specifying the geographic location of the study's project site, which is Kumasi Central Market. Kumasi, being Ghana's second-largest city after the capital, Accra, was chosen due to its industrial potential and the opportunity to diversify the country's renewable energy projects beyond the already somewhat saturated Accra. Upon selecting the location, SolarGis automatically generated the project site's coordinates. It then employed historical weather and solar irradiance data for Kumasi to predict the expected energy yield.

It's crucial to highlight that SolarGis accounts for several factors that influence energy production. These include the orientation and angle of solar panels, potential obstructions that might cause shading, and the specific climate conditions of the area. The system then simulated the solar irradiance that hits the panel surface and calculated the energy output, considering the efficiency of the solar panels and the system's overall performance ratio. This ratio reflects the potential energy losses due to various factors such as temperature variations, inverter efficiency, and other system-specific inefficiencies.

The final output from the simulation provided us with an estimated annual energy production in kilowatt-hours (kWh). This yield was crucial in the financial modelling of the project, allowing the study to project revenue from electricity sales.

**Figure 2: Interface of the SolarGis Energy Simulation System**



PV electricity: Monthly statistics

Summary

Specific photovoltaic power output
Yearly average
1368.5 kWh/kWp

Total photovoltaic power output
Yearly average
1,368,536.4 kWh

Rooftop large tilted roof
Installed capacity: 1000kWp • c-Si - crystalline silicon (mono or polycrystalline) with 2% first year and 0.55% next years degradation
Azimuth: 180° • Tilt: 8°
String inverter [96.4% Euro efficiency] • Standard transformer [1% loss] • 100 %
DC cabling 1 % • DC mismatch 0.5 % • AC cabling 0.4 %
Monthly soiling losses up to 3.5 % • Monthly snow losses up to 0.0 %

Theoretical estimate of solar electricity production by a photovoltaic system without considering the long-term ageing and performance degradation of PV modules and other system components.

THEORETICAL PV ELECTRICITY POTENTIAL

| Month | GTI kWh/m² | PVOUT specific kWh/kWp | PVOUT total kWh | PR % |
|---|---|---|---|---|
| Jan | 155.8 | 122.5 | 122,457.2 | 78.6 |
| Feb | 149.2 | 116.0 | 116,026.7 | 77.8 |
| Mar | 164.4 | 128.0 | 127,999.1 | 77.8 |
| Apr | 160.9 | 125.7 | 125,692.5 | 78.1 |
| May | 157.1 | 123.7 | 123,720.9 | 78.8 |
| Jun | 129.7 | 103.3 | 103,317.1 | 79.7 |

Source: (SolarGis, 2024)

### 4.4.Financial Modelling of the Project

After accurately estimating the project's energy yield using SolarGis, the study progressed to the crucial stage, which involves financial modelling. The modelling process is shown in Figure 3. This stage is key as it translates the physical energy production into financial outcomes, enabling a comprehensive analysis of the project's economic viability. To help do this, the study constructed a detailed financial model in Microsoft Excel, a choice motivated by several authors including Bodmer (2014) and Oluwa (2019) on Excel's widespread use, flexibility, and powerful analytical capabilities. Also, the author of this study currently works in the solar energy financing space and has been dealing with project financial modelling in the past using MS Excel, so that made it also easier to handle the project during the modelling process. Key components of the model include the CAPEX, OPEX, and other inputs and assumptions which are detailed in Table 2. It is important to note that while debt financing is a common method in funding renewable energy projects, this thesis assumes equity as the sole form of financing and does not consider any debt financing elements. This approach simplifies the financial analysis and focuses on assessing the viability of the project from an equity investor's perspective, consistent with the author's direct experience and expertise in solar project financing.

The CAPEX represents the initial investment required to launch the project. It includes costs associated with purchasing solar panels, inverters, and other necessary equipment, as well as installation expenses. The CAPEX was a fundamental input as it directly impacted the project's initial financial burden and subsequent profitability calculations.

The OPEX are the ongoing expenses necessary for the day-to-day operation and maintenance of the solar PV system. It covers items such as routine maintenance, insurance, and any other recurring costs that ensure the project's operational efficiency over its lifespan.

After assembling all the inputs, the study went ahead to model the revenue streams for the project primarily from solar electricity sales. Potential revenue generated from the sale of Renewable Energy Certificates (RECs) was also included in the revenue stream calculation highlighting the financial incentives provided by environmental credits.

What was done next was the modelling of the profit and loss account where the estimated total revenue from the annual earnings from electricity sales and RECs was used. The study subtracted the Operational Expenditures (OPEX) from the total revenue to assess operational profitability. The study then accounted for asset depreciation using the straight-line method, providing a realistic view of the project's value decrease over time. This gave the Profit Before Tax, from which the study applied a Corporate Income Tax rate of 25%, leading to the final figure, the Profit After Tax.

In the cash flow analysis for the project, the study began by considering the Equity invested as the initial financial input, alongside the Profit After Tax, which signified the project's earnings after all expenses and taxes were deducted. To these earnings, the study added back the Book Depreciation—a non-cash expense representing the reduction in the asset's value over time—to calculate the Total Cash Inflows. This adjustment provided a truer reflection of the project's available cash. Against this, the study identified the Capital Expenditures (CAPEX) as the Total Cash Outflows. By subtracting the outflows from the inflows, the study calculated the Net Cash Inflows, offering a clear view of the project's liquidity and its capacity to generate cash throughout its operational lifespan, crucial for evaluating the financial viability of the investment.

Following this analysis, the study then modelled key financial metrics: the Net Present Value (NPV), the Internal Rate of Return (IRR), and the Equity Turnaround representing the payback period. The NPV calculation reflected the present value of the project's future cash flows, discounting them back to their value today, to determine the project's profitability over its expected life. The IRR was calculated as the discount rate that made the NPV equal to zero, providing insight into the project's expected rate of return compared to alternative investments. Lastly, the Equity Turnaround time was assessed, representing the payback period, which indicated the time required for the project to recoup its initial investment through its net cash flows. These analyses were instrumental in offering a comprehensive financial overview of the project, showcasing its potential for profitability and financial sustainability over time.

Mathematical formulas for modelling the NPV and IRR both in theory and in MS Excel:

**NPV in theory** (Miller, 2022):

$$\text{NPV}= \quad -C_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \qquad (1)$$

Where:

- $CF_t$ = Net cash flow at time t
- r = Discount rate or required rate of return
- t = Time period
- n = The total number of time periods or project lifetime
- $C_0$ = Initial investment

Calculating **NPV in MS Excel** (Bodmer, 2014; Oluwa, 2019):

*“= NPV (rate, value1, value2, ...)”*

Where:

- Rate is the discount rate.
- Values represent the individual cash flows, comprising the initial investment and later cash flows in each year.

**IRR in theory** (Miller, 2022):

$$\text{IRR} \Rightarrow \quad 0 = -C_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \qquad (2)$$

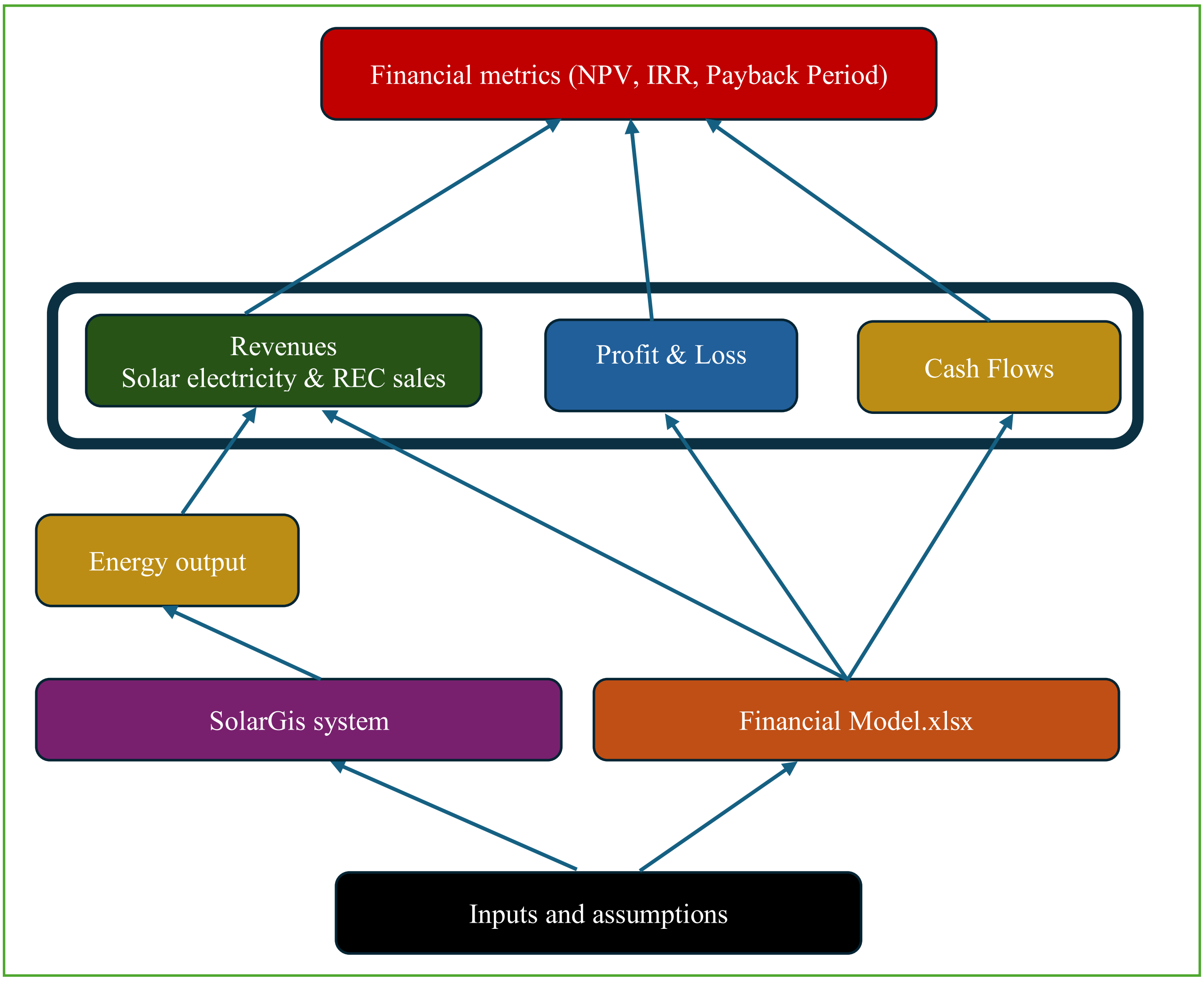
Calculating **IRR in MS Excel** (Bodmer, 2014; Oluwa, 2019):

*"= XIRR (values, dates)"*

Where:

- Values represent the Net Equity Cashflows
- Dates are the years covering the project's lifetime.

**Figure 3: A simplified overview of the methodological steps in modelling the energy yield and financials of the project.**



(Source: Own illustration)

## 4.5.Reliability and Validity

Reliability in this context refers to the consistency and stability of the measurement processes and analytical methods over time (Bryman, 2012). To enhance reliability, the study employed standardised quantitative methods for data collection and analysis. SolarGis, a reputable and widely used tool for predicting solar energy yield, provided consistent and precise data for modelling the energy generation capacity of the project. This tool's historical accuracy and broad acceptance in the solar industry underpin the reliability of the energy yield estimates.

For the financial modelling, Microsoft Excel was used due to its widespread use, flexibility, and powerful analytical capabilities, ensuring consistent application of financial formulas and calculations. The study's methodology, including the step-by-step process for calculating financial metrics such as NPV, IRR, and the payback period, has been clearly documented, allowing for replication and verification by other researchers, which further reinforces the study's reliability.

Validity concerns the accuracy and truthfulness of a study's findings (Bryman, 2012). To ensure validity, the study carefully selected its data sources and inputs. The assumptions made for financial modelling, such as cost estimates, revenue projections, and discount rates, were based on current market data and reputable industry reports. This approach ensures that the financial model accurately reflects real-world conditions and provides credible projections of the project's economic viability.

Also, the study's use of a sensitivity analysis to explore the effects of varying key parameters (e.g., REC prices, discount rates, and electricity tariffs) on the financial outcomes lends validity to the findings by demonstrating how changes in external factors could impact the project's profitability in the practical economic environment.

Besides, the financial model and the results of the energy generation data were also reviewed by an industry expert—a PhD holder currently working for a top renewable energy firm in Europe, under the recommendation of the supervisor of this thesis project. This expert, who possesses both academic knowledge and practical industry experience, conducted a thorough evaluation of the models and provided constructive feedback. This peer-review process not only enhanced the analytical thoroughness of the study but also confirmed its applicability and relevance to current industry practices.

# CHAPTER FIVE

# PRESENTATION OF FINDINGS

## 5.0.Introduction

This chapter presents the findings from the study. The findings are presented in accordance with the research questions that the study seeks to address. To get along with the findings more easily, the research questions for the study are re-emphasised in every subsection of this Chapter.

## 5.1.Research Question 1:

***What do the financial metrics for a 1 MWp rooftop solar PV project in Ghana under a third-party financed Power Purchase Agreement (PPA) model look like, excluding the impact of Renewable Energy Certificates (RECs)?***

### 5.1.1. Solar Energy Generation Data from SolarGis System

This section presents the results of the energy generation simulation performed using the SolarGis simulation system. The data highlights both the total power output in kilowatt-hours (kWh) and the performance ratio as a percentage, which measures the efficiency of the solar system relative to its theoretical maximum output under ideal conditions. The total power output and performance ratio for each year are detailed in Table 3 and Figure 4. The data shows a gradual decline in both total power output and performance ratio over the 25-year period. This trend is typical in solar power projects due to the natural degradation of solar panels over time. The performance ratio starts at 77.6% in the first year and decreases to 68.0% by the 25th year. This gradual decline reflects the ageing of the solar panels and associated efficiency losses. The total power output begins at approximately 1.35 million kWh in the first year and decreases to around 1.18 million kWh by the 25th year, underscoring the decrease in efficiency and the effect of panel degradation over time.

### 5.1.2. Revenue Modelling Data from the Financial Model

This section presents the results of the revenue modelling from the financial model using the average annual energy yield from the SolarGis simulation system. The model focuses on comparing the costs and savings from using solar energy versus conventional energy sources, incorporating changes in tariffs for both solar and conventional energy over time. As seen from Table 4 and Figure 5, the model provides detailed year-by-year data on total annual production in kilowatt-hours (kWh), solar energy tariffs, conventional energy tariffs, total conventional energy costs, total solar energy costs, annual savings for the potential off-taker, and cumulative annual savings.

Both solar and conventional energy tariffs increase over the 25-year period, with solar tariffs starting at USD 0.11 per kWh in Year 1 and rising to USD 0.2232 per kWh by Year 25. The conventional tariffs increase from USD 0.12 per kWh to USD 0.2432 per kWh in the same period. Each year, the total solar energy cost remains consistently lower than the conventional energy cost, leading to annual savings for the off-taker. Annual savings increase each year as the difference between the conventional and solar tariffs widens, starting at USD 13,267 in Year 1 and growing to USD 23,580 by Year 25. The cumulative savings show significant growth over the project's life, illustrating the long-term financial benefits of choosing solar energy. Starting at USD 13,267 in Year 1, the cumulative savings rise to USD 448,807 by Year 25.

**Table 3: Energy Generation Overview**

| Year | Total power output (kWh) | Performance ratio (%) |
|---|---|---|
| 1 | 1,346,650 | 77.6 |
| 2 | 1,339,243 | 77.2 |
| 3 | 1,331,877 | 76.8 |
| 4 | 1,324,552 | 76.4 |
| 5 | 1,317,267 | 76.0 |
| 6 | 1,310,022 | 75.5 |
| 7 | 1,302,817 | 75.1 |
| 8 | 1,295,651 | 74.7 |
| 9 | 1,288,525 | 74.3 |
| 10 | 1,281,438 | 73.9 |
| 11 | 1,274,390 | 73.5 |
| 12 | 1,267,381 | 73.1 |
| 13 | 1,260,411 | 72.7 |
| 14 | 1,253,478 | 72.3 |
| 15 | 1,246,584 | 71.9 |
| 16 | 1,239,728 | 71.5 |
| 17 | 1,232,910 | 71.1 |
| 18 | 1,226,129 | 70.7 |
| 19 | 1,219,385 | 70.3 |
| 20 | 1,212,678 | 69.9 |

|  |  |  |
|---|---|---|
| 21 | 1,206,009 | 69.5 |
| 22 | 1,199,376 | 69.2 |
| 23 | 1,192,779 | 68.8 |
| 24 | 1,186,219 | 68.4 |
| 25 | 1,179,694 | 68.0 |

**Figure 4: Bar chart of the Energy Generation Overview**

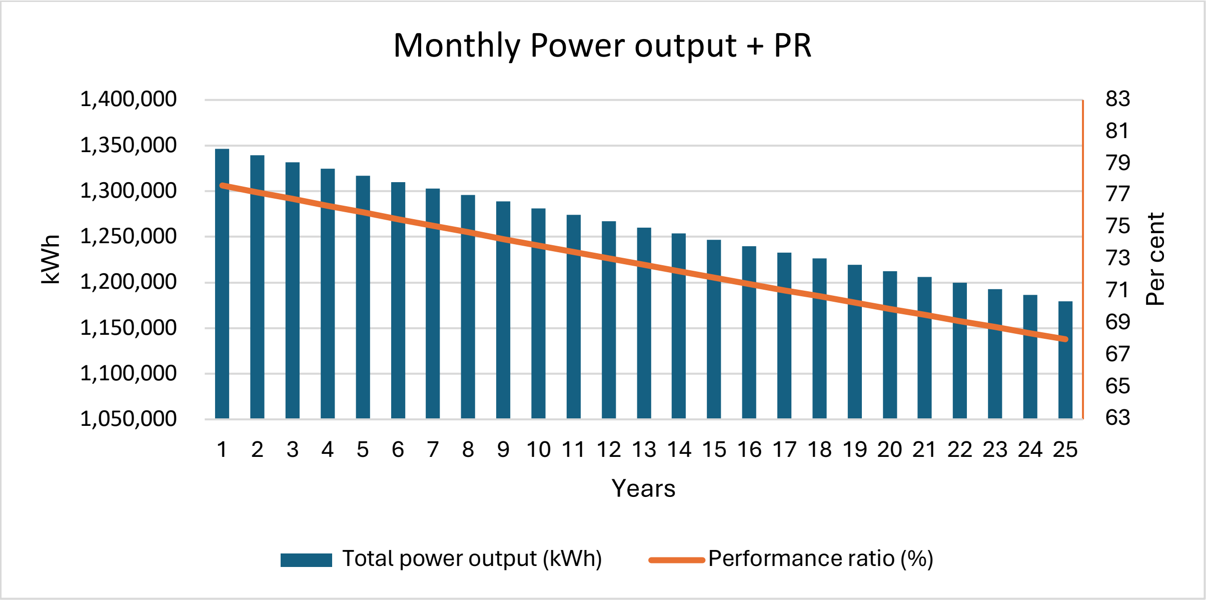
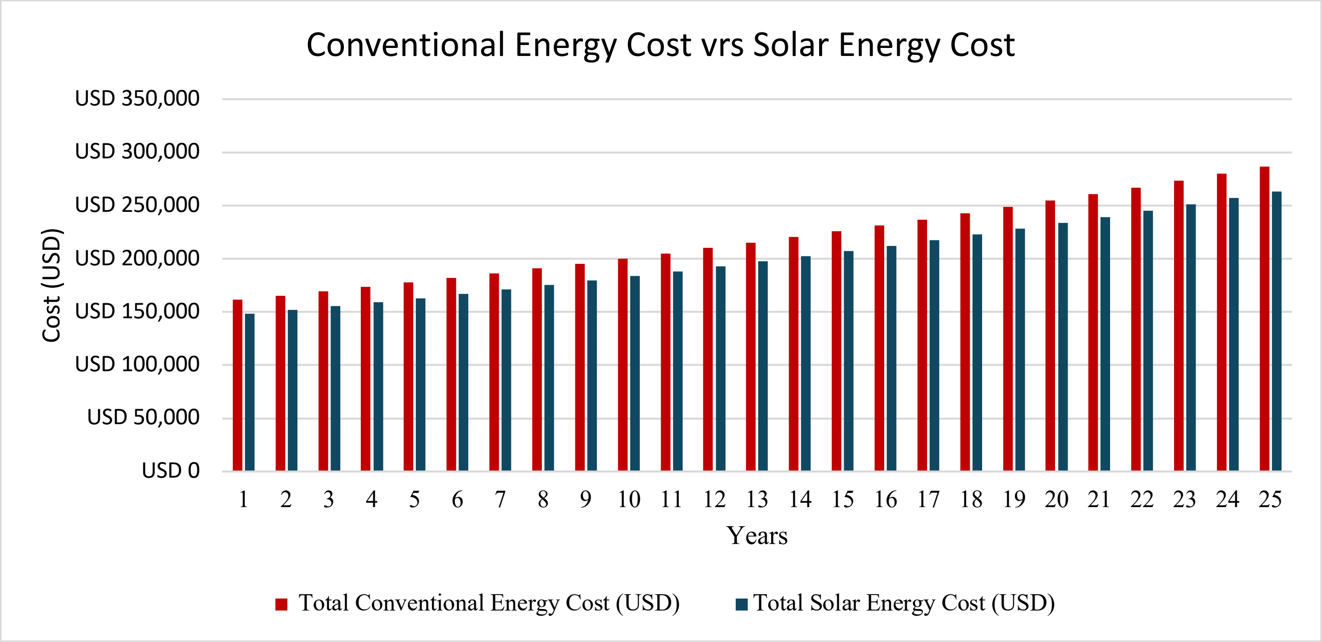


**Figure 5: Annual Energy Cost Between Conventional and Solar Energy**



### Table 4: Overview of the Revenue Model

| Year | Total Annual Production (kWh) | Solar Energy Tariff (USD) | Conventional Tariff (USD) | Total Conventional Energy Cost (USD) | Total Solar Energy Cost (USD) | Annual Savings for the Offtaker (USD) | Cummulative Annual Savings (USD) |
|---|---|---|---|---|---|---|---|
| Year 1 | 1,346,618 | USD 0.11 | USD 0.12 | USD 161,395 | USD 148,128 | USD 13,267 | USD 13,267 |
| Year 2 | 1,339,212 | USD 0.1133 | USD 0.1234 | USD 165,309 | USD 151,721 | USD 13,589 | USD 26,856 |
| Year 3 | 1,331,846 | USD 0.1167 | USD 0.1271 | USD 169,318 | USD 155,400 | USD 13,918 | USD 40,774 |
| Year 4 | 1,324,521 | USD 0.1202 | USD 0.1309 | USD 173,425 | USD 159,169 | USD 14,256 | USD 55,029 |
| Year 5 | 1,317,236 | USD 0.1238 | USD 0.1349 | USD 177,631 | USD 163,029 | USD 14,602 | USD 69,631 |
| Year 6 | 1,309,991 | USD 0.1275 | USD 0.1389 | USD 181,939 | USD 166,983 | USD 14,956 | USD 84,587 |
| Year 7 | 1,302,786 | USD 0.1313 | USD 0.1430 | USD 186,351 | USD 171,033 | USD 15,318 | USD 99,905 |
| Year 8 | 1,295,621 | USD 0.1352 | USD 0.1473 | USD 190,871 | USD 175,181 | USD 15,690 | USD 115,595 |
| Year 9 | 1,288,495 | USD 0.1393 | USD 0.1517 | USD 195,500 | USD 179,430 | USD 16,070 | USD 131,665 |
| Year 10 | 1,281,408 | USD 0.1434 | USD 0.1563 | USD 200,242 | USD 183,781 | USD 16,460 | USD 148,125 |
| Year 11 | 1,274,360 | USD 0.1477 | USD 0.1609 | USD 205,098 | USD 188,239 | USD 16,859 | USD 164,985 |
| Year 12 | 1,267,351 | USD 0.1521 | USD 0.1658 | USD 210,072 | USD 192,804 | USD 17,268 | USD 182,253 |
| Year 13 | 1,260,381 | USD 0.1567 | USD 0.1707 | USD 215,167 | USD 197,480 | USD 17,687 | USD 199,940 |
| Year 14 | 1,253,449 | USD 0.1614 | USD 0.1758 | USD 220,386 | USD 202,270 | USD 18,116 | USD 218,056 |
| Year 15 | 1,246,555 | USD 0.1662 | USD 0.1811 | USD 225,731 | USD 207,175 | USD 18,555 | USD 236,611 |
| Year 16 | 1,239,699 | USD 0.1712 | USD 0.1865 | USD 231,205 | USD 212,200 | USD 19,005 | USD 255,617 |
| Year 17 | 1,232,881 | USD 0.1763 | USD 0.1921 | USD 236,813 | USD 217,346 | USD 19,466 | USD 275,083 |
| Year 18 | 1,226,100 | USD 0.1816 | USD 0.1978 | USD 242,556 | USD 222,617 | USD 19,938 | USD 295,021 |
| Year 19 | 1,219,356 | USD 0.1870 | USD 0.2037 | USD 248,439 | USD 228,017 | USD 20,422 | USD 315,443 |
| Year 20 | 1,212,650 | USD 0.1926 | USD 0.2098 | USD 254,464 | USD 233,547 | USD 20,917 | USD 336,361 |
| Year 21 | 1,205,980 | USD 0.1984 | USD 0.2161 | USD 260,635 | USD 239,211 | USD 21,425 | USD 357,785 |
| Year 22 | 1,199,347 | USD 0.2043 | USD 0.2226 | USD 266,957 | USD 245,012 | USD 21,944 | USD 379,729 |
| Year 23 | 1,192,751 | USD 0.2104 | USD 0.2292 | USD 273,431 | USD 250,955 | USD 22,476 | USD 402,206 |
| Year 24 | 1,186,191 | USD 0.2167 | USD 0.2361 | USD 280,062 | USD 257,041 | USD 23,022 | USD 425,227 |
| Year 25 | 1,179,667 | USD 0.2232 | USD 0.2432 | USD 286,855 | USD 263,275 | USD 23,580 | USD 448,807 |

### 5.1.3. Profit and Loss Account

This section details the Profit and Loss (P&L) account for the project. The P&L account as seen in Table 5 provides a comprehensive view of the project's financial performance, including total revenue, operating expenses (OPEX), depreciation, profit before tax, corporate income tax, and profit after tax. The total revenue generated from the solar energy project shows a steady increase from USD 148,128 in Year 1 to USD 263,275 in Year 25. This increase is primarily driven by the escalating tariffs over the years. Both OPEX and depreciation are significant components of the cost structure. While depreciation remains constant at USD 50,280 annually, representing a straight-line depreciation of the solar equipment, OPEX gradually increases due to inflation and possibly increasing maintenance costs as the equipment ages.

It is important to note that the strange spike in OPEX observed in Year 13 is a result of the replacement of inverters. This maintenance activity is a critical aspect of managing a solar energy project, as inverters typically have a shorter lifespan compared to solar panels. While solar panels may exceed a lifespan of 25 years, inverters generally require replacement approximately every 10 to 15 years due to their continuous operational stress and technological wear and tear. The profit before tax demonstrates a rising trend, starting at USD 90,148 in Year 1 and reaching USD 200,610 by Year 25, reflecting the increasing revenue and relatively stable depreciation costs. The corporate income tax, calculated at 25% of the pre-tax profit, significantly impacts the net profitability. However, the profit after tax still shows healthy growth, indicative of the project's increasing financial viability. Profit after tax starts at USD 67,611 in Year 1 and increases to USD 150,457 in Year 25, highlighting the project's capacity to deliver growing returns to stakeholders over time.

**Table 5: Overview of the Profit & Loss Account**

| Year | Total Revenue | OPEX | Depreciation (Straight line method)* | Profit (Before Tax) | Corporate Income Tax (25%) | Profit (After Tax) |
|---|---|---|---|---|---|---|
| Year 1 | USD 148,128 | USD 7,700 | USD 50,280 | USD 90,148 | USD 22,537 | USD 67,611 |
| Year 2 | USD 151,721 | USD 7,854 | USD 50,280 | USD 93,587 | USD 23,397 | USD 70,190 |
| Year 3 | USD 155,400 | USD 8,011 | USD 50,280 | USD 97,109 | USD 24,277 | USD 72,832 |
| Year 4 | USD 159,169 | USD 8,171 | USD 50,280 | USD 100,718 | USD 25,179 | USD 75,538 |
| Year 5 | USD 163,029 | USD 8,335 | USD 50,280 | USD 104,415 | USD 26,104 | USD 78,311 |
| Year 6 | USD 166,983 | USD 8,501 | USD 50,280 | USD 108,202 | USD 27,050 | USD 81,151 |
| Year 7 | USD 171,033 | USD 8,671 | USD 50,280 | USD 112,082 | USD 28,020 | USD 84,061 |
| Year 8 | USD 175,181 | USD 8,845 | USD 50,280 | USD 116,056 | USD 29,014 | USD 87,042 |
| Year 9 | USD 179,430 | USD 9,022 | USD 50,280 | USD 120,128 | USD 30,032 | USD 90,096 |
| Year 10 | USD 183,781 | USD 9,202 | USD 50,280 | USD 124,299 | USD 31,075 | USD 93,224 |
| Year 11 | USD 188,239 | USD 9,386 | USD 50,280 | USD 128,572 | USD 32,143 | USD 96,429 |
| Year 12 | USD 192,804 | USD 9,574 | USD 50,280 | USD 132,950 | USD 33,238 | USD 99,713 |
| Year 13 | USD 197,480 | USD 74,504 | USD 50,280 | USD 72,696 | USD 18,174 | USD 54,522 |
| Year 14 | USD 202,270 | USD 9,961 | USD 50,280 | USD 142,029 | USD 35,507 | USD 106,522 |
| Year 15 | USD 207,175 | USD 10,160 | USD 50,280 | USD 146,735 | USD 36,684 | USD 110,051 |
| Year 16 | USD 212,200 | USD 10,363 | USD 50,280 | USD 151,557 | USD 37,889 | USD 113,667 |
| Year 17 | USD 217,346 | USD 10,570 | USD 50,280 | USD 156,496 | USD 39,124 | USD 117,372 |
| Year 18 | USD 222,617 | USD 10,782 | USD 50,280 | USD 161,556 | USD 40,389 | USD 121,167 |
| Year 19 | USD 228,017 | USD 10,997 | USD 50,280 | USD 166,739 | USD 41,685 | USD 125,054 |
| Year 20 | USD 233,547 | USD 11,217 | USD 50,280 | USD 172,049 | USD 43,012 | USD 129,037 |
| Year 21 | USD 239,211 | USD 11,442 | USD 50,280 | USD 177,489 | USD 44,372 | USD 133,117 |
| Year 22 | USD 245,012 | USD 11,671 | USD 50,280 | USD 183,062 | USD 45,765 | USD 137,296 |
| Year 23 | USD 250,955 | USD 11,904 | USD 50,280 | USD 188,771 | USD 47,193 | USD 141,578 |
| Year 24 | USD 257,041 | USD 12,142 | USD 50,280 | USD 194,619 | USD 48,655 | USD 145,964 |
| Year 25 | USD 263,275 | USD 12,385 | USD 50,280 | USD 200,610 | USD 50,152 | USD 150,457 |

### 5.1.4. Cash Flow Analysis

This section presents the cash flow analysis for the project. As seen from Table 6, Table 7, Table 8, and Figure 6, the analysis provides a detailed view of the project's financial inflows and outflows, capturing key components such as initial capital expenditure (CAPEX), annual revenues, operating expenses, and the financial impacts of depreciation.

The project begins with a significant initial investment (CAPEX) of USD 1,257,000. This investment covers all costs associated with setting up the project, including purchasing equipment and installation. From Year 1 onwards, the project starts generating revenue, primarily from the sale of electricity produced by the solar panels. This revenue is supplemented by profits after tax and book depreciation values that are considered non-cash benefits adding back to the cash inflows.

The project proceeds to show positive net cash inflows from Year 1 onwards, indicating that the project generates sufficient annual revenue to cover its initial investment over time. The increasing trend in annual cash inflows reflects the growing financial benefits of the project due to rising energy tariffs and efficient operation. Notably, as seen from Table 8 and Figure 6, Year 13 shows a reduced net cash inflow of USD 104,802 compared to adjacent years. But as mentioned earlier in the Profit and Loss Account, this is due to the additional OPEX incurred from the replacement of inverters, a necessary expenditure to maintain the efficiency and operational capability of the solar panels.

## Table 6: Cash Inflows

| Year | Date | Equity | Profit (After Tax) | Book Depreciation | Total Cash Inflows |
|---|---|---|---|---|---|
| Year 0 | 01/08/2024 | USD 1,257,000 | | | USD 1,257,000 |
| Year 1 | 01/01/2025 | | USD 67,611 | USD 50,280 | USD 117,891 |
| Year 2 | 01/01/2026 | | USD 70,190 | USD 50,280 | USD 120,470 |
| Year 3 | 01/01/2027 | | USD 72,832 | USD 50,280 | USD 123,112 |
| Year 4 | 01/01/2028 | | USD 75,538 | USD 50,280 | USD 125,818 |
| Year 5 | 01/01/2029 | | USD 78,311 | USD 50,280 | USD 128,591 |
| Year 6 | 01/01/2030 | | USD 81,151 | USD 50,280 | USD 131,431 |
| Year 7 | 01/01/2031 | | USD 84,061 | USD 50,280 | USD 134,341 |
| Year 8 | 01/01/2032 | | USD 87,042 | USD 50,280 | USD 137,322 |
| Year 9 | 01/01/2033 | | USD 90,096 | USD 50,280 | USD 140,376 |
| Year 10 | 01/01/2034 | | USD 93,224 | USD 50,280 | USD 143,504 |
| Year 11 | 01/01/2035 | | USD 96,429 | USD 50,280 | USD 146,709 |
| Year 12 | 01/01/2036 | | USD 99,713 | USD 50,280 | USD 149,993 |
| Year 13 | 01/01/2037 | | USD 54,522 | USD 50,280 | USD 104,802 |
| Year 14 | 01/01/2038 | | USD 106,522 | USD 50,280 | USD 156,802 |
| Year 15 | 01/01/2039 | | USD 110,051 | USD 50,280 | USD 160,331 |
| Year 16 | 01/01/2040 | | USD 113,667 | USD 50,280 | USD 163,947 |
| Year 17 | 01/01/2041 | | USD 117,372 | USD 50,280 | USD 167,652 |
| Year 18 | 01/01/2042 | | USD 121,167 | USD 50,280 | USD 171,447 |
| Year 19 | 01/01/2043 | | USD 125,054 | USD 50,280 | USD 175,334 |
| Year 20 | 01/01/2044 | | USD 129,037 | USD 50,280 | USD 179,317 |
| Year 21 | 01/01/2045 | | USD 133,117 | USD 50,280 | USD 183,397 |
| Year 22 | 01/01/2046 | | USD 137,296 | USD 50,280 | USD 187,576 |
| Year 23 | 01/01/2047 | | USD 141,578 | USD 50,280 | USD 191,858 |
| Year 24 | 01/01/2048 | | USD 145,964 | USD 50,280 | USD 196,244 |
| Year 25 | 01/01/2049 | | USD 150,457 | USD 50,280 | USD 200,737 |

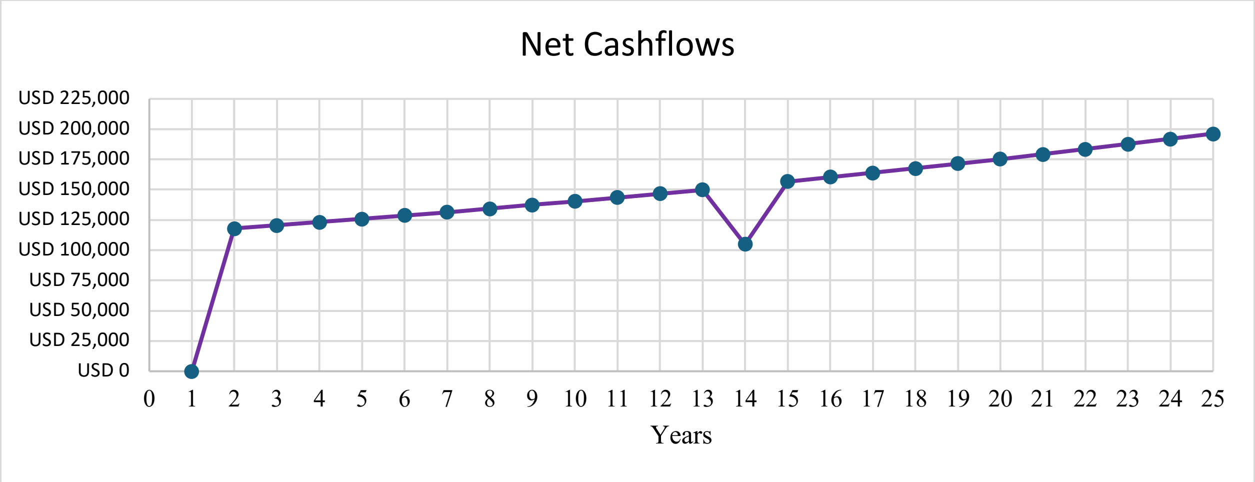
## Table 7: Cash Outflows

| Year | Date | CAPEX | Total Cash Outflows |
|---|---|---|---|
| Year 0 | 01/08/2024 | USD 1,257,000 | USD 1,257,000 |
| Year 1 | 01/01/2025 | | USD 0 |
| Year 2 | 01/01/2026 | | USD 0 |
| Year 3 | 01/01/2027 | | USD 0 |
| Year 4 | 01/01/2028 | | USD 0 |
| Year 5 | 01/01/2029 | | USD 0 |
| Year 6 | 01/01/2030 | | USD 0 |
| Year 7 | 01/01/2031 | | USD 0 |
| Year 8 | 01/01/2032 | | USD 0 |
| Year 9 | 01/01/2033 | | USD 0 |
| Year 10 | 01/01/2034 | | USD 0 |
| Year 11 | 01/01/2035 | | USD 0 |
| Year 12 | 01/01/2036 | | USD 0 |
| Year 13 | 01/01/2037 | | USD 0 |
| Year 14 | 01/01/2038 | | USD 0 |
| Year 15 | 01/01/2039 | | USD 0 |
| Year 16 | 01/01/2040 | | USD 0 |
| Year 17 | 01/01/2041 | | USD 0 |
| Year 18 | 01/01/2042 | | USD 0 |
| Year 19 | 01/01/2043 | | USD 0 |
| Year 20 | 01/01/2044 | | USD 0 |
| Year 21 | 01/01/2045 | | USD 0 |
| Year 22 | 01/01/2046 | | USD 0 |
| Year 23 | 01/01/2047 | | USD 0 |
| Year 24 | 01/01/2048 | | USD 0 |
| Year 25 | 01/01/2049 | | USD 0 |

### Table 8: Net Cashflows

| Year | Date | Net Cash Inflows |
|---|---|---|
| Year 0 | 01/08/2024 | USD 0 |
| Year 1 | 01/01/2025 | USD 117,891 |
| Year 2 | 01/01/2026 | USD 120,470 |
| Year 3 | 01/01/2027 | USD 123,112 |
| Year 4 | 01/01/2028 | USD 125,818 |
| Year 5 | 01/01/2029 | USD 128,591 |
| Year 6 | 01/01/2030 | USD 131,431 |
| Year 7 | 01/01/2031 | USD 134,341 |
| Year 8 | 01/01/2032 | USD 137,322 |
| Year 9 | 01/01/2033 | USD 140,376 |
| Year 10 | 01/01/2034 | USD 143,504 |
| Year 11 | 01/01/2035 | USD 146,709 |
| Year 12 | 01/01/2036 | USD 149,993 |
| Year 13 | 01/01/2037 | USD 104,802 |
| Year 14 | 01/01/2038 | USD 156,802 |
| Year 15 | 01/01/2039 | USD 160,331 |
| Year 16 | 01/01/2040 | USD 163,947 |
| Year 17 | 01/01/2041 | USD 167,652 |
| Year 18 | 01/01/2042 | USD 171,447 |
| Year 19 | 01/01/2043 | USD 175,334 |
| Year 20 | 01/01/2044 | USD 179,317 |
| Year 21 | 01/01/2045 | USD 183,397 |
| Year 22 | 01/01/2046 | USD 187,576 |
| Year 23 | 01/01/2047 | USD 191,858 |
| Year 24 | 01/01/2048 | USD 196,244 |
| Year 25 | 01/01/2049 | USD 200,737 |

### Figure 6: Chart of the Net Cash Inflows



### 5.1.5. Key Financial Metrics

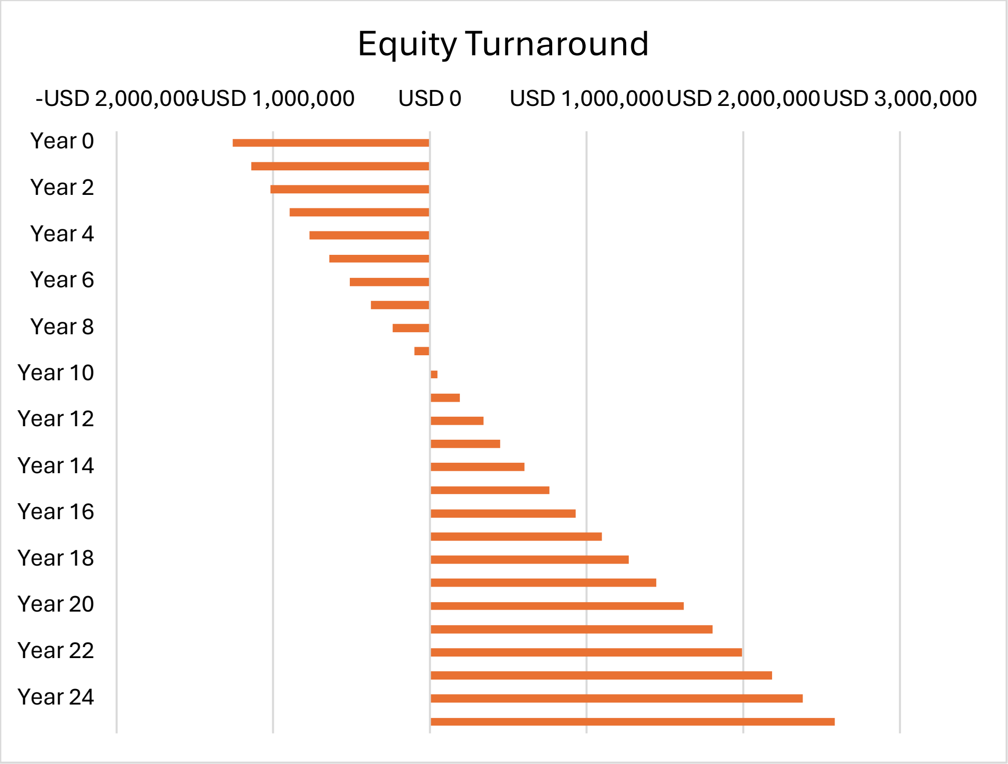
This section provides a summary of the key financial metrics used to evaluate the overall financial viability and investment attractiveness of the project. These metrics include the Net Present Value (NPV), the Internal Rate of Return on Equity (Equity IRR), and the Payback Period. Each of these metrics plays a crucial role in assessing the economic feasibility and the risk-return profile of the project.

As seen from Table 9, the Net Present Value (NPV) stands at USD 186,736, indicating the project's potential to create value over its expected life after accounting for the time value of money. The Equity Internal Rate of Return (IRR) is calculated at 10.72%, reflecting the rate of return on equity investment, which suggests a favourable outcome against typical investment benchmarks in the renewable energy sector. The Payback Period is within the first 10 years of operation, showing that the initial equity investment will be fully recovered from the project's net cash flows by Year 10, as seen in Figure 7 and Table 10**.**

**Table 9: Overview of Financial Metrics**

| | |
|---|---:|
| Net Present Value (NPV) | USD 186,736 |
| Equity IRR | 10.72% |
| Payback Period | Year 10 |

**Figure 7: Equity Turnaround Indicating Payback Period**



## Table 10: Overview of the Equity Turnaround

| Year | Date | Net Equity Cashflows | Equity Turn Around |
|---|---|---|---|
| Year 0 | 01/08/2024 | -USD 1,257,000 | -USD 1,257,000 |
| Year 1 | 01/01/2025 | USD 117,891 | -USD 1,139,109 |
| Year 2 | 01/01/2026 | USD 120,470 | -USD 1,018,639 |
| Year 3 | 01/01/2027 | USD 123,112 | -USD 895,527 |
| Year 4 | 01/01/2028 | USD 125,818 | -USD 769,709 |
| Year 5 | 01/01/2029 | USD 128,591 | -USD 641,118 |
| Year 6 | 01/01/2030 | USD 131,431 | -USD 509,687 |
| Year 7 | 01/01/2031 | USD 134,341 | -USD 375,345 |
| Year 8 | 01/01/2032 | USD 137,322 | -USD 238,023 |
| Year 9 | 01/01/2033 | USD 140,376 | -USD 97,647 |
| Year 10 | 01/01/2034 | USD 143,504 | USD 45,857 |
| Year 11 | 01/01/2035 | USD 146,709 | USD 192,567 |
| Year 12 | 01/01/2036 | USD 149,993 | USD 342,559 |
| Year 13 | 01/01/2037 | USD 104,802 | USD 447,361 |
| Year 14 | 01/01/2038 | USD 156,802 | USD 604,163 |
| Year 15 | 01/01/2039 | USD 160,331 | USD 764,494 |
| Year 16 | 01/01/2040 | USD 163,947 | USD 928,442 |
| Year 17 | 01/01/2041 | USD 167,652 | USD 1,096,094 |
| Year 18 | 01/01/2042 | USD 171,447 | USD 1,267,540 |
| Year 19 | 01/01/2043 | USD 175,334 | USD 1,442,875 |
| Year 20 | 01/01/2044 | USD 179,317 | USD 1,622,191 |
| Year 21 | 01/01/2045 | USD 183,397 | USD 1,805,588 |
| Year 22 | 01/01/2046 | USD 187,576 | USD 1,993,165 |
| Year 23 | 01/01/2047 | USD 191,858 | USD 2,185,022 |
| Year 24 | 01/01/2048 | USD 196,244 | USD 2,381,267 |
| Year 25 | 01/01/2049 | USD 200,737 | USD 2,582,004 |

### 5.2.Research Question 2:

***How does the inclusion of RECs in the financial model of the project influence the key financial metrics: Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period?***

#### 5.2.1. Impact of RECs on Financial Metrics

This section focuses on the results of the second research question, which examines how the inclusion of REC prices using the Distributed Renewable Energy Certificates (D-RECs) programme in the financial model influences key financial metrics of the project, specifically the Net Present Value (NPV), the Internal Rate of Return (IRR), and the Payback Period.

The integration of RECs into the financial model is conservatively estimated based on a fixed price of $10 per 1 MWh for a duration of 4 years. The analysis assumes that all volumes of MWh produced by the project are purchased annually by the RECs buyer. Table 11 shows the detailed outcomes.

**Table 11: Comparison of the Financial Metrics Before and With RECs**

| Financial Metric | Value Before RECs | Value With RECs ** | Notes |
|---|---|---|---|
| Equity IRR | 10.72% | 11.07% | Increase due to additional revenue from RECs. |
| Net Present Value (NPV) | USD 186,736 | USD 220,872 | Improvement reflecting the added REC revenues. |
| Payback Period | Year 10 | Year 10 | Remains unchanged as initial investment outflow and major inflows remain constant in early years. |

*****NB**: RECs at $10 per 1 MWh for 4 years*

As seen from Table 11**,** the NPV has increased from USD 186,736 to USD 220,872, indicating a more favourable financial outlook with the inclusion of RECs. There is a noticeable improvement in the Equity IRR, rising from 10.72% to 11.07%. This improvement in IRR reflects the additional income stream generated from selling the RECs, thus yielding a higher return on equity invested. The payback period remains consistent at 10 years, despite the inclusion of REC revenues. This stability is due to the fact that the payback period calculation primarily depends on when the cumulative net cash flows turn positive, which in this scenario, is influenced more by the larger early-year cash inflows relative to the consistent annual REC benefits. Further analysis in the next research question where sensitivity and scenario analysis are conducted, the study explores more optimistic scenarios where REC prices exceed USD 10 per MWh, and the duration of the contractual agreements for trading the RECs is extended beyond the conservative estimate of 4 years.

### 5.3.Research Question 3:

***How do changes in key variables such as REC prices and contract duration, solar electricity tariffs, CAPEX, OPEX, and discount rates impact the key financial metrics of the project through sensitivity and scenario analysis?***

#### 5.3.1. Sensitivity Analysis on REC Pricing and Contract Duration

Following the exploration of how the inclusion of RECs influences key financial metrics under a conservative situation, this section presents the results from a sensitivity analysis that varied REC prices and contract durations.

As presented in Table 12, as the REC price increases and the contract duration extends, both the NPV and IRR show substantial improvements. This trend illustrates the significant impact that favourable REC market conditions can have on the financial viability of solar projects. The payback period shortens from Year 10 to Year 9 as REC prices increase. Notably, in the most optimistic situation of $30 per MWh, the project is almost able to recoup its initial investment by the end of Year 8, effectively making the payback period just over 8 years.

**Table 12: Financial outcomes under different REC pricing and contract duration situations**

| REC Pricing and Duration | NPV | IRR | Payback Period | Notes |
|---|---|---|---|---|
| RECs at $10 per 1 MWh for 4 years | USD 220,872 | 11.07% | Year 10 | Base case before sensitivity analysis. |
| RECs at $20 per 1 MWh for 8 years | USD 302,310 | 11.91% | Year 9 | Reflects improved financial metrics with higher REC price and longer contract. |
| RECs at $30 per 1 MWh for 8 years | USD 360,097 | 12.54% | Year 9 ** | Highest improvement, with payback nearly at the start of Year 9. |

*****NB:** In the scenario with RECs priced at $30 per MWh for 8 years, the project is just $247 short of breaking even at the end of Year 8, which would be quickly recuperated in the following month of Year 9.*

### 5.3.2. Sensitivity Analysis on Solar Electricity Tariffs

This section presents the outcomes of the sensitivity analysis conducted to understand the impact of varying solar electricity tariffs on the financial metrics of the project. The analysis focuses on three different tariff rates: $0.11, $0.10, and $0.09 per kWh.

As seen from Table 13, The project shows a healthy NPV of USD 220,872 with an IRR of 11.07%, and the initial investment is recovered by the 10th year. Lowering the tariff to $0.10 results in a significant reduction in NPV to USD 93,525 and decreases the IRR to 9.89%. The payback period extends to Year 11, indicating a slower return on investment due to reduced revenue from electricity sales. At a further reduced tariff rate ($0.09 per kWh), the project's viability is critically affected, as reflected by a negative NPV of -USD 33,822, and the IRR drops to 8.67%. The payback period is delayed to Year 12, further indicating that the project is not financially sustainable if the solar electricity tariff falls to this level.

**Table 13: Impact of Changes in Solar Electricity Tariffs**

| Solar Tariff | NPV | IRR | Payback Period | Notes |
|---|---|---|---|---|
| $0.11 | USD 220,872 | 11.07% | Year 10 | Base case before sensitivity analysis. |
| $0.10 | USD 93,525 | 9.89% | Year 11 | |
| $0.09 | - USD 33,822 | 8.67% | Year 12 | Negative NPV indicates a non-viable project under this tariff rate. |

### 5.3.3. Sensitivity Analysis on Discount Rates

This section presents the findings from the sensitivity analysis conducted to evaluate how changes in the discount rate affect the Net Present Value (NPV) of the project.

As presented in Table 14, at a 9% discount rate, the project shows a robust NPV of USD 220,872. This rate likely reflects the project's risk profile and the opportunity cost of capital, serving as the base scenario for this analysis. Increasing the discount rate to 11% dramatically reduces the NPV to USD 6,836. The higher discount rate implies a higher perception of risk or a higher alternative return rate, which significantly impacts the present value of future cash flows. Lowering the discount rate to 8% increases the NPV to USD 352,177. This scenario suggests that if the project risks are lower than anticipated, or if the cost of capital decreases, the project's value would increase substantially.

Table 14: Impact of Changes in Discount Rates

| Discount Rate | NPV | Notes |
|---|---|---|
| 9% | USD 220,872 | Base case before sensitivity analysis. |
| 11% | USD 6,836 | |
| 8% | USD 352,177 | |

### 5.3.4. Scenario Analysis

This section presents the results of the scenario analysis conducted to explore the financial outcomes under varying conditions involving key variables such as REC prices, contract duration, solar electricity tariffs, CAPEX, OPEX, and discount rates. Unlike the Sensitivity Analysis where a particular single variable is varied at a time while holding all other key variables constant, the Scenario Analysis involves changing multiple key variables simultaneously. In all, three distinct scenarios were analysed to understand how these variables interact and impact the financial metrics of the project.

Table 15: Scenario 1 - Base Case Scenario

| Key variables | Defined Inputs | Values |
|---|---|---|
| REC Prices & Contract Duration | Low REC price with Short contract | \$10/MWh for 4 years |
| Solar Electricity Tariff | High tariff | \$0.11/kWh |
| CAPEX | High CAPEX | \$1,257/kWp |
| OPEX | High OPEX | \$7.7/kWp/Annum |
| Discount Rate | Moderate Discount Rate | 9% |

| NPV | IRR | Payback Period |
|---|---|---|
| USD 220,872 | 11.07% | Year 10 |

As presented in Table 15, this scenario serves as the baseline for comparison. The financial outcomes are solid, with a decent NPV and IRR, reflective of the high tariff and moderate discount rate offsetting the higher initial and operational costs.

Table 16: Scenario 2 - Optimised Investment Scenario

| Key variables | Defined Inputs | Values |
|---|---|---|
| REC Prices & Contract Duration | High REC price with long contract | \$30/MWh for 8 years |
| Solar Electricity Tariff | High tariff | \$0.11/kWh |
| CAPEX | Low CAPEX | \$962/kWp |
| OPEX | Low OPEX | \$6.5/kWp/Annum |
| Discount Rate | Low Discount Rate | 8% |

| NPV | IRR | Payback Period |
|---|---|---|
| USD 770,460 | 16.99% | Year 7 |

Scenario 2 in Table 16 shows significantly improved financial metrics due to the harmonious effect of high REC prices, longer contract duration, and lower CAPEX and OPEX. The lower discount rate also contributes to a much higher NPV and a faster payback period, indicating a highly attractive investment opportunity.

Table 17: Scenario 3 - Challenging Market Scenario

| Key variables | Defined Inputs | Values |
|---|---|---|
| REC Prices & Contract Duration | Moderate REC price with long contract | \$20/MWh for 8 years |
| Solar Electricity Tariff | Low tariff | \$0.09/kWh |
| CAPEX | Moderate CAPEX | \$1,110/kWp |
| OPEX | Moderate OPEX | \$7.1/kWp/Annum |
| Discount Rate | High Discount Rate | 11% |

| NPV | IRR | Payback Period |
|---|---|---|
| USD 4,322 | 11.05% | Year 10 |

As shown in Scenario 3 from Table 17, despite a longer contract duration and moderate REC pricing, the low solar electricity tariff combined with higher discount rates drastically reduces the NPV. The project remains viable but is less attractive compared to the other scenarios, with marginal profitability and no improvement in the payback period.

**Table 18: Scenario 4 - Worst Case Scenario**

| Key variables | Defined Inputs | Values |
|---|---|---|
| REC Prices & Contract Duration | Low REC price with long contract | $10/MWh for 8 years |
| Solar Electricity Tariff | Lower tariff | $0.08/kWh |
| CAPEX | Moderate CAPEX | $1,110/kWp |
| OPEX | Higher OPEX | $9.1/kWp/Annum |
| Discount Rate | High Discount Rate | 11% |

| NPV | IRR | Payback Period |
|---|---|---|
| -USD 173,890 | 8.79% | Year 11 |

As shown in Scenario 4 from Table 18, dubbed the "Worst Case Scenario", this scenario illustrates a challenging financial outcome under conservative assumptions. The low REC price over a long contract of 8 years, combined with a low solar electricity tariff, reduces the project’s potential earnings significantly. Also, the moderately high CAPEX alongside elevated OPEX, compounded by a high discount rate, results in a negative NPV. The Internal Rate of Return (IRR) is low at 8.79%, and it takes 11 years to recover the initial investment, which is longer than usual. This scenario is less appealing and presents a risky investment compared to the others, showing the impact of unfavourable financial and market conditions on the project's success.

# CHAPTER SIX

# DISCUSSION OF FINDINGS

## 6.1.The Financial Metrics of the Project Without the Inclusion of Income from Renewable Energy Certificates (RECs)

Research Question 1 examines the financial metrics excluding the impact of Renewable Energy Certificates (RECs). As presented in CHAPTER FIVE, the findings detail a comprehensive view of the project's financial viability and performance over a 25-year period, emphasising both energy production and financial outcomes.

The SolarGis simulation highlighted a gradual degradation in the performance ratio and total power output of the solar panels, typical for such technology over time. Financially, the project demonstrated robust viability with significant annual savings compared to conventional energy sources. These savings are due to the consistently lower costs of solar energy across the project lifespan, with the total annual savings increasing each year as the gap between solar and conventional energy tariffs widens.

Key financial metrics indicated strong economic benefits:

- **Net Present Value (NPV)** of USD 186,736 suggests that the project is expected to generate a net profit over its lifetime, considering the time value of money.
- **Internal Rate of Return (IRR)** at 10.72% highlights the project's profitability and its attractiveness compared to typical market returns.
- **Payback Period** within the first 10 years of operation reflects a relatively quick return on investment, which is particularly appealing to investors.

Comparing the findings from this study with that of the study by Asumadu-Sarkodie and Owusu (2016) which analysed a 5 MW solar PV project in Kumasi, they reported a pre-tax IRR of 6.7%, significantly lower than the 10.72% IRR identified in this project within the same city. This difference could be attributed to several factors including lower capital expenditure and operational costs in this study. Specifically, the capital cost in this study’s analysis is \$1,257 per kWp, considerably less than the \$2,039 per kWp reported in their study. Furthermore, the operational expenses in this study are also lower at \$7.7 per kWp annually compared to their \$10 per kWp. These reductions in initial and recurring costs likely contribute to the higher financial returns observed in this project. Additionally, this study benefits from the updated technological efficiencies and the latest policy enhancements in Ghana which favour renewable energy investments, unlike the period (i.e., 2016) assessed by Asumadu-Sarkodie and Owusu, which did not fully capture these evolving benefits.

Considering the project’s positive NPV and attractive IRR, strategic options derived from the Real Options Theory, such as the “Expansion Option”, present an excellent opportunity to capitalise on economies of scale and potentially enhance profitability. This is particularly relevant if market demand for renewable energy increases or if the government of Ghana introduces additional incentives, like the tax incentives on solar equipment, etc.

Despite these positive financial projections, it remains crucial to consider other strategic options like “Contraction or Abandonment” due to potential market dynamics that could impact long-term sustainability and profitability. As stated in the first research question, the project’s profitability largely hinges on maintaining a favourable tariff differential between solar and conventional power. The assumption here is that conventional energy will continue to be expensive as we move into the future. However, this study could be incorrect in that assumption, especially if the prices of conventional energy potentially stay the same or decrease, which is uncertain since it pertains to the future. While there is a chance that fossil fuel prices might decrease, thus making conventional energy cheaper and potentially compromising the project's revenue model, historical data in Ghana (Public Utilities Regulatory Commission, 2020) shows that electricity prices generally tend to rise, with decreases being rare and minimal.

Moreover, the global shift towards combating climate change suggests that it's increasingly unlikely that conventional energy costs will significantly decrease in the future (IEA, 2021; IRENA 2022). Many nations, including Nigeria, for example, have eliminated fossil fuel subsidies (Usigbe, 2023), signalling a shift towards more sustainable energy solutions. This global policy action trend suggests that conventional energy prices may continue to rise, thus supporting the financial viability of renewable energy projects like this hypothetical project in Ghana. That notwithstanding, the strategic option to “Contract” remains an important risk management tool. This option could be particularly necessary in the event of a global economic recession, which could lead to decreased industrial activity and lower consumer spending in Ghana, thus reducing the demand for electricity. Although Ghana is historically stable and ranks as one of the most peaceful countries in Africa (Institute for Economics & Peace, 2023), external economic factors, such as what COVID-19 did to the country’s economy (Ghana Statistical Service, World Bank, & UNDP, 2020) can still influence its economic landscape. In such cases, adjusting the scale of the solar installation to match the reduced demand would help preserve the project's financial health and prevent overinvestment during periods of low electricity consumption.

The study findings have significant practical implications, particularly for policymakers and investors. For policymakers, the strong performance of the project underscores the worth of current incentives and supports the case for continuing, if not expanding, such measures to foster the growth of renewable energy. These incentives not only enhance the financial attractiveness of solar investments but also align with global environmental goals. For investors, the favourable IRR and quick payback period highlighted in this analysis present a robust investment opportunity, especially in a stable economic climate like Ghana's. Moreover, the strategic options of Contraction or Abandonment incorporated into the financial analysis provide necessary risk management tools, allowing for flexibility in response to potential economic downturns or unfavourable market changes. These strategic insights equip stakeholders to make informed decisions, ensuring that investments not only yield favourable returns but also contribute to the broader agenda of sustainable energy development.

## 6.2.The Financial Metrics of the Project With the Inclusion of Income from Renewable Energy Certificates (RECs)

The inclusion of income from Renewable Energy Certificates (RECs) evidently influences the financial outlook of the project in Ghana, as detailed in the presentation of the results of the second research question in Chapter 5. The integration of RECs into the financial model, based on a conservative price estimation of $10 per MWh for a four-year duration, reveals significant improvements in both the Net Present Value (NPV) and the Internal Rate of Return (IRR), while maintaining a constant Payback period.

### Net Present Value (NPV)

The NPV of the project increased from USD 186,736 to USD 220,872 with the inclusion of RECs. This improvement by USD 34,136 underscores the added financial value that RECs contribute to the project. The increase in NPV highlights that the revenue from RECs not only compensates for any potential financial shortfalls but also boosts the overall profitability of the project. This finding is crucial for investors and stakeholders as it demonstrates the tangible benefits of integrating RECs into the project’s revenue stream, enhancing the project's attractiveness and financial viability.

### Internal Rate of Return (IRR)

The IRR saw a modest increase from 10.72% to 11.07%. Although the rise might seem slight, it represents a significant enhancement in the project’s yield, attributing directly to the additional income from selling RECs. This increase in IRR reflects a better return on investment, making the project more appealing to potential investors who look for robust returns in renewable energy projects.

### Payback Period

Despite the financial benefits observed in NPV and IRR, the payback period remains unchanged at 10 years. This consistency is explained by the structure of the financial inflows: the payback period calculation depends heavily on the timing of the initial major cash inflows, which are not altered significantly by the annual REC revenue. This outcome indicates that while RECs enhance profitability, they do not necessarily accelerate the recovery of the initial investment, under the conservative assumptions made.

A comparative study by Ghosh et al. (2015) in India offers insights into the role of RECs in boosting revenue models of rooftop photovoltaic systems, although it doesn't specify the direct financial impact of their REC pricing set at Rs. 9,300 per MWh on NPV or IRR. It does provide some sort of qualitative impact of success seeing that RECs are part of their revenue model, and with the right mix of policy subsidies and economic conditions provide some success. By comparing these studies, it is seen that policies for renewable energy, like those for RECs, need to be carefully designed to fit the local environment to really help boost renewable energy projects effectively.

This financial increase in the financial metrics driven by RECs supports strategic Real Options such as Expansion, which could capitalise on economies of scale and additional government incentives, further boosting profitability in a growing renewable energy market. Notwithstanding these positive indicators, it remains critical to maintain flexibility through other strategic Real Options such as the Options to Postpone or even Abandon the project, as global energy prices and market conditions remain volatile. These strategic options, derived from the Real Options Theory, allow for the ability to adapt in response to economic shifts or policy changes, ensuring the project remains economically viable under varying future scenarios.

The impact of RECs in this study's findings as evidenced by increased NPV and IRR presents some implications. The boost in financial metrics underlines the potential of RECs to attract more investment into renewable energy in Ghana, suggesting that Ghanaian policymakers can start putting plans in place to develop and support REC initiatives to leverage environmental and economic benefits. This study, similar to the findings from Ghosh et al. (2015) in India, demonstrates that well-designed REC policies tailored to local conditions can substantially enhance the success of renewable projects, aligning them with broader Sustainable Development Goals and ensuring long-term community and economic benefits.

But it is important to understand the details of the REC pricing used in the analysis for the REC benefit in the study. The study used a conservative estimate of $10 per MWh for RECs, aligning with pricing from specialised programmes like the Distributed Renewable Energy Certificate (D-REC) initiative. Unlike the broader International Renewable Energy Certificate (I-REC) market, where REC prices generally range from $1 to $3 per MWh, D-REC targets projects that achieve more comprehensive sustainability impacts, offering higher pricing as an incentive (Green Power Hub, n.d.; Powertrust, 2023).

The D-REC programme is distinct because it does not only support general renewable energy goals (such as those outlined in SDGs 7 and 13, which focus on clean energy and climate action) but also rewards projects that contribute to a wider range of Sustainable Development Goals (SDGs) (Powertrust, 2023). This broader focus means that projects with significant social or environmental impacts can secure better REC pricing under D-REC. However, securing this higher REC pricing through D-REC is not straightforward. Projects must demonstrate substantial additional financial and environmental benefits—termed 'financial additionality'—to qualify for these higher rates (Powertrust, 2023). This requirement ensures that only projects contributing meaningfully to sustainability beyond the basic generation of renewable energy are compensated at this higher rate. Therefore, project owners need to thoroughly document and prove these additional impacts to access the greater benefits of D-REC pricing.

## 6.3.Sensitivity and Scenario Exploration of Key Variables on the Project Financial Metrics

### Sensitivity Analysis

The sensitivity analysis reveals that increasing REC prices and extending contract durations significantly improve the project's NPV and IRR. This improvement highlights the crucial role that favourable REC market conditions play in enhancing the financial viability of solar projects. Specifically, the ability to recoup the initial investment by the end of Year 8 in the most "Optimistic Scenario" demonstrates the potent impact of strategic financial planning and the adaptability of the project to market incentives. These results emphasise the importance of REC pricing in renewable energy policies, suggesting that well-structured REC incentives can accelerate investment recovery and increase project attractiveness.

The analysis of varying solar electricity tariffs indicates a direct correlation between tariff rates and financial sustainability. With a decrease from \$0.11 to \$0.09 per kWh, the project transitions from viable to non-viable, evidenced by a negative NPV and an extended Payback period. This finding is critical for policymakers and stakeholders, as it emphasises the need for maintaining competitive tariff rates to sustain the economic attractiveness of renewable energy projects. It also illustrates the delicate balance required in setting tariffs that can make or break the financial success of such projects.

Changes in the discount rate have a dramatic effect on NPV, reflecting the project's sensitivity to financing costs and risk perceptions. A higher discount rate, indicating greater risk or alternative investment opportunities, substantially reduces the present value of future cash flows, thereby lowering the project's assessed value. On the other hand, a lower discount rate increases the project's NPV, suggesting more favourable conditions for investment. This analysis highlights the critical role of perceived risk and the cost of capital in renewable energy investments, suggesting that investor confidence and stable economic policies are crucial for the success of such projects.

### Scenario Analysis

The scenario analysis provides a comprehensive view of how different combinations of variables affect the project's financial metrics. The "Optimised Investment Scenario" showcases an ideal setting where high REC prices, low CAPEX and OPEX, and a favourable discount rate combine to offer a highly attractive investment opportunity with a significantly shortened payback period. In contrast, the "Challenging Market Scenario" demonstrates the resilience of the project under less favourable conditions, maintaining viability but with reduced attractiveness. In the "Worst Case Scenario," the financial metrics present significant challenges to the project viability. The NPV turns negative and the IRR becomes relatively low at 8.79%, especially when compared to the high discount rate of 11% applied in the scenario. Normally, investors avoid projects where the IRR is below the discount rate because it implies that the project earns less than its cost of capital. Moreover, the payback period also extends to 11 years, which is one year longer than in the study's baseline scenario. Although a one-year extension might seem manageable, it increases the duration of financial risk, potentially affecting the reliability of payments from off-takers during this time. Typically, a negative NPV and an IRR below the discount rate are clear indicators that a project should be reconsidered or rejected.

But again, while this "Worst Case" scenario might look financially unattractive from a purely numerical standpoint (negative NPV and lower IRR), the broader context of global portfolio diversification provides another dimension through which the project could be evaluated. From a broader investment perspective, it is noteworthy that many European and American investors are currently underweighted in Africa. Therefore, investing in projects like this could offer a diversification benefit, contributing to a more balanced international investment portfolio. UNCTAD's (2023) World Investment Report for 2023 highlights a significant gap that emerging countries require about $1.7 trillion annually for renewable power but secured only $544 billion in 2022. This underscores the potential for impactful investments in Africa, where there is a considerable need for sustainable development funding.

Scholars such as Schoenmaker and Schramade, in their 2018 sustainable finance book, advocate for an "Integrated Value" approach, suggesting that the true value of projects like this one (with its worst-case scenario) extends beyond just financial metrics. The environmental value of such a project, for example, could be quantified by calculating the avoided greenhouse gas (GHG) emissions over the project's 25-year period. This integrated value, which includes positive environmental impacts, is likely much greater than the NPV alone.

The part on the sensitivity analysis on REC prices and contract durations in this study can be associated with similar financial assessments in other renewable energy projects, such as the Korean study by Lee & Xydis (2023) on offshore wind power. Both studies highlight the significant influence of REC pricing on the financial viability of renewable energy projects, illustrating that higher REC prices clearly improve key financial metrics like NPV and IRR. However, while this study's analysis applies a straightforward REC price per MWh, the Korean study introduces a complex REC weight system tailored by project-specific factors like linkage distance and water depth. This approach not only highlights the variability in REC pricing mechanisms but also emphasises the need for policy frameworks that adapt REC strategies to local project conditions, ensuring the financial attractiveness and feasibility of renewable energy investments. These comparative insights reinforce the importance of structured REC policies that are sensitive to both market demands and sustainable development goals, providing a broader perspective that enhances the understanding of REC impacts across different renewable energy sectors.

Based on the findings from the sensitivity and scenario analysis, several strategic options from the Real Options Theory are suggested to enhance financial viability and adaptability. The Expansion Option could be applicable when market conditions are more favourable, such as when REC prices are high or solar electricity tariffs increase. The sensitivity analysis showed substantial improvements in NPV and IRR with increased REC prices and stable high tariffs. Therefore, the project could expand its capacity to capitalise on these favourable conditions, potentially generating even greater returns. Conversely, given the sensitivity of the project to various financial metrics such as discount rates and solar electricity tariffs, the strategic Option to Delay investment until more favourable economic conditions arise could also be crucial. This option reduces the risk associated with higher financing costs or lower tariff rates that might adversely affect the project's viability under such unfavourable scenarios. In tandem with this, the flexibility option to adjust project size offers a practical alternative to delaying outright. By initiating the project at a smaller scale, investors can start early, reducing initial risks while retaining the ability to scale up as conditions improve. This strategic flexibility ensures that the project remains adaptive to market dynamics, enabling growth in alignment with economic opportunities without the full commitment of resources from the onset.

Additionally, in the face of a "Challenging Market Scenario" where the combination of low tariffs, moderate REC prices, and high discount rates makes the project less attractive, having the abandonment option allows the project to be terminated before incurring further losses. This strategic option acts as a safeguard against sustained unfavourable market conditions. In the specific context of Scenario 4, the "Worst Case Scenario," where low REC prices and lower solar electricity tariffs contribute to a negative NPV and lower IRR, the Option to Postpone emerges as particularly relevant. This option advises delaying the project until potential positive shifts in economic or market conditions occur, such as an increase in REC prices or solar tariffs, which could restore the project’s financial viability. Furthermore, the Option to Scale Down could be considered, allowing for a reduction in the project’s scale initially, with the possibility to expand as conditions improve. This strategy minimises the initial financial exposure while maintaining flexibility for future growth, ensuring that the project remains a viable investment option even under the most adverse conditions.

The implications of the sensitivity and scenario analyses highlight the importance of strategic financial planning and robust policy frameworks for renewable energy projects. They advocate for a regulatory environment that optimally sets REC prices to reflect the true environmental value of renewables, enhancing their financial attractiveness and accelerating their adoption. Additionally, these findings emphasise the need for adaptive investment strategies that include real options such as delaying investments or adjusting project scales based on current economic conditions, which can significantly manage risk and improve returns. It is also crucial for ongoing education and advocacy efforts to ensure all stakeholders are well-informed about the dynamics of renewable energy financing. Clear communication about the benefits of well-structured REC markets and competitive tariffs can lead to more informed decisions and stronger policy support, ultimately contributing to the broader goal of a sustainable energy future.

# CHAPTER SEVEN

# CONCLUSIONS

## 7.0.Introduction

This final chapter puts together the insights gathered from the entire study, leading to a comprehensive understanding of the typical financial metrics for an investment in a 1 MWp scale rooftop solar project in Ghana under a third-party financed Power Purchase Agreement (PPA) model. It also examines how Renewable Energy Certificates (RECs) influence these financial metrics and the overall attractiveness of the project investment. Specifically, the concluding insights provide a summary of the findings, discuss the theoretical and practical implications derived from these findings, identify factors that limit the applicability of the knowledge gathered from the findings, and recommend areas for future research and policymaking, bearing in mind that the REC market is still under-developed in Ghana.

## 7.1.Summary of Findings

The preliminary investigation of the study first looked at exploring the viability of the project focusing initially on the baseline financial metrics without the inclusion of RECs. The initial findings indicate that even without RECs, the project presented a feasible economic profile, with a specific emphasis on the Net Present Value (NPV) and Internal Rate of Return (IRR) as fundamental financial indicators. Subsequently, the research explored the integration of RECs and uncovered that their inclusion evidently enhances the project's financial metrics, specifically improving NPV and IRR. These improvements establish the significant role of RECs in increasing the economic attractiveness of solar projects.

A sensitivity analysis was then conducted, which delved into the effects of variations in REC prices, solar electricity tariffs, and other economic factors on the project's financial outcomes. This analysis revealed that higher REC prices are closely linked with improved NPV and IRR, suggesting potential substantial gains under favourable REC market conditions. Also, the sensitivity to changes in solar electricity tariffs was critically examined. Results demonstrated that higher tariffs substantially boost the project's financial sustainability, while lower tariffs significantly hinder its economic viability.

Following the sensitivity analysis, a scenario analysis was performed to provide a fine view of how simultaneous changes in multiple variables—such as REC prices, contract duration, CAPEX, OPEX, and discount rates—affect the financial metrics. This comprehensive approach presented various potential outcomes. Out of those scenario outcomes, the "Optimised Investment Scenario" emerged as particularly favourable, characterised by high REC prices, reduced capital and operational expenditures, and a beneficial discount rate, collectively shortening the payback period and enhancing overall profitability. On the other hand, another scenario outcome titled the "Challenging Market Scenario" demonstrated the project's capacity to remain viable under less beneficial conditions, although with reduced attractiveness, emphasising the necessity for flexible financial strategies and robust policy support to navigate potential market difficulties. Similarly, Scenario 4, known as the "Worst Case Scenario," provided a stark contrast by showcasing the potential financial vulnerabilities under extremely unfavourable conditions. With low REC prices, lower tariffs, and a high discount rate, this scenario resulted in a negative NPV and a longer payback period. It underscored the significant impact that adverse market and financial conditions can have on the project's economic viability, highlighting the need for careful risk assessment and management in project planning and execution.

## 7.2.Implications of the Study Findings

### 7.2.1. Theoretical Implications

The findings of this study have several theoretical implications and contribute to the existing body of knowledge in the field of Real Options, particularly within the context of developing countries like Ghana. Traditionally, Real Options Theory has been applied within the context of large-scale, capital-intensive projects in sectors like oil and gas and real estate. However, this study extended its application to the renewable energy sector by demonstrating how strategic options such as Expansion, Abandonment, Delay, and Postponement can be effectively used to manage the uncertainties associated with solar energy investments.

In scenarios where REC prices were elevated, the Expansion Option proved particularly beneficial. The sensitivity analysis showed that higher REC prices directly correlated with improved NPV and IRR, indicating that the project could expand its capacity to capitalise on these favourable conditions and potentially generate greater returns. This proactive approach aligns well with the theoretical adaptability highlighted by Real Options Theory, demonstrating the practical implications of scaling project capacity in response to rising REC prices.

Conversely, in scenarios characterised by significant market or policy uncertainty—particularly regarding future REC pricing and solar tariffs—the Option to Delay was identified as a crucial strategy. This option mitigates risks associated with fluctuating market conditions or impending policy changes that could negatively impact the project's financial outcomes, emphasising the value of waiting for more favourable or stable conditions before committing capital.

For scenarios presenting a high degree of financial risk, such as Scenario 4's "Worst Case Scenario" with its combination of low REC prices, lower tariffs, and a high discount rate, the Option to Postpone becomes highly relevant. This option allows investors to avoid committing to significant expenditures during unfavourable economic periods, thereby protecting the investment from potential losses. Similarly, the Abandonment Option serves as a rational choice in scenarios where continuing the project might lead to unsustainable losses. This option is a practical mechanism to limit financial exposure and act as a safeguard, reflecting a strategic approach to managing investment risks in volatile markets.

### 7.2.2. Implications of the Study for Policy Contributions

The findings of this study hold significant implications for policy development in Ghana. While Ghana is included in the global I-REC system which facilitates the global trading of RECs, the country has not yet established its own state-managed REC market system. This gap presents a unique opportunity for policymakers to design a tailored REC framework that leverages both the global insights provided by I-REC participation and the detailed findings from the sensitivity analysis of this study. Here are the tailored insights:

I. **Establish a Basic and Transparent REC Framework:** The first step for Ghana is to develop a basic regulatory and operational framework for Renewable Energy Certificates (RECs). This framework should define what constitutes a REC, alongside its monitoring, verification, and trading processes. To enhance market transparency and credibility, a national REC registry should be implemented. This registry would track REC issuance, trade, and retirement, which is crucial for building investor confidence in the authenticity and integrity of RECs. Insights from this study’s Literature Review in Chapter Two underline that a clear and transparent REC system can significantly boost the attractiveness of renewable energy investments.

II. **Incorporate Findings from the Sensitivity Analysis into REC Pricing Strategy:** The study's sensitivity analysis highlighted how changes in REC pricing significantly impact project financial metrics like Net Present Value (NPV) and Internal Rate of Return (IRR). As Ghana is yet to establish a nationally owned REC system, these insights could guide policymakers in creating initial REC pricing strategies that balance market attractiveness with economic feasibility. In markets where RECs are typically traded based on supply and demand dynamics, private companies and other entities purchase RECs at prices they find suitable, with sellers accepting offers that meet their expectations. However, in an emerging market like Ghana, which has not yet fully entered the REC market, the government or regulatory bodies could play an influential role in setting initial, possibly higher REC prices, to stimulate market entry and investment. These initial prices could be adjusted as the market matures and more data becomes available, incorporating a model with minimum or floor prices to ensure that projects remain economically viable.

III. **Legislating Renewable Energy Quotas to Propel REC Demand and Market Growth**: Implementing mandatory renewable energy targets is an effective strategy that the Ghanaian government could consider to promote demand for Renewable Energy Certificates and renewables. Currently, the country is taking steps towards renewable energy promotion. The country's Renewable Energy Master Plan, which was developed to augment the Renewable Energy Act of 2011, sets ambitious targets for renewable energy generation. For instance, Ghana aims to increase the proportion of renewable energy in the national energy mix. But the problem is that, the implementation of these targets does not set mandatory renewable energy quotas for certain sectors of the economy. By introducing arrangements similar to those adopted in the United States where states like California have established comprehensive targets, or the Renewable Energy Directive in the European Union, which sets binding renewable energy goals for its member states, Ghana can stimulate a robust REC market. Such legislation arrangements could compel specific sectors to source a defined percentage of their energy from renewable sources by a predetermined date, thereby organically fostering a market demand for RECs. Companies could either invest directly in renewable energy projects or purchase RECs to comply, thus allowing flexibility in meeting these targets. To enforce these standards, penalties for non-achievement could be levied, and the proceeds could be channelled back into renewable energy subsidies or research and development initiatives.

### 7.2.3. Implications of the Study for Investors

Investors in the solar energy sector can leverage insights from this study to enhance the profitability of their projects and mitigate potential risks associated with solar investments in Ghana. They can employ risk management through careful financial planning to navigate the volatility of renewable energy investments. Sensitivity and scenario analyses are crucial tools for understanding potential future changes in key financial metrics such as NPV and IRR. Investors should employ these analyses to foresee how changes in REC prices, electricity tariffs, and other economic factors might impact their projects. This proactive financial planning helps in making informed decisions that align with both short-term and long-term investment goals.

Further to this, adopting diversification strategies through the application of Real Options Theory could also enhance investment outcomes. For instance, using the “Expansion Option” during periods of high REC prices can significantly amplify returns, aligning with the favourable market trends. On the other hand, readiness to employ the “Abandonment Option” also provides a safeguard, allowing for limited losses when market conditions turn adverse. In scenarios of heightened financial risk, such as the one depicted in Scenario 4’s “Worst Case Scenario,” the “Option to Postpone” becomes especially pertinent. This strategy enables investors to delay significant expenditures during periods marked by low REC prices, lower tariffs, and high discount rates, thereby protecting the investment from potential losses. Similarly, considering that strategic investment timing plays a crucial role, investors can also employ the “Option to Delay” to optimise the timing of their commitments to coincide with more favourable market conditions, such as higher REC prices or the emergence of supportive policies. By using these different strategies, investors can create a strong and flexible approach to their investments. This way, they can ensure they succeed in Ghana's growing solar market and help the country progress towards a more sustainable energy future.

## 7.3.Limitations of the Study

This study provides valuable insights into RECs and solar PV project investment in Ghana. However, certain constraints may have influenced the research outcomes. The REC pricing data used in the study, ranging from $10 to $30 per MWh as mentioned during one of the D-REC seminars on YouTube, presents a limitation. While this data provides a useful reference point, it may not reflect the full variability and transactional data of the REC market, especially since the I-REC Standard platform also operates in Ghana with potentially differing prices, typically averaging \$1 to \$3 per MWh. Moreover, the study's findings are based on the assumption that Ghana's REC market would mirror the pricing and dynamics of the D-REC initiative. But, the actual development of a REC market in Ghana could diverge significantly from these assumptions, given different market drivers, regulatory environments, and local stakeholder engagement. These limitations can affect the interpretation of the study's results by potentially overestimating or underestimating the financial benefits of RECs in Ghana. Therefore, caution should be taken when generalising these findings to the broader REC market or the future state of Ghana's renewable energy sector.

Also, the study employs the Real Options Framework to suggest strategic options based on qualitative assessment. A quantitative real options model was not constructed due to the complexity and data-intensive nature of such analyses. While qualitative insights are valuable, the lack of a quantitative model means that the potential economic value of these options is not explicitly calculated, which could limit the precision of the strategic recommendations provided.

### 7.4.Recommendations for Future Research

I. When the REC system potentially develops within Ghana, future research should conduct an empirical analysis of REC pricing and trading within the country using actual market data.

II. Future research should look into exploring how implementing a renewable purchase obligation influences the development and functioning of the REC market in Ghana. Renewable purchase obligation mandates that a certain percentage of electricity consumed must be generated from renewable sources. So, studies could look at how such obligations drive the demand side of the REC market. For example, if a private entity cannot meet their renewable purchase obligation, they might need to purchase RECs to comply with the policy, hence driving up demand for RECs.

III. Future studies could build on this research by incorporating quantitative real options valuation to assess the strategic options under various market conditions, providing a more detailed economic justification for decisions in the renewable energy sector.

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# APPENDIX 1: KEY FINANCIAL METRICS TERMINOLOGIES

### a. Net Present Value (NPV):

NPV is the difference between the present value of cash inflows and the present value of cash outflows over a project's lifetime (Žižlavský, 2014). It accounts for the time value of money, meaning future cash flows are discounted back to their value today using a specific discount rate, often reflecting a project's risk or the cost of capital. A positive NPV indicates that a project is expected to generate value over its costs, making it a financially viable option (Žižlavský, 2014).

### b. Internal Rate of Return (IRR):

IRR is the discount rate that makes the NPV of all cash flows from a particular project equal to zero (Ben-Horin & Kroll, 2017). In simpler terms, it's the annualised effective compounded return rate that can be earned on an invested capital, assuming a project proceeds as planned. IRR is used to evaluate the attractiveness of a project: the higher the IRR compared to the required return or hurdle rate, the more desirable the project (Kierulff, 2008).

### c. Payback Period:

This metric measures the time it takes for a project to repay its initial investment from its cash inflows (Talavera et al., 2007). It is a simple calculation that divides an initial investment by the annual cash inflow, assuming uniform cash inflows every year. A shorter payback period is generally preferred as it indicates a quicker recovery of the invested funds, reducing the risk exposure (Talavera et al., 2007).

## APPENDIX 2: COST COMPONENTS OF THE CAPEX

### CAPITAL EXPENSES (CAPEX)

| Key parameters | Units | Amount |
|---|---|---|
| Total capital cost for installed PV | $ | USD 1,257,000.00 |
| | | |
| ***Installation*** | | |
| *Mechanical istallation* | | - |
| *Becinical installation* | | - |
| *Inspection* | | - |
| | | |
| ***Soft costs*** | | |
| *Margin* | | - |
| *Financing costs* | | - |
| *System design* | | - |
| *Permitting* | | - |
| *Incentive application* | | - |
| *Customer acquisition* | | - |
| | | |
| ***Hardware*** | | |
| *Modules* | | - |
| *Inyerters* | | - |
| *Racking and mounting* | | - |
| *Grid connection* | | - |
| *Cabling/wiring* | | - |
| *Satety and security* | | - |
| *Monitoring and control* | | |
| **Total** | $ | **USD 1,257,000** |

**NB**: *Solar Panels and equipment are exempted from VAT and Import Duties* in Ghana.

# APPENDIX 3: COST COMPONENTS OF THE OPEX

## OPERATING EXPENSES (OPEX)

| Key parameters | Units | Inputs |
|---|---|---|
| Total operations & maintenance cost for installed PV | $ | 7,700.00 |
| *Technical operation* | | - |
| *Insurance* | | - |
| *Preventive maintenance* | | - |
| *Commercial operation* | | - |
| *Corrective maintenance* | | - |
| *Green keeping* | | - |
| *Security* | | - |
| *Panel cleaning* | | - |
| **Total** | **$** | **USD 7,700** |