Université Cheikh Anta Diop de Dakar

****

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

****

MASTER THESIS

Speciality : Economics/Policies/Infrastructures and Green Hydrogen Technology

Topic:

Economies of Scale in Electricity Generation from Renewables in West Africa

Submitted on the 12th of September, 2025 by :

Norgbey Prince

Major Supervisor	Co-Supervisor
Dr. Morten Endrikat	Dr. Khady Yama Sarr

DEDICATION

This work is dedicated to my beloved parents, who taught me the importance of education and resilience. To my friends and colleagues, who stood by me during this challenging rewarding journey. And most importantly, to God Almighty for granting me the patience, strength, and wisdom I needed to complete this thesis.

ACKNOWLEDGEMENTS

Foremost, I extend my deepest appreciation to the West African Science Service Centre on Climate Change and Adapted Land Use for the prestigious scholarship, and The German Federal Ministry of Education and Research (German: Bundesministerium für Bildung und Forschung) (**BMBF**) for the full financial support that made this intensive master's program possible. Your investment in building scientific capacity is truly commendable. My sincere appreciation goes to the President of Abdou Moumouni University for the esteemed admission and academic endorsement granted for the first and second semesters of study, and to Cheikh Anta Diop University for ultimately conferring the master' program upon completion of the program.

I am deeply indebted to my supervisors; whose expertise and patience guided this research. My profound thanks to my supervisors, Dr. Morten Endrikat, and Dr. Khady Yama Sarr, for their meticulous attention to detail, constant availability for discussion, unwavering guidance, insightful critiques, and steadfast encouragement throughout the entire research process. I am equally grateful to the head of International Economics at RWTH Aachen University, Professor Dr. Oliver Lorz, for hosting me to do my research under his chair. His mentorship is a testament to the success of this research.

I wish to acknowledge the leadership and administrative support of Prof. Assane Beye and Prof Fatou Gueye, directors of the graduate Research Program. Thank you for overseeing a robust academic program. For the invaluable international experience, I thank the Vice Chancellor of RWTH Aachen University where I conducted my internship. My gratitude also extends to the director of the internship program. Prof. Peter Letmathe, for welcoming me into his esteemed institution and providing access to remarkable resources. I would like to honor the members of the jury who will preside over the defense of this thesis. Thank you for dedicating your time and expertise to evaluating my work.

ACRONYMS AND ABBREVIATIONS

CAPEX	Capital Expenditure
EE	Energy Efficiency
EIA	Environmental Impact Assessment
FiTs	Feed in Tariffs
GDP	Gross Domestic Product
GW	Gigawatt
HVDC	High-Voltage Direct Current
ICE	Institute of Energy and Climate Research
IRR	Internal Rate of Return
kW	kilowatt
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Hydrogen
LPSP	Loss of Power Supply Probability
MW	Megawatt
O&M	Operation and Maintenance
PPAs	Power Purchase Agreements
PV	Photovoltaic
R&D	Research and Development
RDG	Renewable Distributed Generation
RE	Renewable Energy
RETs	Renewable Energy Technologies
SNG	Synthetic Natural Gas
S-LCOE	System-Levelized Cost of Energy
TELCOE	Techno-Economic Levelized Cost of Energy
VRES	Variable Renewable Energy Source
WT	Wind Turbine

LIST OF TABLES

LIST OF FIGURES

Contents

ABSTRACT

The rapid expansion of renewable energy technologies in West Africa presents both opportunities and challenges for addressing energy poverty and achieving sustainable development. Meanwhile, large-scale deployment continues to be hindered by the high costs associated with electricity generation from renewable sources. Therefore, understanding the role of economies of scale in driving cost is critical in guiding policy and investment decisions. This thesis investigates the impact of project size on the Levelized Cost of Electricity (LCOE) in solar Photovoltaic and On-shore wind energy projects across West Africa. Utilizing 2020 project-level data from the H2-Atlas Africa, the analysis employed regression with both log-linear and parabolic specifications. Country and regional dummy variables were included to capture spatial variations.

The results show a statistically significant inverse relationship between project capacity and Levelized Cost of Electricity for both solar PV and Wind Energy projects, confirming the presence of economies of scale. However, the quadratic models reveal divergent scale-cost dynamics: for solar PV projects, the cost relationship suggests the Levelized Cost of Electricity (LCOE) rises at smaller scales due to financing and regulatory barriers but falls once projects reach utility-scale deployment. For wind projects, costs initially decline with capacity but rise beyond a threshold, indicating diseconomies of scale linked to grid absorption limits and logistical challenges.

These findings indicate that project scaling can reduce costs but only under supportive conditions. Policy implications are clear: governments should encourage optimal project sizing, expand grid infrastructure, and reduce financing barriers for full exploit. Overall, economies of scale must be complemented by institutional and infrastructural reforms to unlock Africa's renewable energy potential.

Key words: Economies of Scale; Levelized Cost of Electricity (LCOE); Renewable Energy; Solar PV; Wind Energy.

RÉSUMÉ

L'expansion rapide des technologies d'énergie renouvelable en Afrique de l'Ouest présente à la fois des opportunités et des défis pour lutter contre la pauvreté énergétique et atteindre le développement durable. Cependant, le déploiement à grande échelle reste limité par les coûts élevés associés à la production d'électricité à partir de sources renouvelables. Par conséquent, comprendre le rôle des économies d'échelle dans la réduction des coûts est crucial pour orienter les décisions de politique et d'investissement. Cette thèse étudie l'impact de la taille des projets sur le coût actualisé de l'électricité (Levelized Cost of Electricity, LCOE) dans les projets solaires photovoltaïques et éoliens terrestres à travers l'Afrique de l'Ouest. En utilisant des données de projets de 2020 provenant de H2-Atlas Africa, l'analyse a employé une régression avec à la fois des spécifications log-linéaires et paraboliques. Des variables fictives nationales et régionales ont été incluses pour capturer les variations spatiales.

Les résultats montrent une relation inverse statistiquement significative entre la capacité des projets et le Coût Nivelé de l'Électricité pour les projets d'énergie solaire photovoltaïque et d'énergie éolienne, confirmant la présence d'économies d'échelle. Cependant, les modèles quadratiques révèlent des dynamiques de coût échelle divergentes : pour les projets solaires photovoltaïques, la relation coût suggère que le Coût Nivelé de l'Électricité (CNE) augmente à des échelles plus petites en raison des barrières de financement et réglementaires, mais diminue une fois que les projets atteignent le déploiement à l'échelle des services publics. Pour les projets éoliens, les coûts diminuent initialement avec la capacité mais augmentent au-delà d'un seuil, indiquant des déséconomies d'échelle liées aux limites d'absorption du réseau et aux défis logistiques.

Ces constatations indiquent que l'extension des projets peut réduire les coûts, mais seulement dans des conditions favorables. Les implications politiques sont claires : les gouvernements doivent encourager un dimensionnement optimal des projets, étendre les infrastructures de réseau et réduire les obstacles au financement pour une pleine exploitation. Dans l'ensemble, les économies d'échelle doivent être complétées par des réformes institutionnelles et infrastructurelles pour libérer le potentiel énergétique renouvelable de l'Afrique.

Mots clés : Économies d'échelle ; Coût nivelé de l'électricité (LCOE) ; Énergie renouvelable ; Énergie solaire photovoltaïque ; Énergie éolienne.

INTRODUCTION

1.1 Background

Africa faces a dual challenge of addressing energy poverty while simultaneously transitioning to sustainable energy sources that can meet rising electricity demand. About 600 million Africans lack access to reliable electricity, which is almost half of the continent's population and more than 80% of the global electricity access gap (United Nation Sustainable Development Group, 2025). Majorities of countries in Northern Africa and countries like Ghana, South Africa and Gabon have made tremendous advancement with regards to electricity access. The proportion of population with access to electricity in these countries is between 80% to100%. However, most countries in Central Africa and Sahel regions have very low access to electricity (Global SDG Database, 2022). This energy crisis within the continent hinders economic growth and social development, affecting the overall quality of life. Renewable energy presents an opportunity to reduce this issue while contributing to global climate goals.

The United Nations has considered Africa as one of the continents with maximum vulnerability to the impacts of climatic change due to population growth and its associated human activities. The quest for renewable energy in advanced economies is driven by air pollution caused by fossil fuel, insecurity in terms of electricity supply, and the need for resource diversification and the probability of resource depletion, Africa however, remains in jeopardy to vagaries of fossil fuels (Aliyu et al., 2018). Renewable energy contributes positively to sustainable development, and it is therefore significant in meeting our energy needs sustainably. By nature, renewable energy offers an environmentally sustainable alternative to fossil fuels. It reduces greenhouse gas emissions and minimizes environmental degradation, aligning with global climate change mitigation efforts such as the Paris agreement which aims to fight climate change by limiting the global rise in temperature to well below 2°C above pre-industrial levels, while aiming for a more ambitious targets of 1.5°C (Delbeke et al., 2019).

However, despite the importance of renewable energy, the scalability and affordability of renewable energy projects in Africa and for that matter West Africa continues to be a significant challenge and requires attention. A major factor affecting the economic viability of renewable energy projects is the concept of economies of scale. Economies of scale refer to the advantages that arise when the scale of operation increases, leading to a reduction in the average cost per unit of output (Silberston, 1972). In the context of renewable energy, as project size increases, the fixed cost such as those associated with the grid integration, construction, and equipment procurements can be spread over a larger quantity of energy produced, thereby lowering the overall cost per kilowatt (kW) (Dismukes & Upton, 2015a).

When production expands, certain cost efficiencies are realized. These include financial economies of scale, which arise from improved borrowing conditions and risk of diversification, technical economies of scale, which are associated with the efficient utilization of infrastructure and technology, and operational economies of scale, which include more effective management practices and lower per unit administrative costs (Neuhoff, 2005a). For instance, large scale solar farms can benefit from bulk purchasing of photovoltaic panels and inverters, while large scale wind projects may secure better financing terms due to lower risk profiles.

Although economies of scale in renewable energy projects in developed countries are well documented, their applicability is less straightforward. Despite West Africa been favourable for large scale renewable energy projects due to the availability of sources, the continent is however faced with several unique challenges. Infrastructure in many West African countries is antiquated, and the costs associated with improving the grid to accommodate large-scale renewable energy projects are often exorbitant. Moreover, financial markets in the region in support of large-scale renewable energy projects are relatively at an embryonic phase, limiting access to the capital necessary for large-scale investments.

Given these challenges, it is important to examine whether the cost efficiencies observed in larger renewable energy projects elsewhere can be replicated in the West African context. If economies of scale can be harnessed effectively, they could play a pivotal role in reducing the Levelized Cost of Electricity (LCOE) for renewable energy projects. LCOE is comprehensive metric that accounts for total costs of energy project over its lifetime divided by total energy produced (Hallam & Contreras, 2015). A lower LCOE would not only make renewable energy more competitive with traditional fossil fuel sources but also make it a more attractive investment for both private and public stakeholders.

Moreover, many West African countries are striving to achieve Sustainable Development Goal 7 (SDG7), which aims to ensure access to affordable, reliable, sustainable and modern energy for all (United Nations, 2015). Therefore, this research is underscored in broader development agenda in

West Africa. SDG 7 is a key driver of economic development and poverty reduction across West Africa and the globe as large. Therefore, understanding the impact of project size on LCOE is not just an academic exercise but also has a practical implication for energy policy investment decisions. Insight from this research will guide policymakers in designing regulatory frameworks and incentives that promote large-scale renewable energy investments, which will lead to a more reliable energy access for millions of Africans.

Furthermore, this research contributes to a growing body of literature that explores the intersection of technology, sustainable development, and economics. Previous studies have largely focused on the technical and economic aspects of renewable energy projects in regions with mature energy markets (Terca & Wozabal, 2021). However, West Africa's unique characteristics necessitates a suitable analysis that considers local conditions. By applying an econometric approach to the relationship between project size and LCOE, this research aims to fill a critical gap in the literature and offer context-specific recommendations that are impactful.

In addition, this research is timely considering the rapid technological improvements in renewable energy. In recent times the cost dynamics of renewable projects are continually being reshaped by innovations in solar panel efficiency, and energy storage. These technological advancements together with an increasing global emphasis on clean energy transitions provide a perfect opportunity to re-examine cost models and investigate new approaches for achieving energy affordability. Therefore, investigating economies of scale in this context is crucial to making sure that West Africa fully leverages its renewable energy potential.

1.2 Problem Statement

A significant barrier to expanding renewable energy projects in West Africa is the lack of clear, comprehensive information regarding the impact of project size on LCOE. While theoretical models suggest that larger projects should benefit from economies of scale - spreading fixed costs over greater output to lower the average cost per kilowatt-hour (Attia, 2015), there is inadequate empirical evidence to confirm this within the unique context of West African countries. This information gap creates significant uncertainty for stakeholders, discouraging large-scale capital investment required to unlock West Africa's vast renewable energy potential. Without evidence-based models, investors are hesitant to commit capital, and as a result, many renewable energy projects operate at suboptimal levels, leading to higher energy costs and diminished economic viability.

This central problem is compounded by several interconnected problems prevalent across Africa. Firstly, Africa's power sector remains heavily reliant on fossil fuels, which account for approximately 80% of total power generation (Amir & Khan, 2022). This dependence persists despite the continent's largely untapped renewable resources, such as solar and wind (IRENA, 2021). The continued used of fossil fuels to meet rising electricity demand undermines sustainable development goals and contributes to energy insecurity (Agoundedemba et al., 2023). Secondly, renewable energy development is hindered by fragmented regulatory frameworks, insufficient infrastructure, and high financing costs, particularly for smaller projects (Deichmann et al., 2011). For instance, small scale solar projects in sub-Saharan Africa often face interest rates above 15% due to perceived investment risks (Grimm & Peters, 2016), while larger projects access favourable concessional financing. Furthermore, fixed regulatory costs for licenses and permits disproportionately burden smaller developers, diminishing their financial margins (Eberhard & Catrina Godinho, 2017).

The consequences of these unresolved issues are profound. Projections indicates that, despite global efforts, approximately 674 million people will still lack access to electricity after 2030, with a substantial portion of this challenge concentrated in Africa (Pan et al., 2021). The inability to harness renewable energy at an optimal scale not only perpetuates energy poverty but also impedes economic growth and innovation, preventing West African counties from achieving energy independence and sustainable development. This is exacerbated by specific constraints, such as insufficient grid infrastructure and high capital costs, which reduce the unanticipated savings from larger projects (Rezaei et al., 2024). Large-scale projects near major transmission corridor may see lower costs, but standalone installations remote areas struggle with grid integration costs that small developers cannot easily absorb (Sanoh et al., 2014).

Therefore, this study examines how project size, in conjunction with financial, regulatory, and infrastructural barriers, impact LCOE. The findings will help mitigate the problems of investment uncertainty and suboptimal project scaling, empowering stakeholders to make informed decisions that accelerate the deployment of large-scale renewable energy and help close West Africa's energy access gap.

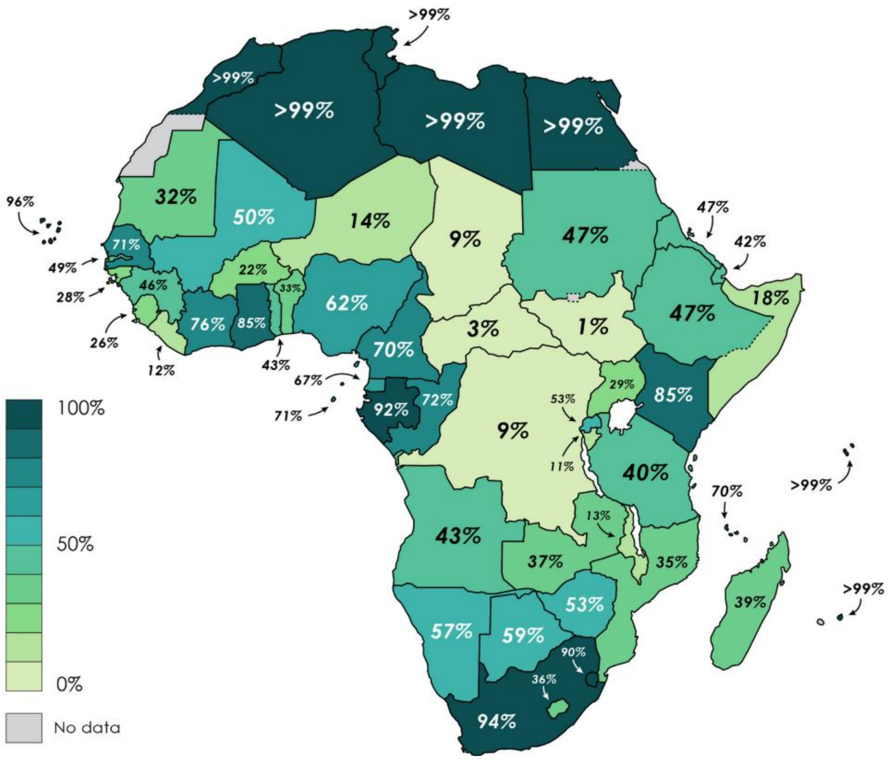

Figure 1 *Access to Electricity in Africa by the Proportion of the Population*
(Source: IEA, 2019)

1.3 Objective of the Study

The general objective is to investigate the impact of economies of scale on the levelized cost of electricity generation from a renewable energy source in West Africa, with the aim of providing insights for optimizing project scalability and investment strategies.

The specific objectives of the study include:

- To analyse the relationship between project size and Levelized Cost of Electricity generated from renewables.
- To provide evidence-based recommendations for investors and policymakers on designing and scaling renewable energy projects to maximize affordability and scalability.

1.4 Research Questions

The research work is guided by the following questions:

Main Research Question

- How do economies of scale impact the levelized cost of electricity generation from renewable energy sources in West Africa?

Sub-Questions

- Does project size (capacity) have a significant negative impact on the Levelized Cost of Electricity (LCOE) from renewable energy source in West Africa?
- How can renewable energy projects be designed and scaled to maximize affordability and investment viability in West Africa?

1.5 Rationale/Justification of the Study

Understanding the relationship between project size and cost per unit electricity produced in West Africa is important, as many renewable energy projects on the continent are currently implemented on a small scale. This challenge stifles the broader adoption of renewable energy technologies and contributes to persistently high cost of energy.

Moreover, the research holds practical significance for both policymakers and investors. By providing evidence-based insights into how scaling up projects can enhance efficiency, the findings can inform the design of targeted policies and investment strategies. Such could help create a more conducive environment for large-scale renewable energy projects, resulting to improved access to affordable energy and enhancing economic development.

1.6 Organization of the Study

The study is organized into three (3) chapters. The first chapter is focused on the review of literature relevant to the research topic. In the second chapter, the data and methodology of the research work is discussed. Chapter three encompasses the analysis of the data collected and the interpretation of the results. Finally, the last section presents the conclusions, perspectives, limitations and recommendations.

CHAPTER 1: LITERATURE REVIEW

This chapter focuses on the theoretical framework, empirical review and the conceptual framework of literature. The chapter begins with definition of key concepts, review of foundational economic theories, then discusses how scale efficiencies emerge in the power systems. The empirical review focus on four thematic areas: (1) Cost competitiveness and Levelized Cost Analysis, (2) Regional Energy Systems and Scalability in Africa, (3) Policy Frameworks, Socioeconomic Impacts and Barriers, and (4) Technological Integration, Storage, and Grid Challenges with the goal of providing actionable insights into the dynamics of project size and how they affect the economic feasibility of renewable energy in Africa.

2.1 Definition of Key Terms

Economies of Scale: Economies of Scale refer to the advantages that a firm enjoys as its output level increases. The benefit results from the inverse relationship between the quantity generated and the fixed cost per unit. The fixed cost per unit decreases by increasing output. With an increase in output, economies of scale also lead to a decrease in average variable costs, or average non-fixed costs. This is the result of increase production scale leading to synergies and operational efficiencies. Therefore, the fixed cost gets spread over more output than before. A firm can achieve economies of scale at any point in the production process. Production in this context relates to the economic concept of production and includes all actions associated with the commodity that do not include the final consumer. The concept of economies of scale can arise as result of buying the inputs necessary for the production process in bulk, by enhancing the internal management structure of the firm, technological advancement, or by location. There are two main types of Economies of scale:

Internal Economies of Scale: Internal economies of scale is a type of economies of scale that refer to the cost advantages that a firm enjoy as it increases its level of output mainly as a result of increase in the plant size of the firm. That efficiency is achieved as the firm improves its output when the average cost per unit output decreases. The factors necessary for this type of economies of scale is independent of the entire industry.

External Economies of Scale: External economies of scale on the other hand is applied to entire industry rather than just one firm. Therefore, external economies of scale are cost advantages that occur outside the boundaries of a single firm but benefit all firms within an industry or locality.

External economies of scale can be realized through industry clustering, the emergence of skilled labor markets, development of shared infrastructure, supportive regulations, and regional investment in logistics and transmission. In the context of renewable energy, external economies are often as the result of the industrial ecosystems that allow all renewable energy firms to operate more cost-effectively.

Diseconomies of Scale: While economies of scale lead to cost savings as production expands, diseconomies occur when expansion becomes inefficient and leads to rising costs. Therefore, diseconomies of scale refer to the increase in the average cost per unit of output as a firm or organization grows beyond an optimal size. This phenomenon can be internal or external just as in the case of economies of scale. The internal diseconomies of scale affect individual firms, and the external diseconomies of scale affect entire industries or regions.

Figure 2 demonstrates the concept of economies of scale. The Long Run Average Costs (LRAC) faced by a firm against its level of output. When the firm increases its output from Q1 to Q2, its cost per unit output falls from C1 to C2. Therefore, the firm experience economies of scale from up to output level Q2. However, any increase in output beyond Q2 leads to an increase in average costs as shown in Figure 3.

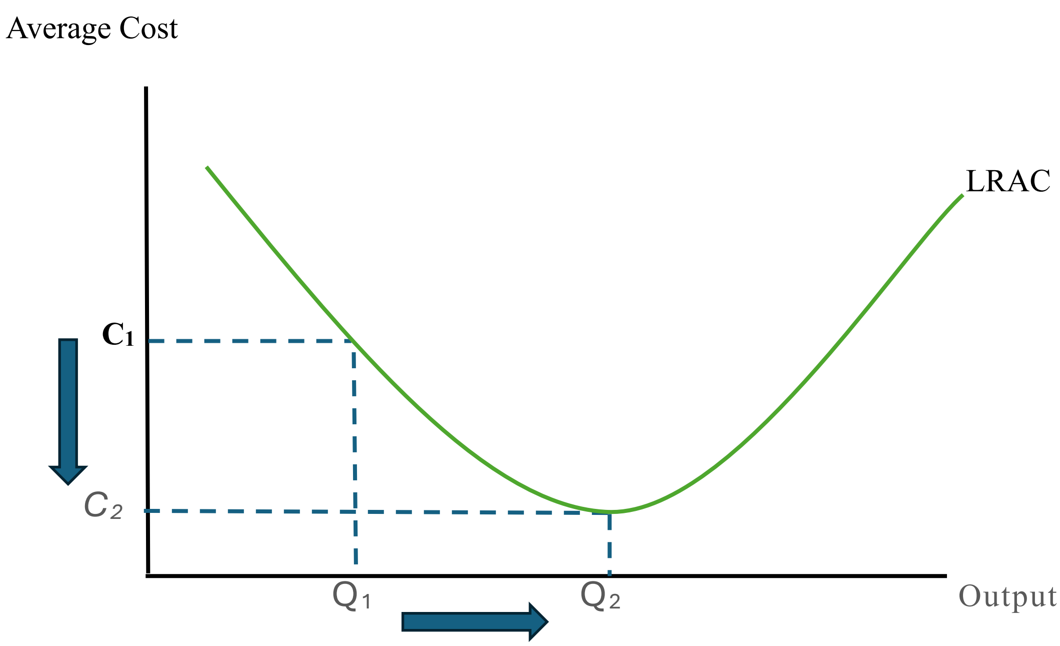

***Figure 2** Economies of Scale*. **Source**: Author's illustration

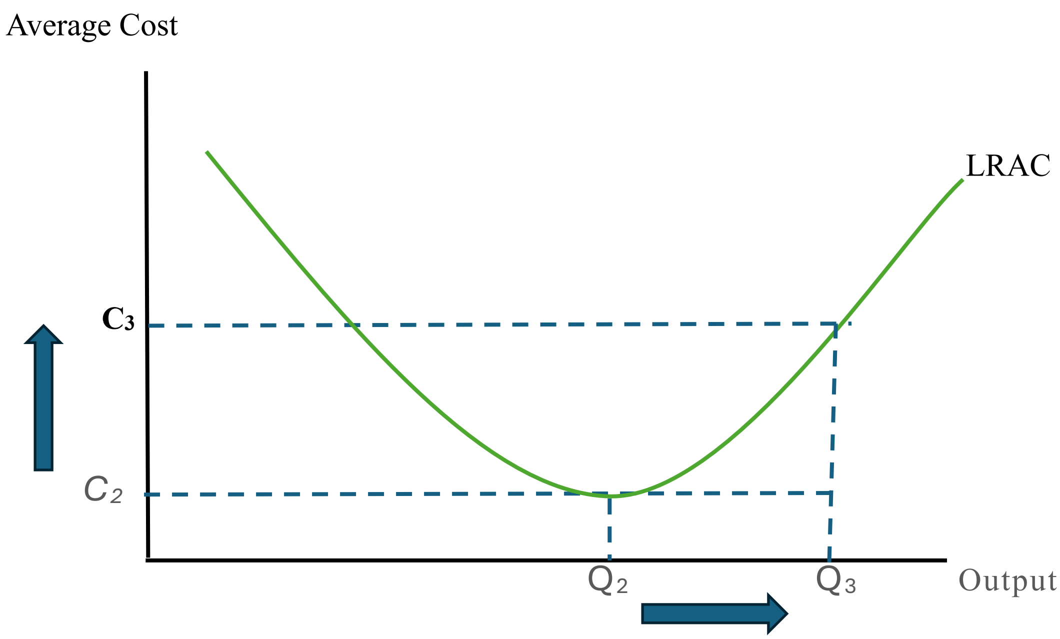

Figure 3 Diseconomies of Scale. **Source**: Author's illustration

2.2 Theoretical Framework

This section presents the theoretical underpinnings that support the analysis of economies of scale in electricity generation from renewable energy sources in West Africa. The aim is to ground the empirical investigation in established economic principles while contextualizing them within the distinct characteristics of renewable technologies and West African energy markets. The theoretical foundation begins by outlining the foundational theories that differentiate between internal and external economies of scale and their mechanisms. These concepts are then connected to the specific dynamics of the power sector, where technical, financial and operational efficiencies play a crucial role in shaping the LCOE. The theoretical underpinning also incorporates insights from modern economic extensions such as learning by doing agglomeration economies.

2.2.1 Foundational Economic Theories of Economies of Scale

The concept of economies of scale originates from classical economic theory, which postulates that increasing the scale of production reduces the average costs of production. Adam Smith first theorized this through the division of labor, arguing that specialization in large scale operations improves efficiency through his famous "pin factory" example. Alfred Marshall (1890) elaborated on this by distinguishing between internal economies of scale which focus on cost savings from firm level expansions, such as bulk purchasing, and external economies of scale which refer to an industry-wide efficiency, such as shared infrastructure. In Marshall's view, large-scale organization and routinization often lower per-unit costs, even as profits may be competed away in mature industries. Stigler et al. (1958) also emphasized the impact of market size and technological innovation in driving economies of scale.

2.2.2 Neoclassical and Contemporary Perspectives

Later researchers expanded on the concept of economies of scale. For instance, researchers like Arrow (1962) identified **learning by doing** as source of increasing returns at aggregate level. Learning by doing are externalities, in which cumulative experience lowers costs over time. Kenneth Arrow argues that knowledge accumulates as firms invest in production, making each unit of capacity slightly more efficient. This implies that the economy's total production function can show an increasing return to scale even if individual firms have constant returns. In modern growth theory, Paul M.Romer (1986) formalized endogenous growth by incorporating scale effects. Innovation and knowledge generate non-diminishing returns, so that larger capacity or R&D investment raises output over time. Hence, larger firms can self-reinforce growth through scale economies innovation. Similarly, Rosenthal & Strange (2004) formalized agglomeration economies, demonstrating how clustered firms share resources and knowledge spillovers, resulting in productivity improvements. In renewable energy, these findings explain how regions where project development is centered have seen faster cost reductions.

Later theories, such as transaction cost theory Williamson (1981) highlight how large firms minimize costs by vertically integrating and streamlining supply chains. These theories explain the reasoning for scaling renewable energy (RE) systems, as larger projects frequently yield lower per-unit costs through shared infrastructure, technological standardization, and efficient logistics. Stigler et al. (1958) used the principle of survivor to determine the optimum size of industry by one or three methods which are comparison of actual costs of firms of different sizes, the comparison of rates of return on investment, and the calculation of probable costs of firms of different sizes based on technological formation.

In a nutshell, contemporary theory sees scale economies as central understanding growth and industrial dynamics: Learning, network effects, and mass production increases the benefits of larger scale, so that larger projects often enjoy lower costs per unit (Schiliro, 2019). Thus, the classical to neoclassical laid the foundation to the concept of economies of scale.

2.2.3 Mechanisms of Scale Efficiencies in Electricity Generation.

Economies of scale in power systems arise through three main channels which are technical, financial and operational efficiencies.

Technical Efficiencies arise when larger installations use more efficient equipment. For example, Utility scale solar PV plants integrate tracking systems and high-capacity inverters to reduce per-unit installation cost. In terms of financial efficiencies, large projects often secure lower financing costs due to reduced perceived risk and greater negotiation power with lenders. In other words, large projects often achieve lower borrowing costs due to stronger credit profiles and risk diversification, reducing the weighted average cost of capital. For operational efficiencies, centralized operation and shared maintenance support services distribute fixed overheads, such as control centers and skilled technicians, across larger energy outputs. This reduces administrative and O&M costs per unit of electricity produced (Haldi & Whitcomb, 1967).

2.2.4 Economies of Scale in Electricity Generation: Traditional vs Renewable Energy Systems.

In traditional energy systems, economies of scale are well documented. Large coal or nuclear plants benefit from lower average costs due to centralized production and bulk fuel procurement. For renewables, scale effects manifest differently but remain critical. Larger turbines and wind farms utilize higher capacity factors and lower maintenance costs per MW. Wiser et al. (2020) attributes 70% cost reduction in wind since 1980 to turbine upscaling and supply chain maturation. Mega dams, such as Grand Ethiopian Renaissance Dam, benefit from long-term cost amortization and grid stability advantages. Utility-scale solar farms through mass production of solar panels, streamlined installation, and grid connection efficiency. Lazard's LCOE Analysis (2023) notes that utility-scale solar costs dropped by 90% since the year 2009, driven by GW-Scale manufacturing. However, renewables face diseconomies of scale in contexts with fragmented demand or weak grids, where decentralized systems such as mini grids may outperform centralized models.

2.2.5 Economies of Scale in Electricity Generation (Global Perspective).

The principle of economies of scale apply strongly to power generation. Electric utilities have high fixed costs (generating units, interconnections, and permits) and low marginal costs, therefore larger plants often have considerably lower LCOE. This is well known in thermal and nuclear plants, and it has a similar impact on renewable energy systems. For instance, large solar PV farms benefit from bulk purchasing of solar panels, efficient installation personnel, and better finance per kW. The uniqueness of solar PV's modularity allows for production in large factories and its installation in small rooftop units. According to IEA, solar panels can be manufactured in large plants, which create economies of scale. This allow utility-scale PV to be significantly cheaper per kWh than distributed systems. At the same time, PV can be scaled down in small increments, but each doubling of capacity yields new learning and price reductions globally (IEA, 2023)

Moreover, large hydropower projects require huge upfront investment, but ones built they generate very low-cost power overtime. Large hydropower projects typically have much lower unit costs and O&M percentages around 2 to 2.5% of capital compared to small hydro. In contrast, small scale hydro (<10MW) often has higher per kW capital costs and O&M costs of 1 to 6%, because it cannot spread fixed cost widely (IRENA, 2012).

Biomass and bioenergy are more complex. On one hand, larger biomass power plants can negotiate cheaper fuel through bulk biomass supply and install larger turbines, resulting in somewhat greater production. However, fuel logistics usually restrict scale. That is transport costs rise when fuel must be transported from a long distance away. In biomass facilities, feedstock constraint often exceeds economies of scale (IRENA, 2012a).

In addition, wind energy shows similar effects. As turbines have grown more powerful, one turbine can sweep much more area, raising capacity per machine. This reduces the number of foundations and connections needed per MW. A study of China's wind sector (Qiu & Anadon, 2012) found that cumulative capacity growth led to 4.1% to 4.3% reduction in price per doubling capacity. Showing learning effects, local manufacturing scale, and experience with larger farms. Therefore, in practice, wind farm developers achieve economies by installing turbines in bulk and by improving operation and maintenance protocols on large farms.

2.2.6 Economies of Scale in Renewable Technologies

As stated earlier, PV modules are mass-produced in factories, hence a significant increase in production volume results in quickly lowering panel prices (learning curve). On site, establishing a 100MW plant requires slightly more planning than installing a 10MW plant, therefore the cost per MW is significantly lower for the bigger plant. Large scale solar PV, for example, can benefit from lower transmission costs per unit, and a single project can achieve capacity factors near to the site maximum, whereas a variety of small systems each incur overheads. IEA notes that solar PV's modularity allows for economies of scale when produced in large quantities. Africa's renewable energy potential is vast but underutilized due to financing and infrastructural gaps. Economies of scale can mitigate these challenges through utility scale solar PV projects like Morocco's Noor Ouarzazate (580MW). Modern onshore wind turbines are capable of producing more than 5MW. Building a 500MW wind farm instead of several 50MW farms means fewer substations, shared roads, and bulk purchases of towers and blades. Learning by doing further lower costs.

For hydro projects, the range of sizes clearly demonstrates economies of scale. Large scale hydro projects (100MW to GW scale) can have capital costs as low as USD $650/kW, just few cents per kWh. However, mini and micro hydro schemes often face LCOEs well above grid prices due to the spread of fixed cost over little energy (IRENA, 2012c).

Africa's context influences how economies of scale operate. Africa has huge renewable potential, but most existing installations are spread across mini grids, limiting scale economies. Several factors such as financial issues, infrastructure constraints, and policy and institutional barriers hinder large-scale deployments.

2.2.7 Sustainable Development Theory and Renewable Energy Nexus

This study is partly grounded in the core principles of Sustainable Development Theory, defined as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987). The theory of sustainable development provides three-dimensional framework known as the three pillars of sustainability. These pillars include Economic, Social, and Environmental sustainability. These pillars are used to evaluate the impact and viability of development projects. The analysis of economies of scale in this thesis directly interacts with all three dimensions. In terms of economic aspect of sustainability, affordable energy is a prerequisite for economic growth, industrial development, and poverty reduction. By making energy more competitive with fossil fuels, an economically sustainable energy transition will be ensured. Environmentally, encouraging the use of renewable energy contributes to climate change mitigation, and resource conservation. In addition, the scale of renewable energy projects has profound social implications, by improving energy accessibility and job creation.

2.3 Conceptual Framework

This part of the literature demonstrates the conceptual framework necessary to investigate how economies of scale influence the cost-efficiency of electricity generation from renewable energy sources in Africa. The framework identifies the primary variables affecting LCOE and illustrates the relationships among them.

The conceptual framework consists of independent variables, mediating variables and the dependent variables. The independent variables are technology type and project size. These independent variables are the main factors influencing other variables. For example, larger project sizes are hypothesized to benefit from economies of scale, leading to lower unit costs and higher capacity factors. Mediating variables include learning effects and integration cost. These mediating variables moderate the relationship between the independent variable (project size) and the dependent variable. For instance, as more projects are developed and experience is gained, efficiency improves, and costs decline (learning-by-doing). Larger projects accumulate more experience, enhancing learning effects. The dependent variable which is the unit costs of electricity (The LCOE) reflects the economic efficiency of producing electricity. Lower unit costs indicate better cost-efficiency, which is essential for affordable renewable energy in Africa.

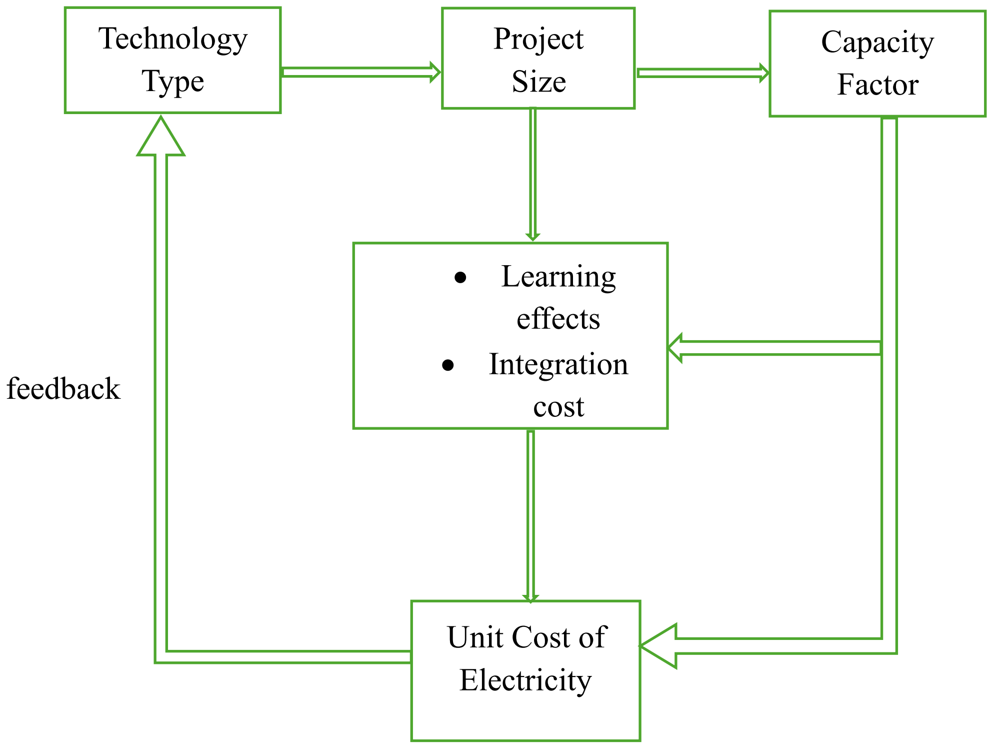

Figure 4 *Conceptual Framework* **Source**: Author's illustration

2.4 Empirical Literature Review

The empirical literature review looks at the economies of scale in renewable electricity generation, specifically how project size affects cost-efficiency. Cost competitiveness, system integration, and socioeconomic benefits like rural electrification and job development are all important considerations. This analysis, which combines global and regional research, examines hurdles, possibilities, and policy considerations crucial to optimal renewable energy development in Africa. The empirical review is classified into four (4) thematic areas: (1) Cost competitiveness and Levelized Cost Analysis, (2) Regional Energy Systems and Scalability in Africa, (3) Policy Frameworks, Socioeconomic Impacts and Barriers, and (4) Technological Integration, Storage, and Grid Challenges with the goal of providing actionable insights into the dynamics of project size and how they affect the economic feasibility of renewable energy in Africa.

2.4.1 Cost Competitiveness and Levelized Cost Analysis.

The LCOE is a primary metric for assessing the cost competitiveness of electricity generation technologies. Timilsina (2021) conducted comprehensive research on renewable energy technology and cost competitiveness for electricity generation, emphasizing on the geographic scope of various studies that assess the global cost competitiveness of renewable energy technologies (RETs), particularly utility-scale solar and onshore wind with the objective of assessing the Levelized Cost of Electricity (LCOE) for various technologies and identify the factors that influence these costs across locations and technologies. The methodology employed involves calculating nearly 4000 LCOEs for 11 different power generation technologies, using a variety of input factors to account for variability in capital costs, operational and maintenance expenses, and discount rates. The findings show that, while RETs, particularly wind and solar, have seen significant cost reductions, their competitiveness against fossil fuels varies depending on local conditions and input assumptions, highlighting the importance of incorporating geographical and technical variety when examining the economics of scale in renewable electricity generation. Similarly, Borenstein (2012) examines the economics of renewable electricity generation in the United States, motivated by the environmental externalities of fossil fuels and the challenges of adopting market-based emission pricing. The paper sought to weigh the direct costs of renewable energy against the societal benefits, considering subsidies and government actions. The technique included comparative cost analysis of various energy technologies due to location, market conditions, and subsidies, underscoring the subtle benefits of renewables in lowering emissions while noting their limited direct competitiveness without subsidies.

Further studies reinforce the importance of scale and local context. For instance, case study by Qiu & Anadon (2012) on China's wind industry attributed a 4.1% - 4.3% cost reduction per doubling of installed capacity of learning effects, cumulative capacity growth, and localized manufacturing. This underscores the importance of scaling production and localizing supply chains, which is applicable to the context of Africa. This principle is further explored by Rezaei et al. (2024) in the context of hydrogen production in Australia. Their Techno-economic modeling revealed that while large-scale photovoltaic (PV) systems benefit significantly from economies of scale, wind turbine (WT) systems were more cost-effective for smaller plants due to higher capacity factors. This demonstrates that the optimal technology and scale are not universal but are instead tied to specific resource availability and project size.

The challenge of integrating renewables into existing power grids adds another layer of complexity to cost analysis. Khatib & Difiglio (2016), explores the economic issues posed by nuclear power and renewable energy technologies, with a focus on their integration into power grids and the implications for traditional electricity producing methods. The impetus arises from the growing share of renewables in the energy mix, whereas nuclear energy has stagnated in many industrialized nations. The study's goal is to assess the levelized cost of electricity (LCOE) for both nuclear and renewable energy sources, as well as the effect of subsidies, discount rates, and system integration costs on their economic feasibility. The authors performed a comparative analysis of the LCOE for various energy technologies, considering capital costs, operational expenses, and the effects of subsidies. They also evaluate the integration costs of renewable energy sources, which are intermittent and require backup generation. The results of their research show that, while the costs of renewable energy technologies are reducing, they still face major challenges in terms of system integration and infrastructure investments. In contrast, nuclear power remains economically expensive due to high capital costs and regulatory uncertainties, resulting in a diminishing share of global energy consumption.

The limitation of traditional LCOE model have led to the development of more sophisticated metrics. Okwori et al. (2024) introduced the Techno-Economic Levelized Cost of Energy (TELCOE) model in a study focused on Southwest Nigeria. This model enhances the standard LCOE by incorporating local variables such as technical constraints, governance, and social factors, providing a more accurate assessment for mini-grid projects in Sub-Saharan Africa. Their findings showed that TELCOE values were consistently higher than LCOE values by 4% for solar PV up to 14% for wave power. This finding reflects the real-world costs of operating in developing regions. In similar vein, Chong et al. (2024) developed a system LCOE (S-LCOE) model for China, which integrates grid and balancing costs. Their research revealed that when these additional costs are included, the S-LCOE for PV is currently higher than the price of coal-fired electricity in all provinces, highlighting that true grid parity is more complex than a simple comparison of generation costs.

Finally, studies from African countries provide valuable context Shea & Ramgolam (2019) conducted an LCOE analysis for Mauritius, a small island developing state. They found that the capacity factor was the impactful variable on LCOE and that utility-scale solar PV and bagasse were already more cost-competitive than fossil fuels, even without considering environmental cost-effective option compared to wind, with LCOE of $58.75-$63.82/MWh, while offshore wind was significantly more expensive. These studies collectively demonstrate that while the principles of LCOE and economies of Scale are universal, their practical application yields vastly different results depending on the specific technological, geographical, and socio-economic context of the region.

2.4.2 Regional Energy Systems and Scalability in Africa.

Deichmann et al. (2011) conducted a study focusing on rural Sub-Saharan Africa, prompted by the region's poor energy access and the need for long-term economic development. The goal was to compare the cost-effectiveness of localized renewable energy sources and centralized grid expansion. A geographically explicit model was used, which included spatial data and cost estimates from engineering studies. Case studies from Ethiopia, Ghana, and Kenya provided information on grid and decentralized energy provision costs in current and projected scenarios. The findings revealed that, while decentralized renewable energy is critical for rural electrification, it is only cost-effective in remote places, with grid expansion preferred in denser regions. The paper emphasized the significance of decarbonizing centralized power networks. Barasa et al. (2018) also examines the feasibility of a 100% renewable energy (RE) system for Sub-Saharan (SSA) by 2030, focusing on cost optimization through economies of scale in electricity generation. The study divides SSA into 16 sub-regions and employs a linear optimization model to analyze four scenarios, including decentralized and centralized grid configurations with high-voltage direct current (HVDC) interconnections. The motivation stems from the urgent need to address energy poverty and climate change while leveraging SSA's abundant solar and wind resources. Results revealed that centralized grid scenario reduces the levelized cost of electricity (LCOE) from 57.8 €/MWh to 54.7 €/MWh, highlighting the cost benefits of scaling up RE generation and interregional transmission. The study also finds that integrating desalination and synthetic natural gas (SNG) production further enhances system flexibility, reducing total cost by 6%.

Moreover, Uyigue & Archibong (2010) conducted comprehensive study to examine the potential for scaling up renewable energy technologies (RETs) in Africa emphasizing solar, wind, and biomass. The objective is to address energy poverty and inefficiency tied to traditional biomass use, which dominates Africa's energy mix. The study covers the entire continent but notes regional disparities, such as higher solar insolation in North Africa (5.0-6.0 kWh/m^2) compared to Sub-Saharan Africa. The methodology involves a qualitative review of RET potentials and barriers, including policy gaps and financing challenges. Findings underscore the need for targeted investments, gender-sensitive policies, and international cooperation to overcome barriers. The authors argue that economies of scale in RET deployment can lower costs, citing 80% reduction in solar photovoltaic (PV) costs over two decades evidence. Pueyo et al. (2016) examine the cost and financial viability of renewable energy (RE) projects in Kenya and Ghana, focusing on wind, solar, hydro and geothermal technologies. The study aims to determine whether RE is financially viable and affordable for consumers in these countries. Using a levelized cost of energy (LCOE) model and internal rate of return (IRR) analysis, the authors compare the costs and returns of RE projects under different financing scenarios. Their findings reveal that Kenya's wind and geothermal projects offer low costs and attractive due to high-capacity factors and concessional finance, while Ghana's RE projects, except hydro, face higher costs due to financing challenges and lower resource quality. The study also highlights the role of public finance and policy in improving RE affordability and viability in sub-Saharan Africa.

In addition, Ntumba (2022) examines the challenges and opportunities of scaling RE in South Africa, emphasizing the need to transition from fossil fuels to mitigate load-shedding and climate change. The study employs qualitative interviews with energy sector stakeholders to identify barriers such as skills shortages, incoherent policies, and financing gaps. Results suggest that circular economy principles (reduce, reuse, recycle) can enhance RE adoption by promoting sustainable practices and stakeholder collaboration. The research underscores the potential of RE to diversify South Africa's energy mix with investment in infrastructure and policy coherence are important for scaling up.

2.4.3 Policy Frameworks, Socioeconomic Impacts and Barriers.

Neuhoff (2005) research paper focuses on the worldwide potential for large-scale deployment of renewable energy technology, which is motivated by the need to reduce greenhouse gas emissions while diversifying energy supplies to improve energy security. The primary objective is to identify economic impediments to renewable energy adoption and recommend legislative solutions to overcome these barriers and accelerate the deployment of renewable technologies. The study uses an economic analytical framework to evaluate barriers including market structure, competitiveness, and non-marketplace constraints. It also tackles 'technology lock-out' and the importance of strategic deployment and Research and Development (R&D) assistance. The analysis is based on a comparison of resource assessments and numerous studies on renewable energy potential and costs. The findings show that, while technology and resource limits are minor impediments, economic hurdles and market structures greatly impede large-scale adoption. The report suggests that planned deployment initiatives and improved R&D assistance are required for overcoming these challenges and making meaningful contributions from renewable technologies. Similarly, Abbas et al. (2020) also conducted a comprehensive research to examine the determinant of wind energy deployment across 17 African countries from 2008 to 2017, using panel data fixed-effects model. Their study motivated by the need to address energy security, sustainable consumption, and low carbon emissions, found that socioeconomic factors such as GDP, energy use, and CO2 emissions significantly influenced wind capacity expansion, while policy instruments such as feed in tariffs (FITs) and tax incentives had negligible effects.

These studies align with that conducted by Ramos et al. (2019) examines the environmental and economic impacts of integrating small-scale renewable distributed generation (RDG) technologies in Spain by 2020, driven by EU decarbonization goals. The study aimed to quantify the effects of RDG on employment, production, and CO2 emissions utilizing Input-Output model. Results showed that RDG, particularly from photovoltaic and small hydropower technologies, could significantly boost employment, reduce emissions by 21.67% compared to 2013, and contribute to sustainable economic growth. The findings underscore RDG's potential to improve system flexibility and energy efficiency. Cantore et al. (2017) evaluate the employment and cost effectiveness implications of scaling up renewable energy (RE) and energy efficiency (EE) in Africa. The study, motivated by the need to reconcile climate goals with economic growth, adapts a U.S based methodology to African context, focusing on job creation and generation costs under varying RE and EE adoption scenarios. The authors employ direct and indirect job coefficients from Wei et al. (2010) and adjust for Africa's lower manufacturing efficiency (Cantore et al., 2017, 4). Results indicate that ambitious RE/EE deployment generates highest employment and lowest cost per job created, despite higher upfront expenses (Cantore et al., 2017). The study therefore underscores the viability of RE scaling in Africa but highlights trade-offs between employment benefits and generation costs.

2.4.4 Technological Integration, Storage, and Grid Challenges

Antonelli et al. (2018) conducted thorough research to assess the impact of large-scale renewable energy deployment on Italy's electricity market from 2008 to 2015. The objective was to investigate the effects of integrating intermittent renewable energy sources on market volatility, generation efficiency, and grid stability. The authors used historical data and a case study approach to evaluate the impacts of renewable energy, placing importance on policies like feed-in tariffs and their implications for fossil fuel plant operation. Results highlighted a reduction in fossil fuel plants efficiency due to frequent cycling, increasing price volatility, and the critical need for policy reforms to successfully balance supply and demand. In the paper "Economies of Scope for Electricity Storage and Variable Renewables" by Terca & Wozabal (2021), the authors investigate the economic implications of jointly owning variable renewable energy sources (VRES) and electricity storage, with a primary focus on the German market. The study is motivated by the widely held view that merging these assets can result in considerable economic benefits for VRES owners, which the authors seek to examine. Their goal is to provide a logical analysis of when economies of scale occur in competitive power markets, based on a basic stochastic optimization model that assumes frictionless markets. The methodology includes a theoretical framework that analyzes the potential profits from joint ownership with those from separate operations, coupled with a numerical case study to demonstrate their findings. The results show that, contrary to popular belief, the combination of VRES with storage provides little economic gain under regular market conditions, albeit unique scenarios may allow for economies of scale. This empirical assessment emphasizes the necessity for a comprehensive knowledge of the economic dynamics involved in renewable energy generation and storage integration.

In the African context, the research work of Coppez et al. (2011) addresses the need for reliable and cost-effective renewable energy hybrid power systems with storage to electrify remote areas in South Africa where grid extension is impractical. The objective was to review battery storage technologies and optimization strategies to minimize system cost while ensuring reliability. The core problem identified is the inherent intermittency of renewables such as PV and wind, leading to supply-demand imbalances in off-grid systems, coupled with the high capital cost and management challenges of battery storage. Key findings confirmed that lead-acid batteries offer the best trade-off for rural South Africa; accurate dynamic modelling and intelligent battery management are crucial for reliability and longevity: and optimization must balance LPSP minimization with system cost, with Genetic Algorithms proving effective for sizing hybrid RES components. The research underscores the crucial role of optimized battery storage in enabling feasible off-grid renewable electrification.

Furthermore, in Africa, integrating renewable energy technologies has become both necessary and challenging. Historically built for centralized, fossil fuel-based generation, Africa's electrical systems are currently facing pressure to integrate significant amounts of VRE, including wind and solar PV. Both institutional reforms and improvements to the physical infrastructure are necessary for integration (Ouedraogo, 2019). The lack of adequate monitoring and control equipment in many African grids, particularly at medium and low voltage levels, is one of the primary technical challenges. When variable resources are integrated, this results in dependability problems, violations, and poor observability. Research indicates that countries must make investments in ICT systems, smart-grid technology, and real-time monitoring in order to successfully integrate renewable energy (O et al., 2025). For instance, the transmission company of Nigeria (TCN) has adopted some new technologies for transmission management, but these have not yet expanded to large-scale integration of renewable energy, which limits system transformation (Igbinovia & Krupka, 2018).

2.4.5 Contradictory Evidence on Learning Effects and Scale Economies of Renewable Energy Deployment.

Dismukes & Upton (2015) examines the offshore wind development costs in Europe, motivated by the increasing interest in renewable energy and the potential for cost reductions through economies of scale and learning effects. The objective of the paper is to empirically test the presence of economies of scale and learning effects in the overnight development costs of offshore wind projects across multiple European countries. The authors use a quantitative econometric model to examine the relationship between overnight costs and project capacity, relying on cost-output elasticity to determine economies of scale. They also investigate cumulative capacity to see if there are any potential learning effects, using regression analysis to control for a variety of variables such as water depth and distance from shore. The analysis is based on a dataset of forty-one offshore wind farms built during a twenty-year period in eight European nations, including Denmark, Sweden, the Netherlands, the United Kingdom, Germany, Ireland, Belgium, and Finland. The study found no significant evidence of economics of scale or learning effects in offshore wind production. Specifically, the study indicates that costs rise at a rate roughly equal to capacity, implying constant returns on scale. Furthermore, the research demonstrates that cumulative capacity does not result in cost savings, implying that past experiences with offshore wind projects do not transfer into lower costs for future initiatives. However, for nascent African offshore wind markets, the potential for economies of scale may differ greatly for emerging offshore wind markets in Africa. The potential advantages of Africa include the ability to leverage global learning effects and mature technologies from established markets, avoiding early high-cost learning phases, and the possibility of standardized deployments along more uniform coastlines such as the shelf of South Africa (Umoh et al., 2024).

A comprehensive study conducted by Elsner (2019) focused on the continental-scale examination of Africa's offshore wind potential, points out that Africa's unique conditions could unlock scale efficiencies that Europe was unable achieve. The study of Dismukes & Upton (2015) on European projects revealed costs increasing proportionately with capacity implying continuous returns to scale. In contrast to Europe's dispersed North Sea locations, which call for specialized solutions. Whereas Africa's vast, consistent coastlines permit standardized deployments. Moreover, Elsner (2019) also projects that africa could leverage global learning spillovers from mature markets such as turbine procurement, and grid integration, bypassing early stage efficiencies observed by Europe. Thus, where of Dismukes & Upton (2015) observed stagnation, the paper by Elsner (2019) suggests Africa's offshore wind deployment may indeed realize the economies of scale.

2.4.6 Main Research Gap Identified

The main research gap is the lack of empirical evidence on how economies of scale specifically operate within Africa's renewable energy sector. While studies in developed regions indicate that larger projects reduce per-unit costs through economies of scale and learning effects, there is insufficient research quantifying this relationship in Africa where unique financial, and regulatory challenges may alter these dynamics. This gap limits the ability to develop evidence-based policies and investment strategies tailored to scaling renewable energy projects in the African context.

CHAPTER 2: DATA AND METHODS

This chapter outlines the research design, data sources, variable construction, and analytical tools used to investigate the impact of economies of scale on the per unit cost of electricity generation from wind and solar energy technologies in Africa. The chapter begins by outlining the research area and the nature of data collected, followed by description of how key variables like LCOE and installed capacity are measured. It then provides the theoretical model and describes the econometric framework.

3.1 Study Area: West Africa's Renewable Energy Landscape.

The analysis includes 15 West African countries, which cover latitudes 4°N – 25°N and longitude 26°W – 16°E. These countries include Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo. This region has favorable renewable energy resource heterogeneity due to varying sun irradiation ranging from 1,800–2,400kWh/m^2/year and wind patterns (monsoon-driven coastal versus harmattan-influenced interior) (Dokka, 2021).

Moreover, the West African region was selected because it offers a strong combination of data availability, empirical variations, and policy relevance that makes it an ideal region for examining correlation between scalability and cost in renewable energy than many other African subregions. The availability of public and donor databases such as Institute of Energy and Climate Research (ICE) database, provide comparatively richer project-level information for solar and onshore wind than many other African subregions. This allows for robust econometric analysis and cross-country comparison.

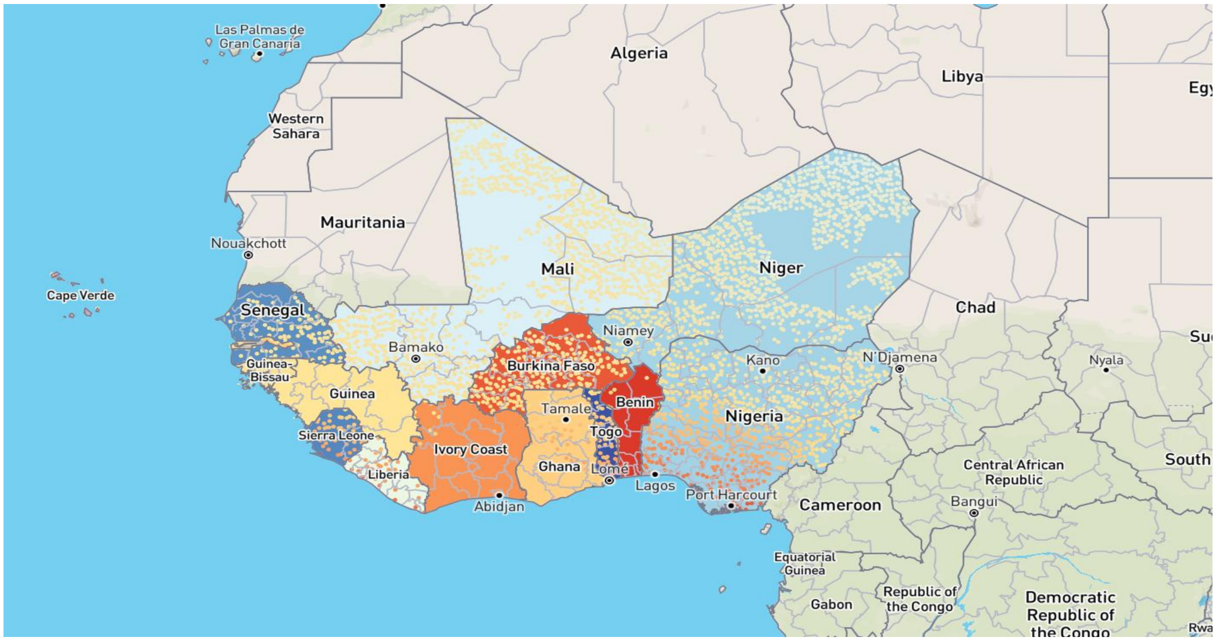

Figure 5 *Study Area Showing the Potential Solar PV Projects Across West Africa*
(**Source**:H2 Atlas)

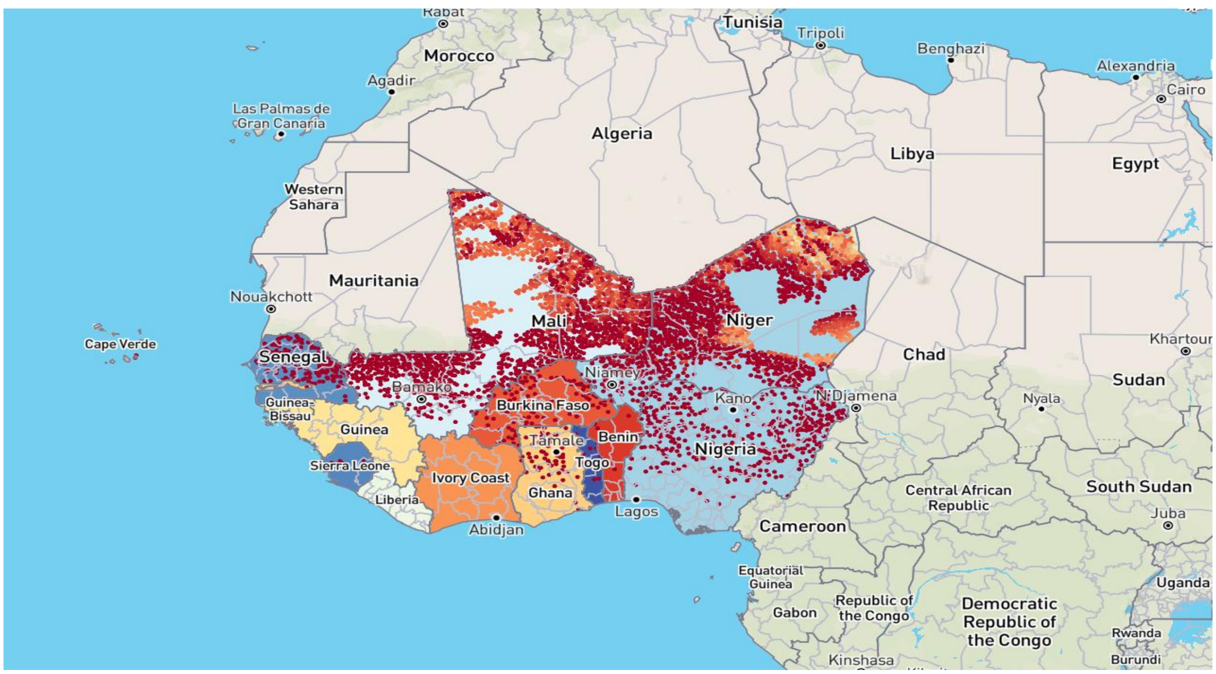

Figure 6 *Study Area Showing the Potential Onshore Wind Energy Projects Across West Africa*
(**Source**:H2 Atlas)

3.2 Research Design and Philosophical Foundation

This study adopts a quantitative, explanatory research design based on positivist epistemology (Bryman, 2016) with secondary data analysis to evaluate economies of scale in renewable energy systems. This approach is particularly suitable for the present research because the major question of whether economies of scale exist in electricity generation from renewables requires objective measurement and statistical analysis of quantifiable variables like installed capacity, and LCOE. The methodological rigor required to find empirical regularities and test causal links between these variables without subjectivity, and this is grounded in positivist framework. The methodological framework employed cross-sectional spatial analysis of 4,912,859 observations of both solar PV and wind energy projects.

3.3 Type and Source of Data

The research based on secondary data from the Green Hydrogen Atlas-Africa, sourced from its 2020 data release. This cross-sectional dataset, developed by the Institute of Energy and Climate Research (IEK-3) in Juelich, Germany, and available at https://africa.h2atlas.de/ecowas, forms the empirical foundation of this study, providing key variables such as installation capacity, LCOE, geographic location, and technology type.

Table 1 Summary table of Variables and Source of data

Variables	**Source**
LCOE, Installed capacity, Geographic location, and technology type.	Institute of Energy and Climate Research (ICE) **Juelich Systems Analysis (ICE-2)** GUI version 3.3.0

3.4 Model Specification

This study investigates the impact of project size (capacity in kW) on the Levelized Cost of Electricity (LCOE in Euro/kWh) generation from a renewable source in Africa. Therefore, in order to capture the relationship between project size and cost per unit electricity generated, log-log linear regression model for solar PV and wind energy projects across West Africa was employed. This method analyzes the degree of proportionality to changes in the dependent variable as a result of a percentage change in one of the independent variables while controlling for country and regional fixed effects. The log-transformed linear regression models are as follows:

I. $\log(LCOE_{pvi}) = \beta_0 + \beta_1 \log(capacity_{pvi}) + \beta_2(country_{pvi}) + \beta_3(region_{pvi}) + \varepsilon_i$

II. $\log(LCOE_{WEi}) = \alpha_0 + \alpha_1 \log(capacity_{WEi}) + \alpha_2(country_{WEi}) + \alpha_3(region_{WEi}) + \varepsilon_i$

Where,

$\log(LCOE_{pvi})$ is the natural log of cost for solar PV project i

β_0 and α_0 are the intercepts and each represent the baseline log (LCOE).

$\log(capacity_{pvi})$ is the natural log of installed capacity (in kW) of solar project i

β_1 and α_1 are the coefficients measuring the elasticity of LCOE with respect to the capacity.

$country_{pvi}$ and $region_{pvi}$ are the set of country and regional dummy variables, where each Solar PV project is located.

β_2, β_3, α_2, and α_3 are the coefficients capturing fixed effects respectively for countries and regions relative to the reference country.

$\log(LCOE_{WEi})$ is the natural log of levelized Cost of Electricity (LCOE) for wind energy project i

ε_i is the error term

3.5 Definition of Variables and Expected Result

In order to empirically investigate the relationship between project scale and cost in electricity generation from renewables, it is necessary to clearly define the variables included in the econometric model and outline their expected influence on the dependent variable. This section provides a detailed description of both the dependent and independent variables, including their measurement, units and theoretical justification. The choice of variables is informed by the econometric theory on economies of scale, contextual realities of the African power sector, and prior empirical studies on renewable energy project costs.

3.5.1 Dependent Variable

Levelized Cost of Electricity (LCOE): Levelized Cost of Electricity (LCOE) for power production from open-field PV and systems and individual onshore wind turbines for 2020 (H2 Atlas, 2020). LCOE is a metric used to measure the average cost of generating electricity over the lifetime of a project and it was measured in €ct/kWh (Shen et al., 2020). The LCOE is an abstraction from reality that was used to compare or rate the levelized costs of the various energy generating technologies. Abstraction was created to eliminate biases between technologies.

3.5.2 Independent Variable

Capacity: The capacity of the project defines the size of the project in kW. This captures economies of scale, with the hypothesis that larger projects lead to lower unit costs of electricity generation from renewable energy. The coefficient of the total capacity expected to be less than 0, indicating a negative relationship between the Levelized cost of electricity and the size of the projects.

Technology Type (Solar PV and On-shore Wind Energy Projects): A categorical variable representing the type of renewable energy technology used. This accounts for cost differences due to variations in technology. The relationship between LCOE and the type of technology used varies depending on the baseline technology.

3.5.3 Control Variables

The control variables are made up of two categorical variables which are the country and regional dummies respectively. These variables account for the differences in resources, policy, infrastructure, labor costs and other country-specific factors. There was no specific expectation with regards to the relationship between these dummies with respect to the dependent variable (LCOE).

Table 2 Summary of Variables, their Definitions, and Measurements.

Variable	**Type**	**Definition/Measurement**	**Justification**
LCOE	Dependent	Levelized Cost of Electricity of project measured in Euro cent/kWh	Indicator for cost efficiency, lower values reflect cheaper electricity generation
Installed Capacity (Capacity)	Continuous (log-transformed)	Size of project in kW	Larger projects benefit from internal economies of scale, but very large projects may experience diseconomies
Country Dummies	Categorical	Binary variable for each country (1=project in country; 0 = otherwise)	Controls for institutional, regulatory, and geographical differences in project costs.
Regional dummies	Categorical	Binary variable for each African sub-region (1=project in region; 0=otherwise)	Captures broader regional variations such as infrastructure, policy, and renewable resource endowment.

Technology	Category	Solar/wind	Used when comparing across technologies: allows identification of technology-specific

3.6 Data Processing

3.6.1 Log-Linear Transformation of the Regression Model

This study uses a log linear regression model to assess the cost-efficiency of electricity generation from solar PV and onshore wind energy technologies in Africa. The primary justification for employing logarithmic transformation stems from both the statistical features of the data and the economic interpretation of the model's parameters. Because of the wide range of project size and cost across countries, the dependent variable (LCOE), and the main continuous variable, which is the installed capacity, have a right skewed distribution. Log-transformation minimize heteroskedasticity, and improve linearity in regression models (Wooldridge, 2016).

The regression models were log-transformed in order to capture the elasticity. That is a percentage change in the dependent variable when the independent variable changes by some percentage holding other factors constant. The dependent variable as well as the ratio scale independent variable were log-transformed capturing the elasticity of change (Benoit, 2011)**.** This interpretation aligns well with economic theory, particularly when analyzing economies of scale, where relative changes are more insightful than absolute changes.

3.6.2 Quartile transformation of data.

Quartile transformation divides a continuous variable into four equal sized groups depending on its distribution. Each quartile represents 25% of the data, ranging from lowest to highest values. In the context of this study, which examines economies of scale in electricity generation from renewable energy technologies across Africa, the quartile transformation was an effective technique used to classify projects by scale (such as capacity) and compare their associated LCOE. Quartile categorization allows for more intuitive understanding of how cost structures react across various project size bands. These project size bands are labelled small scale, medium scale, and large-scale projects. The values of the continuous variable, which is the installed capacity in the model, were sorted in ascending order. The sorted data were then divided into four groups based on the 25th percentile (QI), median (Q2), and 75th percentile (Q3). Each quartile respectively represents small, medium, and large scale projects.

3.6.3 Parabolic Regression

This methodological approach was necessitated by evidence indicating that economies of renewable energy generation are not always linear. This means that although costs may initially decrease as project size grows, they may start to rise as a result of diseconomies of scale after a certain threshold. The rationale for employing a parabolic model was because initial linear models indicated a negative relationship between capacity and LCOE, consistent with internal economies of scale. However, scalability of larger projects is often associated with increased complexity, coordination difficulties, transmission problems, or environmental and costs of land use, especially in emerging markets. Therefore, this implies a U-shaped cost curve, where LCOE decreases with project size up to a certain threshold and begins to rise thereafter. Therefore, a quadratic specification of model was adopted to allow for the detection of this parabolic pattern in the cost function. The parabolic specification is:

$$\log(LCOE_i) = \beta_0 + \beta_1 \log(capacity_i) + \beta_2 [log(capacity_i)^2] + \beta_3(country_i) + \beta_4(region_i) + \varepsilon_i$$

3.6.4 Heteroscedasticity testing and Robustness Checks

The classical linear regression, model based on the Gauss-Markov Theorem assumes homoscedasticity, which means that the variance of the error term remains constant throughout all observations. Violation of this assumption, known as heteroscedasticity, causes inefficiency in Ordinary Least Squares (OLS) estimators. While the coefficient remains unbiased, the standard errors are no more reliable, weakening the validity of hypothesis testing (Wooldridge, 2015b).

Heterogeneity is a particular concern in this study, which investigates the relationship between project size and the LCOE for renewable energy projects in African countries due to the wide variability in project capacities, geographic conditions and policy environments. For example, Solar PV project in Niger may have significantly different cost structures and variability than those in Ghana.

To test for heteroscedasticity, this study uses statistical test known as the Breusch-Pagan Test which is a formal test developed by Breusch and Pagan (1979) to determine if the variance of the residuals is a function of the independent variables. The null hypothesis for this test is that the error variances are constant, that is homoscedastic, with significant p-value indicating heteroscedasticity.

This study adopts robust standard errors (Huber-White standard errors) to correct for the issue of heteroscedasticity. This method ensures for valid inference even when the error variance is not constant (Cameron & Trivedi, 2021).

CHAPTER 3: RESULTS AND DISCUSSION

The empirical results of the study, which were derived from the examination of the data from renewable energy projects around West Africa, are presented and discussed in this chapter, with an emphasis on LCOE as the main outcome variable. It assesses the relationship between project size and LCOE by building on the conceptual framework and econometric models described in earlier chapters. By analyzing solar PV and onshore wind energy technologies independently, the research captures economies of scale dynamics unique to each technology and offers insights into regional and national cost differences. The results are then interpreted, and the significance, direction, and magnitude of key coefficients are analyzed in light of existing literature. Where applicable, graphical illustrations and post-estimation diagnostics are included to strengthen the empirical argument.

4.1 Results

The results are presented systematically, beginning with summary statistics that describe the dataset, followed by outputs from linear and parabolic regression models for both wind and solar PV projects. The analysis employs visual aids, including tables, and charts, to clearly illustrate the relationship between key variables. This section remains factual, presenting only the outcomes of the statistical tests.

4.1.1 Descriptive Statistics

This section presents the descriptive statistics of the key variables used in the analysis. The summary provides overview of the central tendency, dispersion, and range of the project-level data, offering initial insights into the characteristics and distribution of solar PV and On-shore wind energy projects across West Africa.

Table 3 is a standard output of descriptive statistics of installed capacity of solar PV projects in kW. The table shows the total number of observations in the dataset, the mean (average), and the standard deviation of solar PV projects. The dataset includes a wide range of project sizes, from 500kW to 78000kW. The average installed capacity is 34710.51kW, which is characteristic of a small-scale Solar PV project. The high standard deviation of 17.1 kW confirms a significant spread in project sizes around the mean, indicating substantial heterogeneity in scale.

Table 3 Summary Statistics for Capacity of Solar PV projects

Variable	Obs	Mean	Std. dev.	Min	Max
capacity	2,258,988	34710.51	17129.44	500	78000

Source: Author's computation

The summary statistics for the corresponding LCOEs are shown in table 4. The data comprises of 2,258,988 observations. The mean LCOE of 3.787 (0.03787×100) €cent/kWh establishes solar PV on average, as an exceptionally competitive energy source. This average is further characterized by a narrow dispersion, as evidenced from the extremely small standard deviation of approximately 0.321 €cent/kWh. This low standard deviation in relation to the mean indicates that the vast majority of LCOE values are tightly clustered around the mean, indicating very small variability in the projected cost of electricity across the vast number of projects analyzed.

Table 4 Summary Statistics for LCOE of Solar PV projects

Variable	Obs	Mean	Std. dev.	Min	Max
LCOE	2,258,988	.0378706	.0032085	.0319703	.0530995

Source: Author's computation

Table 5 provides the summary statistics of the capacity, measured in kW, for the onshore wind projects within the dataset. The mean capacity of approximately 4,245kW serves as a central tendency indicator, suggesting that hypothetical or observed "average" in this analysis aligns with the scale of modern, small-scale wind projects. This average value is meaningful given the minimal dispersion around it, as evidenced by a standard deviation of approximately 391.5kW. The low standard deviation relative to the mean signifies a remarkably consistent and tight clustering of project capacities. The dataset ranges from 2,615kW to 6,396kW.

Table 5 Summary Statistics for Capacity of On-Shore Wind Energy projects

Variable	Obs	Mean	Std. dev.	Min	Max
capacity	2,653,880	4245.17	391.5033	2615	6396

Source: Author's computation

Table 6 outlines the summary statistics for the LCOE of onshore wind energy projects, expressed in €/kWh. The mean LCOE of 7.29€cent/kWh indicates that the average cost of electricity generation across all sampled sites is highly competitive across the global energy market. However, in stark contrast to the consistent capacity figures, the LCOE values exhibit significant heterogeneity. This is immediately apparent from the standard deviation of 3.35€cent/kWh, which as a proportion of the mean is substantially larger than that of the capacity variable. This wider dispersion shows the core reality of wind energy economics: the financial viability of a project is intensively sensitive to location-specific factors such as wind resource quality, land acquisition costs, topography, and proximity to transmission infrastructure.

The minimum LCOE value of 2.75€cent/kWh identifies the most economically advantageous sites. The maximum value of approximately 298€cent/kWh indicates the presence of extreme outliers, representing sites that are uneconomical for wind energy development.

Table 6 Summary Statistics for LCOE of Onshore Wind Energy Projects

Variable	Obs	Mean	Std. dev.	Min	Max
LCOE	2,653,880	.0729193	.0334786	.0275135	2.978125

Source: Author's computation

Figure 7 illustrates the potential proportional distribution of solar PV projects across the nations of West Africa. The bar chart shows significant disparities in solar resource development potential among the countries in West Africa.

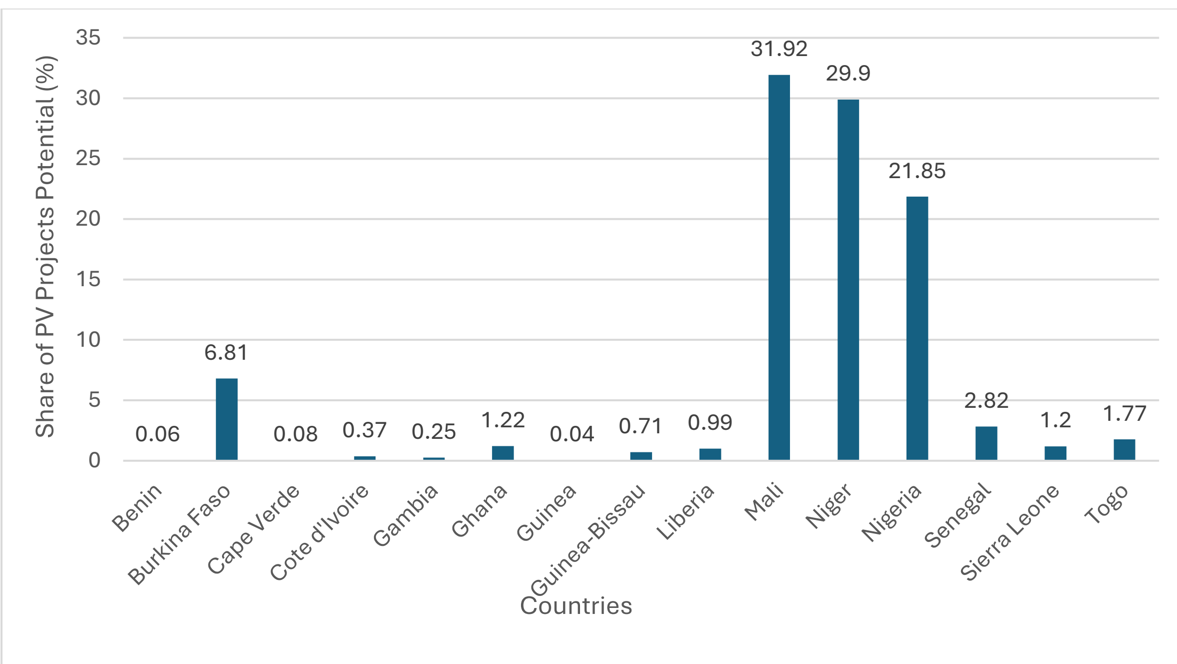

***Figure** 7 Proportion of PV Projects Potential Across West Africa.*
Source: Author's Computation (2025)

Figure 8, on the other hand, depicts the proportional share of onshore wind energy project potential throughout West Africa. The chart reveals a highly concentrated distribution, indicating that the potential for wind energy is heavily focused in a select few countries.

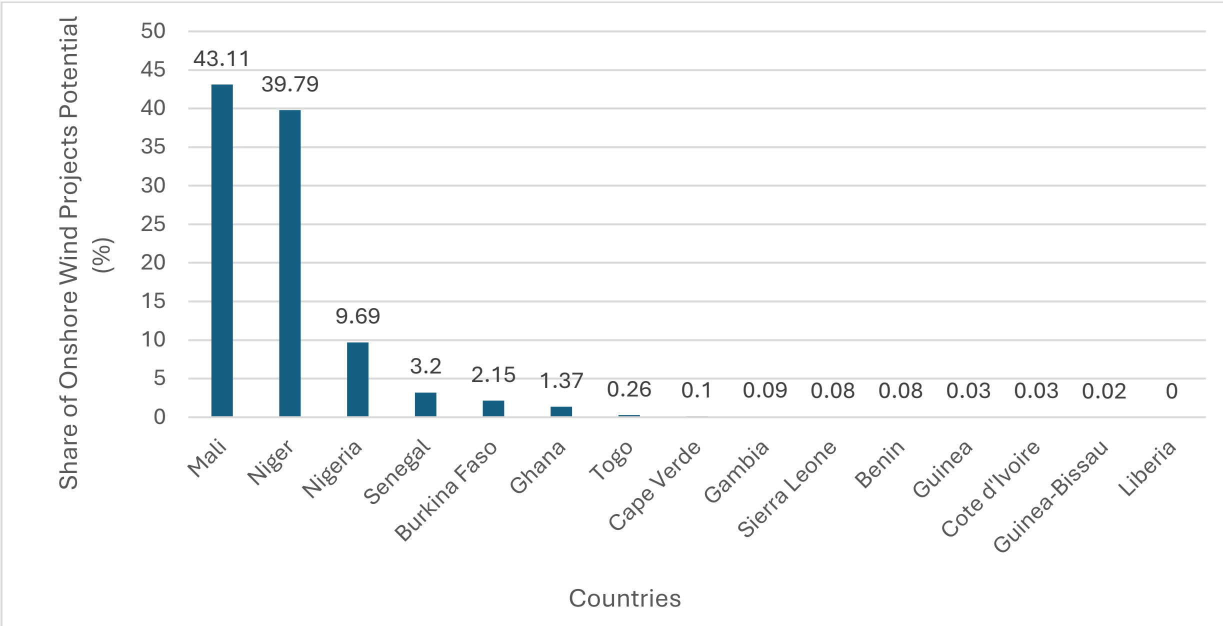

Figure 8 *Proportion of Onshore Wind Energy Projects Potential Across West Africa.*
Source: Author's computation (2025)

The breakdown of solar PV project potential on the continent by scale of development is presented in figure 9. The pie chart categorizes the potential projects into three distinct levels: Entry-Level, Medium Scale, and Industrial Scale.

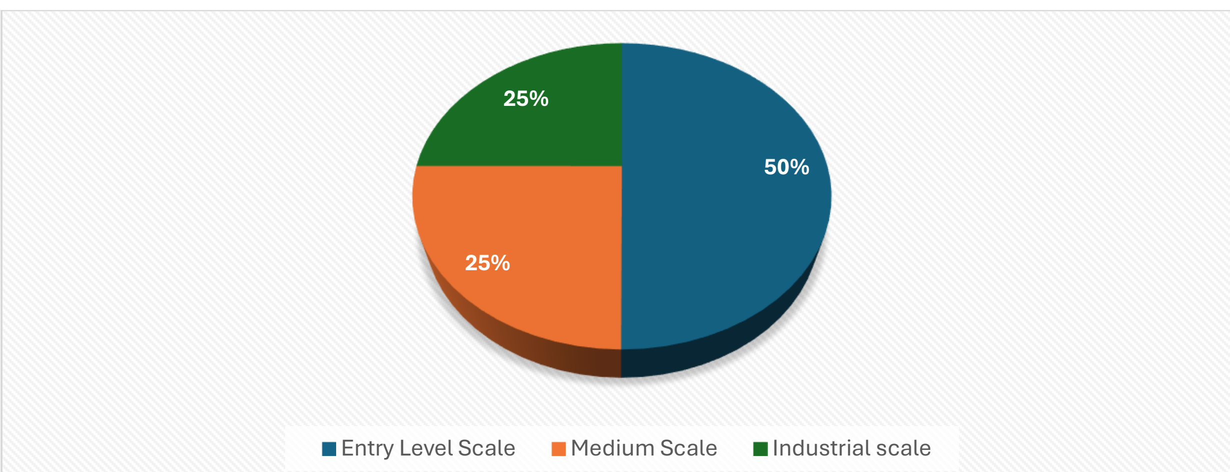

Figure 9 *Solar PV Projects of Different Sizes Across West Africa.*
Source: Author's computation (2025)

4.1.2 The Relationship Between log(capacity) and log(energy) of a solar PV project

There is a strong correlation between log(energy) and log(capacity) of a PV project with an R^2 =99.47%, the root of MSE=0.07139 and prob > f = 0.0000. Table 7 and figure 10 illustrates this significant relationship that exists between project size and energy produced by PV project.

Table 7 Relationship Between log(capacity) and log(energy) of PV projects

$\log(energy_{pvi})$	Coefficient	Robust Std. err.	t	P>|t|	[95% conf. interval]	
$\log(capacity_{pvi})$	1.041445	.0000659	1.6e+04	0.000	1.041574	1.041704
_cons	-6.556651	.0006873	-9537.70	0.000	-6.555304	-6.553957

Source: Author’s computation, (STATA output, 2025).

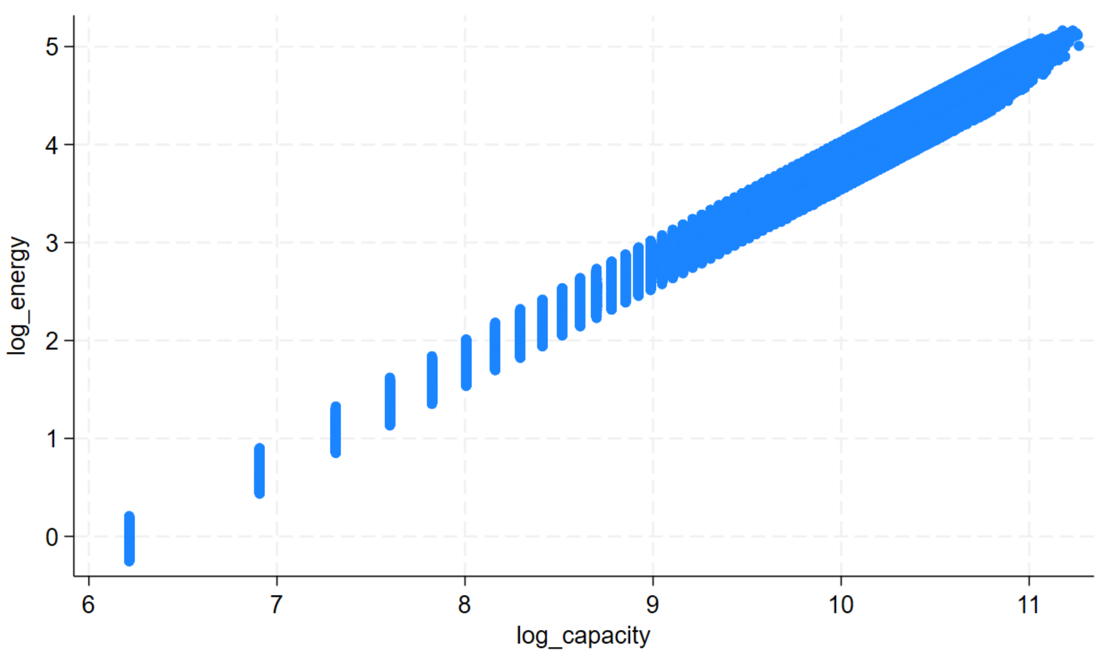

***Figure 10** Relationship Between log(capacity) and log(energy) of a solar PV project.*
Source: Author’s computation (2025)

4.1.3 Regression Results for solar PV

The tables and graphs below represent the outcome of the regression results of the specified PV model (that is model I in chapter 2). Table 8 presents key goodness of fit statistics for a regression model analyzing solar PV projects. It shows that the model explains a very high proportion of the variance in the data and has a low root mean squared error, indicating that the model's predictions are, on average, very close to the actual observed value.

Table 8 Statistical Results for solar PV Projects

Statistic	**Value**
Prob>F	.
R^2	0.9465
Root MSE	0.01884

Source: Author's computation (STATA output, 2025)

Table 9 shows the results of a regression analysis examining the relationship between the log(LCOE) for PV projects and the logarithm of their capacity. The highly significant negative coefficient for log(capacity) indicates a strong economies of scale effect, where larger project capacities are associated with lower costs per unit of energy.

Table 9 Relationship Between log(LCOE) and log(capacity) of PV Project.

$\log(LCOE_{pv})$	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
$\log(capacity_{pv})$	-.0003727	.0000181	-20.63	0.000	-.0004082	-.0003373
_cons	-3.094382	.0021977	-1408.02	0.000	-3.098689	-3.090074

Source: Author's computation (STATA Output, 2025)

Figure 11 illustrates the percentage variation in LCOE for solar PV projects across different West African countries, with the values calculated relative to the base country (which is not shown as it serves as the reference point of 0). This chart allows for direct comparison of how much more expensive or less cheap electricity generated using solar PV costs are in each country compared to the baseline.

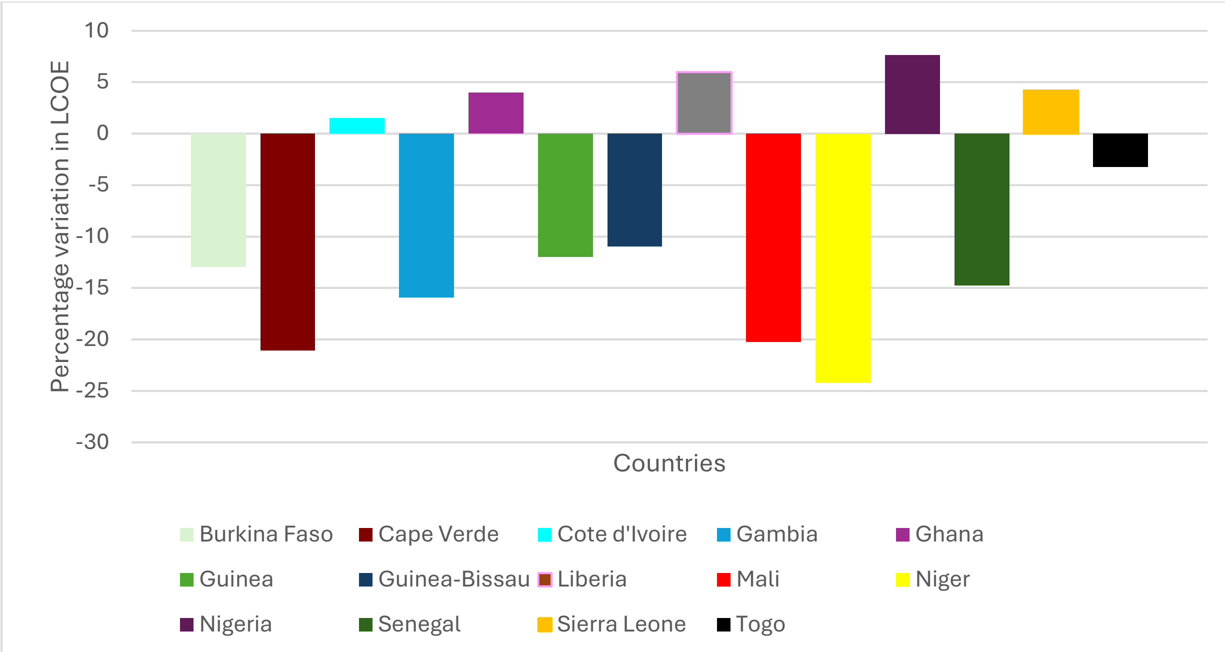

Figure 11 *Country-Level Variation in LCOE of Solar PV Projects Relative to the Base Country.*
Source: Author's computation (STATA Output, 2025)

Figure 12 shows the estimated variation in solar PV LCOE for specific regions relative to the base category. Unlike the country-level result in figure 11, this analysis shows that cost differences at a more localized, sub-national level, highlighting how location within countries can significantly influence the cost of solar energy projects.

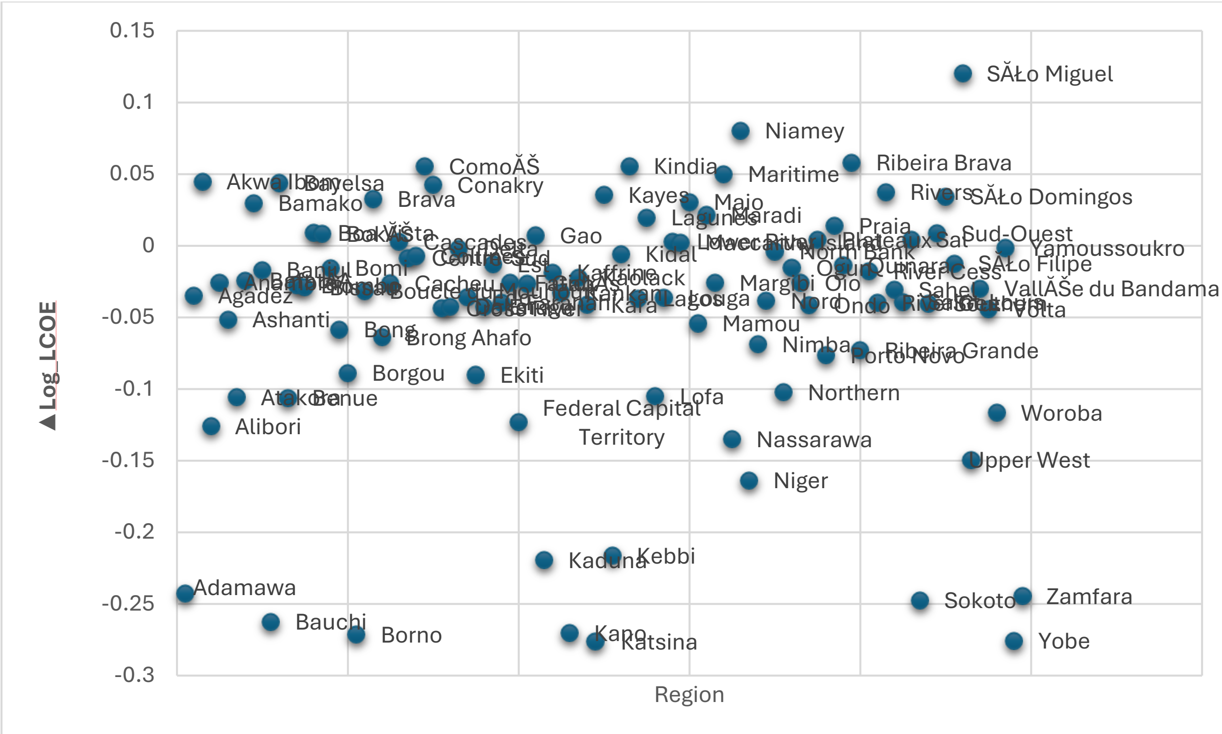

Figure 12 Regional Coefficient Estimate for Solar PV LCOE (Relative to Base Category)
Source : Author's computation (STATA Output, 2025)

4.1.4 Regression Results for On-shore Wind

The tables and graphs below represent the outcome of the regression results of the specified Wind Energy model (that is model II in chapter 2).

Table 10 presents the key statistical metrics for a regression model analyzing onshore wind energy projects. The exceptionally high R-squared value indicates that the model explains nearly all of the variance in the data, while the Root Mean Squared Error (Root MSE) value quantifies the average difference between the observed values and the predicted values by the model.

Table 10 Statistical Results for Onshore Wind Energy Projects

Statistic	Value
Prob>F	.
R^2	0.9890
Root MSE	.03326

Source : Author's computation (STATA Output, 2025)

Table 11 presents the regression results analyzing the relationship between the log(LCOE) for wind projects and log of their capacity. The large, negative, and highly statistically significant coefficient for log(capacity) shows a strong economies of scale effect, showing that larger wind farm capacities are strongly associated with a lower cost per unit energy generated.

Table 11 Relationship Between log(LCOE) and log(capacity) of On-shore Wind Energy Project

$\log(LCOE_{WE})$	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
$\log(capacity_{WE})$	-3.090342	.0010648	-2902.36	0.000	-3.092429	-3.088255
_cons	23.1799	.0093441	2480.69	0.000	23.16159	23.19822

Source : Author's computation (STATA Output, 2025)

Figure 13 presents the country-level percentage variation in LCOE for onshore wind projects. Each country's value represents how much more expensive or cheaper its electricity generated from wind energy costs are relative to a base country (which serves as the reference point), allowing for a direct comparison across the countries of study.

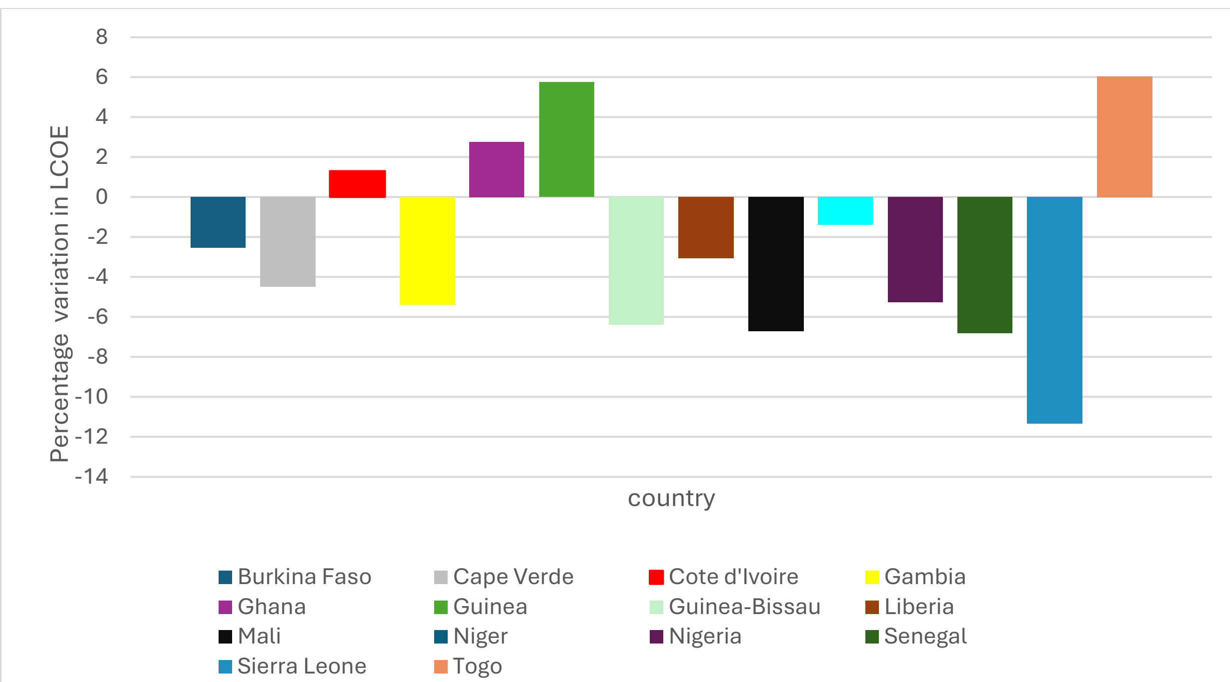

Figure 13 *Country-Level Variation in LCOE of On-shore Wind Projects Relative to the Base Country*

Source: Author's computation (STATA Output, 2025)

Figure 14 shows the estimated variation in wind energy LCOE for specific sub-national regions relative to the base category. This analysis shows how socioeconomic and geographical factors within countries lead to significant differences in the cost of onshore wind energy projects.

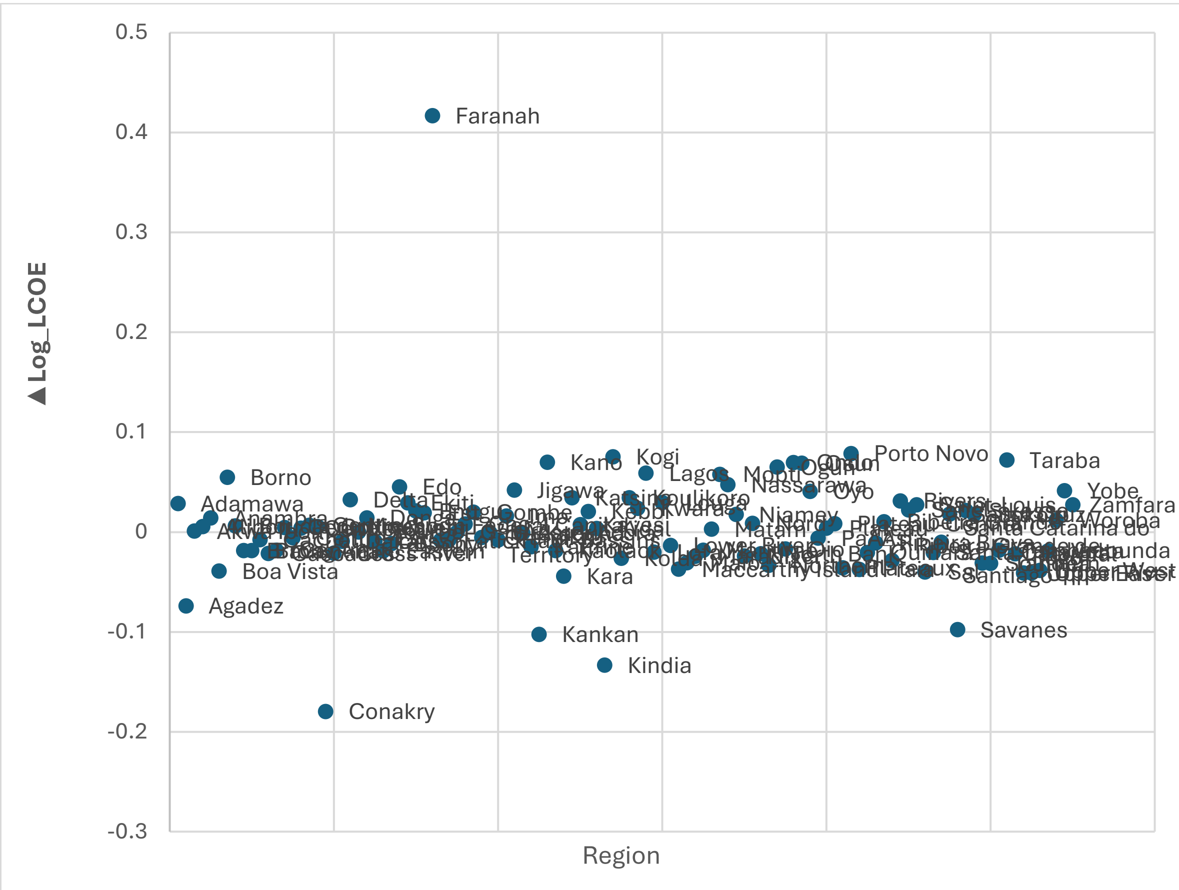

Figure 14 *Regional Coefficient Estimate for Wind Energy LCOE (Relative to Base Category).*
Source: Author's Computation (STATA Output, 2025)

4.1.5 Parabolic Regression Analysis

Following the initial linear regression, this section presents the findings of the parabolic regression analysis, conducted to test for non-linear relationship between LCOE and capacity. The results below also determine if the relationship follows a curvilinear pattern, providing a more distinct understanding of the underlying dynamics.

Table 12 presents the results of a parabolic (quadratic) regression model analyzing the relationship between solar PV capacity and its cost. The inclusion of both log(capacity) and $\log(\text{capacity}_{pv})^2$

as predictors indicates the analysis is testing for a non-linear, U-shaped relationship between project size and cost, rather than a simple straight line.

Table 12 Parabolic Regression Result for solar Energy Project

$\log(LCOE_{pv})$	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
$log(capacity_{pv})^2$	-.0003884	.0000115	-33.91	0.000	-.0004108	-.0003659
$log(capacity_{pv})$	.0066814	.0002108	31.70	0.000	.0062683	.0070945
_cons	-3.125369	.0027168	-1150.38	0.000	-3.130694	-3.120044

Source: Author's Computation (STATA Output, 2025)

Table 13 provides the key result derived from quadratic regression model for solar PV: the calculated cost-mountain capacity (C*).

Table 13 Cost Mountain Capacity from Quadratic Regression model for Solar PV project

$\log(LCOE_{pv})$	Coefficient	Std. err.	z	P>z	[95% conf. interval]	
_nl_1	5440.238	155.2218	35.05	0.000	5136.009	5744.467

Source: Author's Computation (STATA Output, 2025)

Figure 15 is a graphical illustration of the economies of scale for solar PV projects, based on the quadratic regression model.

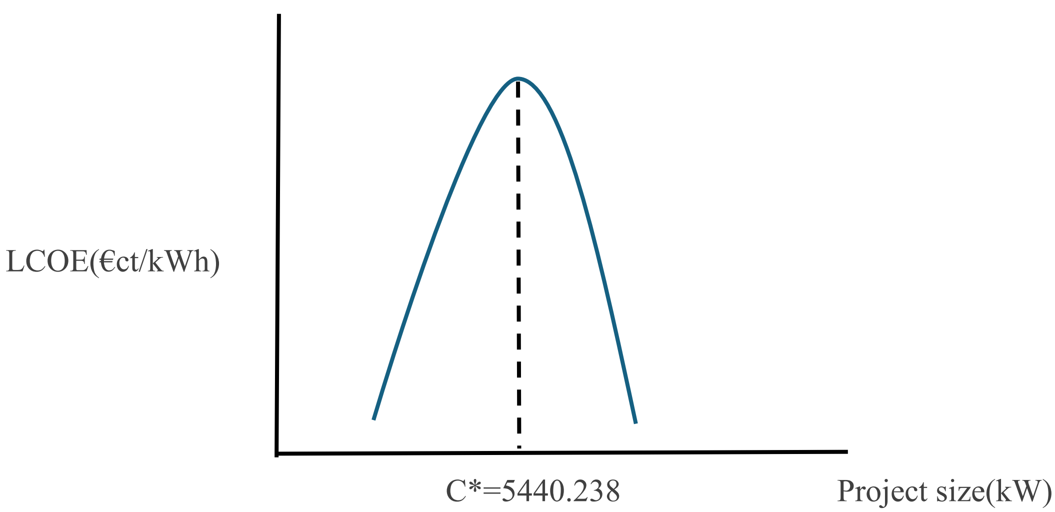

Figure 15 Economies of Scale in Solar PV Project **Source**: Author's Illustration

Note: C* is the turning point capacity "The Cost Mountain"

Table 14 presents the results of a quadratic regression model analyzing the relationship between onshore wind energy capacity and its cost. The model includes both linear and quadratic terms. That is the $\log(\text{capacity}_{\text{WE}})$ and $\log(\text{capacity}_{\text{WE}})^2$ terms to capture the potential non-linear, U-shaped relationship between project scale and LCOE.

Table 14 Parabolic Regression result for Wind Energy Project

$\log(LCOE_{WE})$	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
$log(capacity_{WE})^2$	1.136997	.007524	151.12	0.000	1.12225	1.151744
$log(capacity_{WE})$	-22.00029	.1258485	-174.82	0.000	-22.24695	-21.75364
_cons	101.7491	.5257045	193.55	0.000	100.7187	102.7794

Source: Author's Computation (STATA Output, 2025)

Table 15 provides the key result from the quadratic regression model for wind energy: the calculated cost-minimizing capacity (C*). This value, approximately 15,911Kw, represents the optimal project size at which the LCOE for onshore wind is minimized, indicating the point where economies are most effectively realized.

Table 15 Cost Minimizing Capacity from Quadratic Regression model for On-shore Wind Energy Projects

log_lcoe2020	Coefficient	Std. err.	z	P>z	[95% conf.	interval]
_nl_1	15910.56	138.1351	115.18	0.000	15639.82	16181.3

Source: Author's Computation (STATA Output, 2025)

Figure 16 graphically illustrates the economies of scale for onshore wind energy projects. The parabolic curve depicts how LCOE initially decreases as project size increases, reaches a minimum at optimal capacity (C*), and a potential increase thereafter, highlighting non-linear relationship between scale and cost.

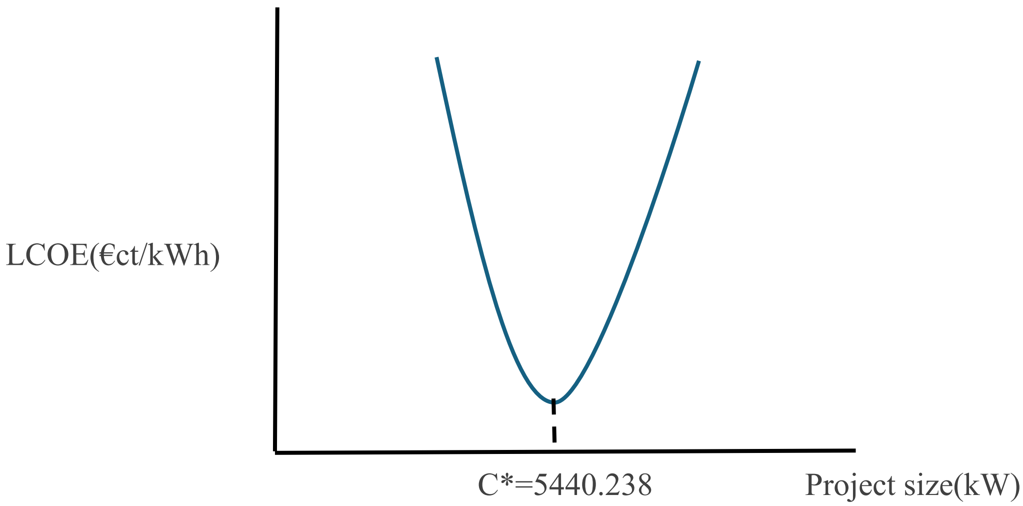

Figure 16 Economies of Scale of Onshore Wind Energy **Source**: Author's Illustration

Note: C* is the cost-minimizing capacity

4.2 Discussion

The interpretation of the findings and their broader significance are discussed in this part, which builds on the empirical results from the preceding section. The main objective is to move beyond what the data shows and explain why the observed patterns and relationship exist.

4.2.1 Distribution of Renewable Energy Potential in West Africa

The total number of PV projects varies across the region based on different factors such as solar resource availability, government regulations and policy, foreign investment etc. From Figure 7, Mali, Niger, and Nigeria have the highest share of PV projects potential as of the year 2020 when the data was collected. Mali and Niger which are part of the Sahelian belt do not receive the rainfall necessary for the development of vegetation, but they do receive abundance of solar energy ranging from 5 to 6kWh/m^2/day (Dajuma et al., 2016), therefore encouraging investment in solar PV project in these countries as compared to a country like Benin which has an average solar irradiation ranging from 3.9 to 6.1kWh/m^2/day from the South to the North (Odou et al., 2020).

Furthermore, West Africa's wind energy potential is dominated by Mali and Niger which collectively host 82.95% of the share of PV projects potential. Mali, which is a landlocked country, is host to 43.11% of onshore wind energy projects. The Saharan wind corridors in the Kidal and Kayes regions of Mali, where capacity factors are very high during Harmattan seasons. Niger is the country with the second largest number of wind energy projects, and this is due to the country's highly significant average wind speed of 5m/s and thereby attracting investment (Manzo et al., 2025). However, most coastal countries such as Ghana despite favorable geography, have less number of wind energy projects because of resource underutilization, policy implementation failures, grid infrastructure deficits, financial and market barriers (Sun et al., 2020).

Moreover, the variation in projects among countries is beyond just resource availability but also socioeconomic factors and policy frameworks play a crucial role. Factors such as GDP, energy use, market structure, and CO2 emissions significantly influenced renewable energy expansion, while policy instruments such as feed in tariffs (FITs) and tax incentives had negligible effects (Abbas et al., 2020; Neuhoff, 2005). In addition, countries become more dominant hosts of large scale solar PV when they combined credible offtakers, predictable regulation, macro-stability, and access to affordable long-tenor finance conditions that lower perceived risk and attract private investment. This mechanism was clearly illustrated in the research work of Pueyo (2018) where he compared Ghana and Kenya. Kenya's power market features cost-reflective tariffs, a history of honoring PPAs, and comparatively creditworthy offtaker, alongside responsive policy shifts such as moving from FiTs toward competitive procurement and significant concessional support for grid connected renewables. These factors made returns on renewable energy attractive. However, Ghana adopted FiT on paper but implementation details such as local currency guaranteed for only 10years) and crucially, a weak offtaker with high losses and cash flow problems meant PPAs did not provide bankable security. Despite apparent policy intent by Ghana, private solar PV investment was suppressed by macroeconomic imbalances such double digit inflation, and cedi depreciation. In addition, extremely high domestic lending rates, and government crowding-out through high-yield bonds, which increased financing costs and risk is also responsible for low investment in renewables in Ghana and considerably, other countries within West Africa (Pueyo, 2018).

4.2.2 Solar PV Projects of different sizes in Africa

Solar PV Projects can be categorized into three (3) different sizes. Solar PV projects can be classified into small-scale, medium-scale and large-Scale projects based on their installation capacities. Majority of the projects which fell within the first and second quarters are small scale projects with installation capacity ranging from 500kWp to 43000kWp and a third quarter with capacity ranging from 43499kWp to 49000kWp in capacity are medium size projects. The largest PV projects which samples fall under the fourth quarter range from 49499 to 78000 kWp. Notable example of a large-scale PV project includes the Mohamed Bin Zayed (Blitta) in Togo with installation capacity of 5000kWp which is operational since 2021 with ongoing expansion.

Figure 9 provides a visual distribution of PV projects across three size categories in West Africa. According to the chart, entry-Level or small-scale projects accounts for 50% of the total observed installations, whereas both medium scale and industrial scale projects represents 25% of the samples. This distribution shows that smaller scale (entry Level Scale) Solar PV Projects are the most common type of project in West Africa. This widespread deployment of entry Level Scale Solar PV projects reflects both the need for flexible, quick-to-deploy solutions and limitations of financial constraint and infrastructure (Owusu-Manu et al., 2021), land acquisition issues, grid connectivity, and power purchase agreement negotiations (Calder & McCollum, 2020) in many parts of Africa.

4.2.3 Relationship Between log(capacity) and log(energy) of Renewable Energy project.

There is a positive relationship between the size and the total energy generated from a renewable energy project in Africa. Table 7 and Figure 10 show a positive relationship between the capacity of a solar PV project and the total energy generated from the project. Hence, the larger the size of the project the more energy the project will generate and the smaller the project, the less energy it produces. From the regression result, a one percent increase in the size of a solar PV project in Africa increases the energy generated by 100% holding other factors constant.

4.2.4 Analysis of Solar PV and On-shore Wind Energy Project: Evidence from Regression Analysis

The regression result reflects the impact of size of solar PV project and its location on LCOE. The result has an R^2=0.9465, showing that 94.65% of LCOE variation explained by exceptional fit. Country and regional dummies explain majority of total LCOE variation of Solar PV projects. However, even though statistically significant, the capacity of the project has secondary impact (refer to appendix A). The root of MSE has a value of 0.01884, which means that predictions deviate from actual log(LCOE) by $\pm$1.884% on average. Practically, for a project with LCOE of 50€/kWh, predictions are accurate within $\pm$ 0.9€ct/kWh.

From the outcome of the regression result, 98.90% of the variation in wind energy output is explained by the model. This is very high, indicating near-perfect fit. Just like in the case of solar PV, the high R^2 is highly explained by the country and regional dummies. The average prediction error is ±0.03326 €ct/kWh of LCOE.

4.2.5 The Nexus Between Project Size and LCOE

For Solar PV project, the coefficient of log(capacity) is negative and statistically significant at the 1% level. This indicates a negative relationship between LCOE capacity of a solar PV project**.** Economically, a 1% increase in project capacity is associated with a 0.037% decrease in LCOE, holding other factors constant. This indicates the presence of economies of scale in solar PV deployment in Africa. However, this reduction is economically trivial.

The coefficient of log(capacity) for a wind energy project is -3.090342 showing that a 1% increase in capacity of an On-Shore wind energy project reduces its LCOE by 300%. This shows the present of economies of scale that as project size increases, the cost per unit electricity generated reduces.

4.2.6 Country Effects on Solar PV LCOE: Evidence from Regression Analysis

In terms of geographical variation, each country is compared to a reference country which is Benin, which was omitted automatically by STATA. The result of solar PV projects shows that all the country coefficients are highly statistically significant with a P value<0.01, indicating that country-level differences have a strong effect on cost per unit electricity generated. The coefficient indicates how a country's LCOE differs from the base after adjusting for capacity and location. For example, Burkina Faso with a coefficient of -0.1297 have a 12.97% lower LCOE in generating electricity from a solar PV project than Benin. However, a country like Nigeria has a coefficient of 0.0766 indicating that Nigeria has a 7.66% larger LCOE in generating electricity from a solar PV project than Benin (Refer to Appendix A)

For wind energy projects, most countries exhibit a significant inverse coefficient, suggesting that wind projects in most countries across West Africa are on average less costly than the base country, Benin. For example, Senegal shows a significant negative coefficient of -.068076, indicating that wind projects in Senegal are on average approximately 6.81% less costly in terms of LCOE than Benin. This result is consistent with Senegal's progress in developing competitive procurement frameworks and early investments in wind, like the Taiba N'Diaye Wind Farm which size is

(158MW), and the largest in West Africa. However, Ghana's positive coefficient of +0.0275 indicates a 2.75% higher LCOE relative to Benin (Refer to Appendix B). Despite the wind potential of Ghana along the coast, Ghana's limited grid integration and small-scale demonstration projects push up the unit cost (Sun et al., 2020b).

4.2.7 Regional Effects (Subnational Level Dummies) on Levelized Cost of Electricity for Solar PV

Just like countries, each region is compared to a reference region. The reference region is Abia State in Nigeria and was automatically omitted by STATA. The regional dummy takes into account local factors such as solar irradiation, geography, grid access, labor costs and regulatory or policy support. From figure 12 and Appendix A regions like Niger, Upper West, Adamawa, and Yobe have negative coefficients. This means that these regions have a lower cost per unit electricity generation from a solar PV project than Abia State in Nigeria. However, regions such as Conakry, Brava, Bamako, and Maritime have a positive LCOE in producing electricity from a PV project compared to Abia state in Nigeria. These regional variations are due to differences in resource availability, local tax, and policy and regulatory framework (Osiolo, 2021).

Similarly, wind energy projects in regions such as Conakry, Kindia and Kankran province in Guinea, has negative LCOE indicating a lower LCOE in generating electricity from renewable sources in these regions in Guinea as compared to Abia in Nigeria. However, in the same country, the province of Faranah demonstrate a very high LCOE as compared to Benin. This is shown in Figure 14**.** In other geographical locations like the Bauchi states in Nigeria have shown that generating electricity from a wind energy project is 5.5% more expensive in terms of LCOE than Abia State in Nigeria. Similarly, Kano state demonstrates a very high LCOE which is 7% more than Abia State which is located in the Southern Nigeria. This is due to the poor transport infrastructure, and increased security-related costs in Kano and Bauchi in the Northern part of Nigeria (Musa Aliyu et al., 2018). Refer to Appendix B.

4.2.8 Parabolic Analysis: Evidence from regression result

After a parabolic check of result of a solar PV project, 94.65% of the variation in LCOE has been explained by the regressors. The average prediction error is ±0.01883 €ct/kWh of LCOE. The coefficient of log(capacity) is +0.00668 with a P-value of 0.000 which is highly significant. This positive coefficient initially suggests that as project size increases, the cost per unit of electricity (LCOE) also increases slightly at a diminishing rate. However, the quadratic term ($log\_capacity^2$) has a coefficient of -0.000388 and a P-value of 0.000 which is highly significant. The negative sign on the squared term confirms the parabolic shape (concave-down curve). This means that increasing capacity slightly increases the LCOE (positive slope). But after a certain threshold, further increases in capacity reduce the LCOE, confirming economies of scale. From table 9, The model also indicates that LCOE is minimized for PV projects with capacity of 5440.238kW with a 95% confidence interval ranging from 5136.009kW to 5744.467kW.

The initial cost increase is attributed to regulatory and transaction costs hurdles as very small projects often fly under the radar of complex regulatory regimes. As projects approximately 1-5MW scale, they prompt a host of mandatory costly requirements such as comprehensive Environmental Impact Assessment (EIA), formal permitting processes, legal structuring, and grid interconnection studies that are disproportionate to their size. The cost of complying to this formal sector bureaucracy is immense for the first few MW (Pueyo et al., 2016). Secondly, loss of subsidies and grant fundings also result in initial diseconomies of scale in PV projects since many small-scale projects benefit from donor grants, NGO supports, or government subsidies aimed at rural electrification. Projects in the 1-5MW range are often too large to qualify for these grants but too small to attract competitive commercial financing, leading to funding gap that increase the capital costs (Probst et al., 2021). In addition, micro-off-grid systems are often community-managed with low overhead. Scaling to a mini grid requires a professionalized, salaried O&M team, security, and sophisticated monitoring systems. This introduces an increase in fixed operational costs that is not immediately offset by the increased generation, causing LCOE to rise.

However, LCOE begins to fall for larger projects because of access to commercial financing, true bulk procurement as developers can negotiate directly with manufacturers for major PV components (panels, and inverters) at significantly lower per-unit prices. Furthermore, large-scale PV projects benefit from amortization of soft costs. High upfront expenses, such as those for EIA, are spread across significantly larger energy output, which substantially lowers cost per kilowatt-hour.

For wind energy projects, negative linear term and a positive quadratic term were exhibited (refer to Appendix D). The linear term which is log(capacity) has a coefficient of -22.00029 and the quadratic term which is log(capacity^2) has a coefficient of +1.137. This shows that as wind projects initially increase, the LCOE reduces, consistence with the presence of economies of scale. However, after a certain threshold of capacity, diseconomies of scale set in, and further increase in capacity raise LCOE. The quadratic regression for wind energy projects shows a statistically significant concave relationship between capacity and LCOE. From table 11, the model estimates a cost minimizing turning point at 15910.56kW (15.9MW) at 95% confidence interval spanning from 15639.82kW to 16181.3kW (15.64MW – 16.18MW). According to literature, initial economies of scale can be attributed to procurement and bulk discounts, operational efficiency, and capital cost dilution. However, the subsequent diseconomies of scale is driven by West Africa's unique challenges such as grid absorption constraints, logistical and transmission complexities. This finding casts doubt on the global narrative of wind farms growing in size and emphasizes how crucial it is to tailor renewable energy deployment to infrastructure realities.

CONCLUSION, PERSPECTIVE, LIMITATION AND RECOMMENDATION

5.1 Conclusion

The main objective of this study is to investigate the relationship between project size and LCOE in electricity generation from renewables in Africa. Utilizing project-level data on solar photovoltaic (PV) and wind energy technologies, both log-linear and parabolic regression models were used in the study, which used project level data on wind and solar photovoltaic (PV) technologies. Country and regional fixed effects were included to account for spatial variations in cost performance.

The empirical results confirmed that existence of economies of scale in both solar PV and wind projects, with larger capacities generally associated with lower LCOE up to an optimal scale. Beyond this threshold, however, diseconomies of scale emerged, driven by increased operational complexity, logistical limitations, grid integration challenges, and land acquisition issues. The non-linear relationship was effectively captured using quadratic model, which provided robust estimates of the turning points for cost minimization. Significant spatial disparities in LCOE were found using country and regional dummy variables, suggesting that geography, policy, infrastructure availability, and resource endowment all have a substantial impact on cost results.

Overall, the study offers strong empirical evidence that optimal project sizing is essential for achieving cost reduction in African renewable energy projects. It also highlights the importance of supportive institutional environments and targeted investments to maximize the benefits of scaling up.

5.2 Perspective

The findings of this research have important implications for the future development of renewable energy in Africa. The result show that “bigger” is not always “better. While scaling up leads to significant cost reductions at the early stages but going over the optimal capacity results in increasing costs. Therefore, cost minimization modelling should be incorporated into future planning to ascertain project size prior to making investments commitments.

Moreover, in large scale projects, grid capacity limitations have become a major source of diseconomies of scale. These limitations could be lessened by incorporating energy storage systems, demand response strategies, and transmission upgrades into project design. Establishing manufacturing hubs, training facilities, and service clusters for renewable energy, countries can promote external economies of scale. Such initiatives can reduce costs for all players in the market, not just individual developers. In addition, investment plans should be technology-specific, taking into account site-specific constraints, technical performance, and resource availability, as the cost-capacity relationship varies between solar PV and wind energy.

A more comprehensive knowledge of cost drivers in the African environment can be obtained by broadening the focus to include additional renewable technologies such as biomass, and hydropower and exploring the role of learning curves, financing structures, and policy initiatives can provide a more holistic understanding of cost drivers in the African context

5.3 Limitations of the Study

Although this study provides valuable insight into the role of economies of scale in electricity generation from renewables in Africa, several limitations were noted.

Firstly, the research relies secondary data source. Although these data source is reputable and widely used, the availability and reliability of project-level data for many African countries remain limited. In some cases, missing or incomplete data may have constrained the robustness of the regression models.

Secondly, although scale effects can be identified using the regression approach, which includes log-linear and parabolic transformations, financial, institutional, and regulatory dynamics that could affect project costs are not fully captured. For instance, country and regional dummy variables only serve as an indirect representation of variations in risk profiles, funding conditions, and policy frameworks.

Thirdly, the study focusses on West Africa due to data availability. While this provides a rich regional analysis, the findings may not be directly generalizable to other parts of the continent with different market structures, infrastructure, and policies.

In addition, the analysis is limited to only solar PV and wind technologies, as these are the sectors with the most reliable and comparable data across the region. Other renewable energy sources like biomass, hydropower, and geothermal were not included in the focus of the study. These excluded renewable energy resources may also demonstrate economies of scale but could not be systematically analyzed due to insufficient data coverage.

5.4 Recommendations

Based on the empirical findings of this study, the following targeted recommendations are proposed for key stakeholders to optimize renewable energy deployment and cost-efficiency in Africa.

- Promotion of Optimal Project Sizing:

The analysis confirms strong economies of scale in solar PV, with LCOE declining as project capacity increases. Policymakers should therefore prioritize large-scale PV development, supported by concessional finance and risk-reduction instruments to overcome upfront capital challenges. For onshore wind, the parabolic results indicate that very large projects can face diseconomies of scale due to logistical and grid integration challenges. Governments should therefore encourage medium-to-large wind farms that balance cost efficiency with operational manageability.

- Investment in Grid and Transmission Infrastructure

Regional and country dummy variables highlight that cost variations are partly driven by infrastructure readiness. Expanding and modernizing grid systems, including cross-border interconnections, will reduce curtailment risks and enhance the capacity of national grids to absorb electricity from large scale renewable projects.

- Tailor Support to Country-Specific Contexts

Significant country-level effects in the regression suggest that institutional and regulatory frameworks strongly affect project costs. Countries with weaker financial and regulatory frameworks should adopt targeted reforms such as tax incentives and guarantees for investors to improve cost competitiveness.

REFERENCES

Abbas, Q., Khan, A. R., Bashir, A., Alemzero, D. A., Sun, H., Iram, R., & Iqbal, N. (2020). Scaling up renewable energy in Africa: measuring wind energy through econometric approach. *Environmental Science and Pollution Research*, *27*(29), 36282–36294. https://doi.org/10.1007/s11356-020-09596-1

Agoundedemba, M., Kim, C. K., & Kim, H. G. (2023). Energy Status in Africa: Challenges, Progress and Sustainable Pathways. *Energies*, *16*(23). https://doi.org/10.3390/en16237708

Aliyu, A. K., Modu, B., & Tan, C. W. (2018). A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, *81*(February 2016), 2502–2518. https://doi.org/10.1016/j.rser.2017.06.055

Amir, M., & Khan, S. Z. (2022). Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa. *Energy and Built Environment*, *3*(3), 348–362. https://doi.org/10.1016/j.enbenv.2021.03.002

Antonelli, M., Desideri, U., & Franco, A. (2018). Effects of large scale penetration of renewables: The Italian case in the years 2008–2015. *Renewable and Sustainable Energy Reviews*, *81*(May 2016), 3090–3100. https://doi.org/10.1016/j.rser.2017.08.081

Arrow, K. J. (1962). *The Economic Implication of Learning by Doing*. *29*(3), 155–173. https://doi.org/https://doi.org/10.2307/2295952

Attia, B. (2015). Cost-reduction strategies in the solar photovoltaic industry: Economies of scale in soft costs and industry level modularity as tools to increase competition. *Sustainable Energy for All*, *2015*, 1–85. https://udspace.udel.edu/server/api/core/bitstreams/69442933-f044-40f1-9dd4-22779b802f45/content

Barasa, M., Bogdanov, D., Oyewo, A. S., & Breyer, C. (2018). A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030. *Renewable and Sustainable Energy Reviews*, *92*(July 2016), 440–457. https://doi.org/10.1016/j.rser.2018.04.110

Benoit, K. (2011). Linear Regression Models with Logarithmic Transformations. *London School of Economics*, 1–8. http://www.kenbenoit.net/courses/ME104/logmodels2.pdf

Borenstein, S. (2012). The private and public economics of renewable electricity generation.

Journal of Economic Perspectives, *26*(1), 67–92. https://doi.org/10.1257/jep.26.1.67

Bryman, A. (2016). *Social research methods* (5th ed.). Oxford University Press.

Cameron, A. C., & Trivedi. (2021). Cross-Sectional and Panel Regression Methods. In *Microeconometrics Using Stata Volume I: Vol. I*.

Cantore, N., Nussbaumer, P., Wei, M., & Kammen, D. M. (2017). Promoting renewable energy and energy efficiency in Africa: A framework to evaluate employment generation and cost effectiveness. *Environmental Research Letters*, *12*(3). https://doi.org/10.1088/1748-9326/aa51da

Chong, S., Wu, J., & Chang, I. S. (2024). Cost accounting and economic competitiveness evaluation of photovoltaic power generation in China —— based on the system levelized cost of electricity. *Renewable Energy*, *222*(September 2023), 119940. https://doi.org/10.1016/j.renene.2024.119940

Coppez, G., Chowdhury, S., & Chowdhury, S. P. (2011). South African renewable energy hybrid power system storage needs, challenges and opportunities. *IEEE Power and Energy Society General Meeting*, 1–9. https://doi.org/10.1109/PES.2011.6039336

Dajuma, A., Yahaya, S., Touré, S., Diedhiou, A., Adamou, R., Konaré, A., Sido, M., & Golba, M. (2016). Sensitivity of Solar Photovoltaic Panel Efficiency to Weather and Dust over West Africa: Comparative Experimental Study between Niamey (Niger) and Abidjan (Côte d'Ivoire). *Computational Water, Energy, and Environmental Engineering*, *05*(04), 123–147. https://doi.org/10.4236/cweee.2016.54012

Deichmann, U., Meisner, C., Murray, S., & Wheeler, D. (2011). The economics of renewable energy expansion in rural Sub-Saharan Africa. *Energy Policy*, *39*(1), 215–227. https://doi.org/10.1016/j.enpol.2010.09.034

Delbeke, J., Runge-Metzger, A., Slingenberg, Y., & Werksman, J. (2019). The paris agreement. *Towards a Climate-Neutral Europe: Curbing the Trend*, 24–45. https://doi.org/10.4324/9789276082569-2

Dismukes, D. E., & Upton, G. B. (2015). Economies of scale, learning effects and offshore wind development costs. *Renewable Energy*, *83*, 61–66.

https://doi.org/10.1016/j.renene.2015.04.002

Dokka, V. K. (2021). *Master of Science Degree in Environomical Pathways for Sustainable Energy Systems GREEN HYDROGEN FROM STRANDED OR SOON TO BE STRANDED OFFSHORE OIL AND GAS PLATFORMS. October*.

Eberhard, A., & Catrina Godinho, C. (2017). *Energy and Economic Growth Title A Review and Exploration of the Status, Context and Political Economy of Power Sector Reforms in Permalink https://escholarship.org/uc/item/11k4210h Publication Date*. https://escholarship.org/uc/item/11k4210h

Elsner, P. (2019). Continental-scale assessment of the African offshore wind energy potential: Spatial analysis of an under-appreciated renewable energy resource. *Renewable and Sustainable Energy Reviews*, *104*(January), 394–407. https://doi.org/10.1016/j.rser.2019.01.034

Grimm, M., & Peters, J. (2016). Solar off-grid markets in Africa. Recent dynamics and the role of branded products. *Field Actions Science Report*, *2016*(Special Issue 15), 160–163.

Gupta, A. (2018). Integration Challenges of Wind Power on Power System Grid A Review. *2018 International Conference on Advanced Computation and Telecommunication, ICACAT 2018*, *2*(4). https://doi.org/10.1109/ICACAT.2018.8933741

Haldi, J., & Whitcomb, D. (1967). Economies of Scale in Industrial Plants. *Journal of Political Economy*, *75*(4, Part 1), 373–385. https://doi.org/10.1086/259293

Hallam, C. R. A., & Contreras, C. (2015). Evaluation of the levelized cost of energy method for analyzing renewable energy systems: A case study of system equivalency crossover points under varying analysis assumptions. *IEEE Systems Journal*, *9*(1), 199–208. https://doi.org/10.1109/JSYST.2013.2290339

Igbinovia, F. O., & Krupka, J. (2018). Renewable Energy Integration in Africa : A Case Study of the Adoption of New Technology by the Electricity Transmission Company of Nigeria. *2018 International Conference on Power System Technology (POWERCON)*, *201805090000001*, 2034–2042.

International Energy Agency. (2019). *Africa energy outlook 2019.* IEA.

https://www.iea.org/reports/africa-energy-outlook-2019

IRENA. (2012a). *Power Generation Biomass for Wind Power. 1 (Power S*(1/5). https://www.irena.org/Publications

IRENA. (2012b). Renewable Energy Techlogies: Cost Analysis Series, Hydropower. *International Renewable Energy Agency*, *1*(3), 5.

IRENA. (2021). Renewable Energy Statistic 2021. In *Renewable Energy Statistic 2021* (Vol. 56, Issue December 2021). www.irena.org

Khatib, H., & Difiglio, C. (2016). Economics of nuclear and renewables. *Energy Policy*, *96*, 740–750. https://doi.org/10.1016/j.enpol.2016.04.013

Manzo, I., Bonkaney, A. L., Ali, A., & Madougou, S. (2025). Wind Characteristics at Agadez and Tahoua Weather Stations. *Wind Energy*, *28*(1). https://doi.org/10.1002/we.2963

Musa Aliyu, M., Adedipe, O., Adegboyega, E. B., Michael, U. N., & Aliyu, A. M. (2018). Energy poverty and the security challenges in Northern Nigeria-Incidence and the potential for renewables. *Covenant Journal of Engineering Technology*, *2*(2), 40–51. https://www.researchgate.net/profile/Adegboyega-Ehinmowo/publication/330076318_Energy_Poverty_and_the_Security_Challenges_in_Northern_Nigeria-Incidence_and_the_Potential_for_Renewables/links/5c2bde7c458515a4c7065bb2/Energy-Poverty-and-the-Security-Challen

Neuhoff, K. (2005). Large-scale deployment of renewables for electricity generation. *Oxford Review of Economic Policy*, *21*(1), 88–110. https://doi.org/10.1093/oxrep/gri005

Ntumba, S. (2022). *The scaling up of renewable energy consumption in South Africa; challenges and opportunities*. *9*(November), 356–363.

O, E., E, J., & A, J. (2025). *A Systematic Review of Barriers to Renewable Energy Integration and Adoption*. *9*, 26–45. https://doi.org/10.24112/jaes.090002

Odou, O. D. T., Bhandari, R., & Adamou, R. (2020). Hybrid off-grid renewable power system for sustainable rural electrification in Benin. *Renewable Energy*, *145*(March 2018), 1266–

1279. https://doi.org/10.1016/j.renene.2019.06.032

Okwori, C. O. O., Ismail, O. S., & Moses, O. (n.d.). *Development and Evaluation of Techno-Economic Levelized Cost of Electricity (TELCOE) for the Planning , Design , and Development of Commercially Viable Mini-Grid Hybrid Renewable Energy Power Generation in Sub-Saharan Africa : A Case Study of Southwest Nigeria*. 1–34.

Osiolo, H. H. (2021). Impact of cost, returns and investments: Towards renewable energy generation in Sub-Saharan Africa. *Renewable Energy*, *180*, 756–772. https://doi.org/10.1016/j.renene.2021.08.082

Ouedraogo, N. S. (2019). *Opportunities , Barriers and Issues with Renewable Energy Development in Africa : a Comprehensible Review*. 52–60.

Owusu-Manu, D. G., Mankata, L. M., Debrah, C., Edwards, D. J., & Martek, I. (2021). Mechanisms and challenges in financing renewable energy projects in sub-Saharan Africa: a Ghanaian perspective. *Journal of Financial Management of Property and Construction*, *26*(3), 319–336. https://doi.org/10.1108/JFMPC-03-2020-0014

Pan, L., Biru, A., & Lettu, S. (2021). Energy poverty and public health: Global evidence. *Energy Economics*, *101*(June), 105423. https://doi.org/10.1016/j.eneco.2021.105423

Paul M.Romer. (1986). Increasing Returns and Long-Run Growth. *Journal of Political Economy*, *94*(5), 1002–1037. http://www.journals.uchicago.edu/t-and-c

Probst, B., Westermann, L., Anadón, L. D., & Kontoleon, A. (2021). Leveraging private investment to expand renewable power generation: Evidence on financial additionality and productivity gains from Uganda. *World Development*, *140*, 105347. https://doi.org/10.1016/j.worlddev.2020.105347

Pueyo, A. (2018). What constrains renewable energy investment in Sub-Saharan Africa? A comparison of Kenya and Ghana. *World Development*, *109*, 85–100. https://doi.org/10.1016/j.worlddev.2018.04.008

Pueyo, A., Bawakyillenuo, S., & Osiolo, H. (2016). Cost and Returns on Renewable Energy in Sub-Saharan Africa: A comparison of Kenya and Ghana. *Evidence Report Pro-Poor Electricity Provision*, *190*, 1–65.

Qiu, Y., & Anadon, L. D. (2012). The price of wind power in China during its expansion: Technology adoption, learning-by-doing, economies of scale, and manufacturing localization. *Energy Economics*, *34*(3), 772–785. https://doi.org/10.1016/j.eneco.2011.06.008

Ramos, C., García, A. S., Moreno, B., & Díaz, G. (2019). Small-scale renewable power technologies are an alternative to reach a sustainable economic growth: Evidence from Spain. *Energy*, *167*, 13–25. https://doi.org/10.1016/j.energy.2018.10.118

Rezaei, M., Akimov, A., & Gray, E. M. A. (2024). Economics of renewable hydrogen production using wind and solar energy: A case study for Queensland, Australia. *Journal of Cleaner Production*, *435*(December 2023), 140476. https://doi.org/10.1016/j.jclepro.2023.140476

Rosenthal, S. S., & Strange, W. C. (2004). Evidence on the Nature and Sources of Agglomeration Economies. *Handbook of Regional and Urban Economics*, *4*, 2119–2171. https://doi.org/10.1016/S1574-0080(04)80006-3

Sanoh, A., Kocaman, A. S., Kocal, S., Sherpa, S., & Modi, V. (2014). The economics of clean energy resource development and grid interconnection in Africa. *Renewable Energy*, *62*, 598–609. https://doi.org/10.1016/j.renene.2013.08.017

Schiliro, D. (2019). The growth conundrum: Paul Romer's endogenous growth Munich Personal RePEc Archive. *International Business Research*, *97956*. https://mpra.ub.uni-muenchen.de/97956/

Shea, R. P., & Ramgolam, Y. K. (2019). Applied levelized cost of electricity for energy technologies in a small island developing state: A case study in Mauritius. *Renewable Energy*, *132*, 1415–1424. https://doi.org/10.1016/j.renene.2018.09.021

Shen, W., Chen, X., Qiu, J., Hayward, J. A., Sayeef, S., Osman, P., Meng, K., & Dong, Z. Y. (2020). A comprehensive review of variable renewable energy levelized cost of electricity. *Renewable and Sustainable Energy Reviews*, *133*(March), 110301. https://doi.org/10.1016/j.rser.2020.110301

Silberston, A. (1972). Economies of Scale in. *Source: The Economic Journal*, *82*(325), 369–391.

Stigler, G. J., Law, J., & Oct, V. (1958). The Economies of Scale THE ECONOMIES OF SCALE *. *The Journal of Law and Economics*, *1*, 54–71. https://www.journals.uchicago.edu/doi/10.1086/466541

Sun, H., Khan, A. R., Bashir, A., Alemzero, D. A., Abbas, Q., & Abudu, H. (2020). Energy insecurity, pollution mitigation, and renewable energy integration: prospective of wind energy in Ghana. *Environmental Science and Pollution Research*, *27*(30), 38259–38275. https://doi.org/10.1007/s11356-020-09709-w

Terca, G., & Wozabal, D. (2021). Economies of Scope for Electricity Storage and Variable Renewables. *IEEE Transactions on Power Systems*, *36*(2), 1328–1337. https://doi.org/10.1109/TPWRS.2020.3022823

Timilsina, G. R. (2021). Are renewable energy technologies cost competitive for electricity generation? *Renewable Energy*, *180*, 658–672. https://doi.org/10.1016/j.renene.2021.08.088

Umoh, K., Hasan, A., Kenjegaliev, A., & Al-Qattan, A. (2024). Assessment of the locational potential of floating offshore wind energy in South Africa. *Sustainable Energy Research*, *11*(1). https://doi.org/10.1186/s40807-024-00104-4

United Nations. (2015). *Transforming our world*: *The 2030 agenda for sustaunable development.* General Assembly Resolution 70/1, A/RES/70/1. https://sdgs.un.org/2030agenda

United Nations. (2025). *Decoding Africa's energy journey*: *Three key numbers*. UN Sustainable Development Group.Retrieved April 25, 2025. https://unsdg.un.org/latest/stories/decoding-africa%E2%80%99s-energy-journey-three-key-numbers

Uyigue, E., & Archibong, E. O. (2010). Scaling-up renewable energy technologies in Africa. *Journal of Engineering and Technology Research*, *2*(8), 130–138. http://www.academicjournals.org/JETR

WCED. (1987). The Brundtland Report: "Our Common Future." *Medicine and War*, *4*(1), 17–25. https://doi.org/10.1080/07488008808408783

Wei, M., Patadia, S., & Kammen, D. M. (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? *Energy Policy*, *38*(2), 919–931. https://doi.org/10.1016/j.enpol.2009.10.044

Williamson, O. E. (1981). The Economics of Organization: The Transaction Cost Approach. *American Journal of Sociology*, *87*(3), 548–577. https://doi.org/10.1086/227496

Wiser, R. H., Bolinger, M., Hoen, B., Millstein, D., Rand, J., Barbose, G., & Berkeley Lab. (2020). *Wind Energy Technology Data Update: 2020 Edition*. https://escholarship.org/uc/item/9r49w83n

Wooldridge, J. M. (2016). Introductory Econometrics 6th Edition. In *An introductory econometrics. A modern approach.* (6th ed.). Cengage Learning.

APPENDIX

Appendix A: Detailed Linear-regression Output for Solar PV Project in West Africa

log_lcoe2020	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
log_capacity	-.0003727	.0000181	-20.63	0.000	-.0004082	-.0003373
country						
Burkina Faso	-.1297301	.002575	-50.38	0.000	-.1347771	-.1246831
Cape Verde	-.2109437	.0041684	-50.61	0.000	-.2191136	-.2027738
CĂ´te d'Ivoire	.014933	.0023609	6.33	0.000	.0103057	.0195603
Gambia	-.1591725	.0022065	-72.14	0.000	-.1634971	-.1548479
Ghana	.0398563	.0044482	8.96	0.000	.0311379	.0485747
Guinea	-.1195464	.0035126	-34.03	0.000	-.126431	-.1126617
Guinea-Bissau	-.1097531	.002199	-49.91	0.000	-.1140632	-.1054431
Liberia	.0598993	.0024501	24.45	0.000	.0550972	.0647014
Mali	-.2023831	.0021936	-92.26	0.000	-.2066824	-.1980838
Niger	-.2419242	.0021936	-110.29	0.000	-.2462236	-.2376248
Nigeria	.0765992	.002244	34.14	0.000	.0722011	.0809973
Senegal	-.1473766	.0022007	-66.97	0.000	-.1516898	-.1430634
Sierra Leone	.0421456	.0044579	9.45	0.000	.0334083	.050883
Togo	-.0324499	.0025697	-12.63	0.000	-.0374865	-.0274134
region						
Adamawa	-.2426559	.0004909	-494.31	0.000	-.243618	-.2416937
Agadez	-.034836	.0000587	-592.96	0.000	-.0349511	-.0347208
Akwa Ibom	.0446744	.0005934	75.28	0.000	.0435113	.0458374
Alibori	-.1259254	.0022102	-56.97	0.000	-.1302574	-.1215935
Anambra	-.0258	.0005277	-48.89	0.000	-.0268343	-.0247656
Ashanti	-.0515038	.0038727	-13.30	0.000	-.0590942	-.0439134
Atakora	-.1058466	.0022061	-47.98	0.000	-.1101704	-.1015227
BafatĂĄ	-.0243034	.0002008	-121.04	0.000	-.024697	-.0239099
Bamako	.0297172	.0006299	47.17	0.000	.0284825	.0309519
Banjul	-.0170929	.0002432	-70.28	0.000	-.0175696	-.0166163
Bas-Sassandra	.0360719	.0069447	5.19	0.000	.0224606	.0496832
Bauchi	-.262404	.0004804	-546.16	0.000	-.2633457	-.2614623
Bayelsa	.0435842	.0011638	37.45	0.000	.0413032	.0458653
Benue	-.1063214	.0005053	-210.42	0.000	-.1073117	-.1053311
Biombo	-.027718	.0003656	-75.82	0.000	-.0284345	-.0270015
Bissau	-.029006	.0004931	-58.83	0.000	-.0299725	-.0280396
Boa Vista	.0087919	.0035648	2.47	0.014	.0018051	.0157787
BokĂŠ	.0081094	.0031628	2.56	0.010	.0019105	.0143084
Bomi	-.0156131	.0011976	-13.04	0.000	-.0179604	-.0132657
Bong	-.0585467	.0011009	-53.18	0.000	-.0607045	-.0563889
Borgou	-.0887704	.0025354	-35.01	0.000	-.0937398	-.0838011
Borno	-.271399	.0004784	-567.30	0.000	-.2723366	-.2704613

Boucle du Mouhoun	-.0317039	.0013519	-23.45	0.000	-.0343536	-.0290542
Brava	.0326107	.0064106	5.09	0.000	.0200461	.0451753
Brong Ahafo	-.0639064	.0038801	-16.47	0.000	-.0715113	-.0563016
Cacheu	-.0264202	.0002058	-128.36	0.000	-.0268236	-.0260168
Cascades	.0027481	.0013559	2.03	0.043	.0000905	.0054057
Central	-.0172131	.0064197	-2.68	0.007	-.0297955	-.0046307
Centre	-.023743	.0013475	-17.62	0.000	-.0263841	-.0211019
Centre-Est	.0005658	.0013546	0.42	0.676	-.0020891	.0032208
Centre-Nord	-.0302436	.0013522	-22.37	0.000	-.032894	-.0275933
Centre-Ouest	-.017005	.0013531	-12.57	0.000	-.0196571	-.0143529
Centre-Sud	-.0086649	.0013563	-6.39	0.000	-.0113231	-.0060066
Collines	-.0072382	.002332	-3.10	0.002	-.0118088	-.0026675
ComoĂŠ	.0553098	.0055604	9.95	0.000	.0444117	.066208
Conakry	.0423206	.0030019	14.10	0.000	.036437	.0482042
Cross River	-.0436323	.0006535	-66.76	0.000	-.0449132	-.0423514
Dakar	-.0424899	.0009862	-43.08	0.000	-.0444229	-.040557
Delta	-.0020711	.0005285	-3.92	0.000	-.0031069	-.0010352
DenguĂŠlĂŠ	-.1468914	.0009051	-162.30	0.000	-.1486652	-.1451175
Diffa	-.0065637	.0000741	-88.53	0.000	-.006709	-.0064184
Diourbel	-.031681	.000193	-164.17	0.000	-.0320592	-.0313028
Donga	-.0784284	.0021929	-35.76	0.000	-.0827263	-.0741304
Dosso	.0689032	.0001359	507.13	0.000	.0686369	.0691695
Eastern	-.0739167	.0038884	-19.01	0.000	-.0815378	-.0662956
Ebonyi	-.0449924	.000521	-86.37	0.000	-.0460135	-.0439713
Edo	-.0359908	.0005478	-65.70	0.000	-.0370645	-.0349172
Ekiti	-.0901741	.0006098	-147.87	0.000	-.0913693	-.0889788
Enugu	-.042635	.0005251	-81.19	0.000	-.0436641	-.0416058
Est	-.0129315	.0013524	-9.56	0.000	-.0155822	-.0102809
Faranah	-.03969	.0029011	-13.68	0.000	-.0453761	-.0340038
Fatick	-.0259579	.0002318	-111.98	0.000	-.0264122	-.0255035
Federal Capital Territory	-.123193	.0005083	-242.36	0.000	-.1241892	-.1221967
GabĂş	-.026494	.0001812	-146.20	0.000	-.0268492	-.0261388
Gao	.0069991	.0000435	161.08	0.000	.0069139	.0070842
Gbapolu	-.0662146	.0011957	-55.38	0.000	-.0685581	-.063871
Gombe	-.2541942	.000489	-519.79	0.000	-.2551526	-.2532357
Grand Cape Mount	-.0297489	.0011885	-25.03	0.000	-.0320783	-.0274196
GrandBassa	-.019638	.0011575	-16.97	0.000	-.0219066	-.0173694
GrandGedeh	-.0635479	.0011364	-55.92	0.000	-.0657753	-.0613205
GrandKru	.0193893	.0013047	14.86	0.000	.0168321	.0219466
Greater Accra	-.0435038	.0044401	-9.80	0.000	-.0522062	-.0348015
GĂ´h-Djiboua	.0062317	.0013511	4.61	0.000	.0035835	.0088799
Haut-Bassins	-.0218736	.0013519	-16.18	0.000	-.0245233	-.0192239
Imo	.0010575	.000511	2.07	0.039	.0000558	.0020591

Jigawa	-.2694764	.0004803	-561.09	0.000	-.2704177	-.2685351
Kaduna	-.2193975	.0005093	-430.80	0.000	-.2203956	-.2183993
Kaffrine	-.0186864	.0001939	-96.37	0.000	-.0190664	-.0183064
Kankan	-.0328678	.0028665	-11.47	0.000	-.0384861	-.0272496
Kano	-.270372	.0004785	-564.98	0.000	-.2713099	-.269434
Kaolack	-.0222709	.000225	-98.98	0.000	-.0227119	-.0218299
Kara	-.0413601	.0013477	-30.69	0.000	-.0440016	-.0387186
Katsina	-.2761387	.0004806	-574.58	0.000	-.2770807	-.2751968
Kayes	.0354942	.0000391	907.50	0.000	.0354175	.0355708
Kebbi	-.2164015	.0004899	-441.75	0.000	-.2173616	-.2154413
Kidal	-.0057462	.0000495	-116.06	0.000	-.0058433	-.0056492
Kindia	.0554888	.0028646	19.37	0.000	.0498743	.0611033
Kogi	-.098349	.0005033	-195.41	0.000	-.0993354	-.0973626
Kolda	-.0010539	.0001908	-5.52	0.000	-.0014278	-.00068
Koulikoro	.0266849	.0000364	732.52	0.000	.0266135	.0267563
Kwara	-.1244435	.0004949	-251.43	0.000	-.1254135	-.1234734
KĂŠdougou	-.0018489	.0001883	-9.82	0.000	-.0022179	-.0014798
LabĂŠ	-.0396297	.0027572	-14.37	0.000	-.0450337	-.0342257
Lacs	.0148379	.0009108	16.29	0.000	.0130527	.0166231
Lagos	-.0368092	.0010359	-35.53	0.000	-.0388395	-.0347788
Lagunes	.0195592	.0034802	5.62	0.000	.0127382	.0263802
Lofa	-.1050403	.0011141	-94.28	0.000	-.107224	-.1028566
Louga	-.0363776	.0002015	-180.53	0.000	-.0367726	-.0359827
Lower River	.0029198	.00025	11.68	0.000	.0024298	.0034097
Maccarthy Island	.0022369	.0002539	8.81	0.000	.0017393	.0027346
Maio	.0303786	.0035925	8.46	0.000	.0233375	.0374198
Mamou	-.0541719	.0028673	-18.89	0.000	-.0597918	-.0485521
Maradi	.0212954	.0002373	89.75	0.000	.0208303	.0217604
Margibi	-.0258549	.0012203	-21.19	0.000	-.0282466	-.0234633
Maritime	.0499094	.0013778	36.22	0.000	.047209	.0526098
Maryland	-.0012908	.0015966	-0.81	0.419	-.00442	.0018384
Matam	-.0245974	.0001921	-128.03	0.000	-.0249739	-.0242208
Montagnes	-.0866477	.0047753	-18.15	0.000	-.0960071	-.0772883
Montserrado	-.0088493	.0014056	-6.30	0.000	-.0116042	-.0060944
Mopti	.0199987	.0000813	246.04	0.000	.0198393	.020158
Nassarawa	-.1351092	.0004927	-274.23	0.000	-.1360748	-.1341435
Niamey	.080346	.000776	103.53	0.000	.078825	.081867
Niger	-.1637444	.0004907	-333.71	0.000	-.1647061	-.1627826
Nimba	-.0687435	.0011091	-61.98	0.000	-.0709174	-.0665696
Nord	-.0385216	.0013522	-28.49	0.000	-.0411717	-.0358714
North Bank	-.0041651	.0002796	-14.90	0.000	-.0047131	-.0036171
Northern	-.1022227	.0038763	-26.37	0.000	-.10982	-.0946253
NzĂŠrĂŠkorĂŠ	0	(omitted)				
Ogun	-.0155511	.0005015	-31.01	0.000	-.0165341	-.0145682
Oio	-.026035	.000175	-148.75	0.000	-.0263781	-.025692
Ondo	-.0416068	.0007427	-56.02	0.000	-.0430625	-.0401511

Osun	-.0426857	.0005693	-74.98	0.000	-.0438015	-.0415698
Oyo	-.065794	.0005223	-125.96	0.000	-.0668178	-.0647703
PaĂşl	-.0680883	.0036026	-18.90	0.000	-.0751492	-.0610274
Plateau	-.2197559	.000556	-395.23	0.000	-.2208457	-.2186661
Plateau-Central	-.0224006	.0013535	-16.55	0.000	-.0250535	-.0197477
Plateaux	.0040946	.0013509	3.03	0.002	.0014468	.0067424
Porto Novo	-.0764488	.0035519	-21.52	0.000	-.0834103	-.0694872
Praia	.0138991	.0036768	3.78	0.000	.0066928	.0211054
Quinara	-.0136871	.0003145	-43.52	0.000	-.0143035	-.0130707
Ribeira Brava	.0580708	.0044969	12.91	0.000	.049257	.0668846
Ribeira Grande	-.0729138	.0035756	-20.39	0.000	-.0799218	-.0659058
Ribeira Grande de Santiago	.0023204	.0036926	0.63	0.530	-.004917	.0095577
River Cess	-.0179693	.0013559	-13.25	0.000	-.0206269	-.0153118
River Gee	-.039808	.0012034	-33.08	0.000	-.0421666	-.0374494
Rivers	.0373146	.0007127	52.36	0.000	.0359178	.0387113
Sahel	-.0307643	.0013546	-22.71	0.000	-.0334193	-.0281094
Saint-Louis	-.0393091	.0002787	-141.02	0.000	-.0398554	-.0387628
Sal	.0042756	.0035818	1.19	0.233	-.0027446	.0112959
Santa Catarina	.0135431	.0042029	3.22	0.001	.0053055	.0217806
Santa Catarina do Fogo	-.0342993	.0094232	-3.64	0.000	-.0527684	-.0158302
Santa Cruz	.0862645	.0054798	15.74	0.000	.0755243	.0970046
Sassandra-MarahouĂŠ	-.015131	.0025381	-5.96	0.000	-.0201056	-.0101564
Savanes	-.0694353	.0013288	-52.25	0.000	-.0720398	-.0668308
Sikasso	.0440615	.000044	1001.54	0.000	.0439752	.0441477
Sinoe	0	(omitted)				
Sokoto	-.2474585	.00049	-505.03	0.000	-.2484189	-.2464982
Southern	-.0403883	.0038895	-10.38	0.000	-.0480117	-.032765
Sud-Ouest	.0085713	.0013563	6.32	0.000	.005913	.0112296
SĂŁo Domingos	.034193	.0041688	8.20	0.000	.0260223	.0423638
SĂŁo Filipe	-.0125368	.0036972	-3.39	0.001	-.0197832	-.0052903
SĂŁo Miguel	.1201537	.0052823	22.75	0.000	.1098005	.1305068
SĂŁo Vicente	-.0687747	.0035552	-19.34	0.000	-.0757427	-.0618067
SĂŠdhiou	-.0029792	.0001974	-15.09	0.000	-.0033661	-.0025923
SĂŠgou	.0252471	.0000482	523.92	0.000	.0251526	.0253415
Tahoua	.0255287	.0000616	414.30	0.000	.0254079	.0256495
Tambacounda	-.0086088	.000188	-45.80	0.000	-.0089772	-.0082404
Taraba	-.1852383	.0004979	-372.03	0.000	-.1862142	-.1842624
Tarrafal	.078152	.0041421	18.87	0.000	.0700336	.0862704
Tarrafal de SĂŁo Nicolau	0	(omitted)				
ThiĂ¨s	-.0370546	.0002655	-139.54	0.000	-.037575	-.0365341
TillabĂŠry	.0617766	.0000656	942.19	0.000	.0616481	.0619051
Timbuktu	0	(omitted)				

Tombali	0	(omitted)				
Upper East	-.1487071	.0038767	-38.36	0.000	-.1563053	-.1411088
Upper River	.0068771	.0002443	28.15	0.000	.0063983	.0073559
Upper West	-.1495946	.0038744	-38.61	0.000	-.1571883	-.142001
VallĂŠe du Bandama	-.0299427	.0010383	-28.84	0.000	-.0319777	-.0279077
Volta	-.044517	.0039142	-11.37	0.000	-.0521887	-.0368453
Western	0	(omitted)				
Woroba	-.116493	.0010261	-113.52	0.000	-.1185042	-.1144817
Yamoussoukro	-.0016753	.0009094	-1.84	0.065	-.0034576	.000107
Yobe	-.2757877	.000479	-575.75	0.000	-.2767266	-.2748489
Zamfara	-.2446408	.000488	-501.27	0.000	-.2455973	-.2436842
Zanzan	0	(omitted)				
Ziguinchor	0	(omitted)				
Zinder	0	(omitted)				
Zou	0	(omitted)				
_cons	-3.094382	.0021977	-1408.02	0.000	-3.098689	-3.090074

Appendix B: Detailed Linear-regression Output for Wind Energy Project in West

log_lcoe2020	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
log_capacity_sq	1.136997	.007524	151.12	0.000	1.12225	1.151744
log_capacity	-22.00029	.1258485	-174.82	0.000	-22.24695	-21.75364
country						
Burkina Faso	.0049372	.0007129	6.93	0.000	.0035399	.0063346
Cape Verde	-.0359729	.0020042	-17.95	0.000	-.0399011	-.0320446
CÃ□Â´te d'Ivoire	-.0076566	.0011988	-6.39	0.000	-.0100062	-.005307
Gambia	-.0144174	.0009423	-15.30	0.000	-.0162643	-.0125706
Ghana	.0209538	.0013703	15.29	0.000	.018268	.0236396
Guinea	-.0022924	.0105043	-0.22	0.827	-.0228805	.0182957
Guinea-Bissau	-.0562138	.0012483	-45.03	0.000	-.0586604	-.0537673
Liberia	-.0291067	.0011495	-25.32	0.000	-.0313597	-.0268538
Mali	-.0236582	.00085	-27.83	0.000	-.0253242	-.0219923
Niger	.0349775	.0008611	40.62	0.000	.0332898	.0366652
Nigeria	-.0465932	.0022671	-20.55	0.000	-.0510366	-.0421498
Senegal	-.0245583	.0011374	-21.59	0.000	-.0267875	-.0223291
Sierra Leone	-.1572123	.0009491	-165.64	0.000	-.1590725	-.155352
Togo	-.0543643	.0016208	-33.54	0.000	-.057541	-.0511875
region						
Adamawa	.0360065	.0022648	15.90	0.000	.0315676	.0404454
Agadez	-.0786793	.0000935	-841.76	0.000	-.0788625	-.0784961
Akwa Ibom	-.0244201	.0055072	-4.43	0.000	-.035214	-.0136262
Alibori	.0447824	.000905	49.48	0.000	.0430086	.0465562
Anambra	-.0362478	.0022946	-15.80	0.000	-.040745	-.0317505
Ashanti	-.0253451	.0013023	-19.46	0.000	-.0278975	-.0227927

Atakora	.037026	.0007509	49.31	0.000	.0355542	.0384977
BafatÃ□Â¡	-.0078113	.0019231	-4.06	0.000	-.0115806	-.0040421
Bauchi	.0804718	.0021934	36.69	0.000	.0761728	.0847707
Bayelsa	.0280788	.0023892	11.75	0.000	.023396	.0327616
Benue	-.0060746	.0022716	-2.67	0.007	-.0105269	-.0016222
Biombo	.0152433	.0012771	11.94	0.000	.0127403	.0177464
Boa Vista	-.0020737	.0018847	-1.10	0.271	-.0057677	.0016203
BokÃ□Â©	-.0823041	.0108647	-7.58	0.000	-.1035986	-.0610096
Bong	-.0731615	.001375	-53.21	0.000	-.0758565	-.0704664
Borgou	.013657	.0012037	11.35	0.000	.0112978	.0160162
Borno	.0948563	.0022021	43.08	0.000	.0905403	.0991723
Boucle du Mouhoun	.0255053	.0002295	111.13	0.000	.0250555	.0259552
Brava	-.0109894	.0039531	-2.78	0.005	-.0187373	-.0032414
Brong Ahafo	-.0478691	.0012898	-37.11	0.000	-.0503972	-.0453411
Cacheu	.0159512	.0011396	14.00	0.000	.0137175	.0181848
Cascades	-.0292354	.0004813	-60.74	0.000	-.0301788	-.028292
Central	.0357999	.0031329	11.43	0.000	.0296596	.0419402
Centre	.0263926	.0006469	40.80	0.000	.0251246	.0276605
Centre-Est	.0114376	.0002905	39.37	0.000	.0108682	.012007
Centre-Ouest	.0205168	.0001979	103.66	0.000	.0201289	.0209047
Centre-Sud	.0225535	.0003442	65.52	0.000	.0218789	.0232282
Collines	-.0463048	.0014761	-31.37	0.000	-.0491978	-.0434117
Conakry	-.2023445	.0111215	-18.19	0.000	-.2241423	-.1805468
Cross River	-.014116	.0028224	-5.00	0.000	-.0196477	-.0085842
Dakar	.0033522	.002364	1.42	0.156	-.0012813	.0079856
Delta	.0290191	.0023122	12.55	0.000	.0244872	.0335509
DenguÃ□Â©lÃ□Â©	-.0367173	.0149255	-2.46	0.014	-.0659706	-.0074639
Diffa	-.0438824	.0001232	-356.09	0.000	-.0441239	-.0436408
Diourbel	.0118091	.0008724	13.54	0.000	.0100993	.0135189
Donga	.000288	.0006703	0.43	0.667	-.0010258	.0016019

Dosso	-.0031914	.0001428	-22.34	0.000	-.0034713	-.0029114
Eastern	-.0870804	.0018434	-47.24	0.000	-.0906935	-.0834674
Ebonyi	-.0174328	.0022547	-7.73	0.000	-.021852	-.0130137
Edo	.0275906	.0028437	9.70	0.000	.022017	.0331642
Ekiti	.0497085	.0023588	21.07	0.000	.0450854	.0543316
Enugu	-.0182144	.0025028	-7.28	0.000	-.0231198	-.0133091
Est	.0444131	.000305	145.64	0.000	.0438154	.0450108
Faranah	.3131783	.0908921	3.45	0.001	.1350329	.4913237
Fatick	.0019989	.0008659	2.31	0.021	.0003017	.0036961
Federal Capital Territory	-.1063829	.0026264	-40.51	0.000	-.1115305	-.1012353
GabÃ□Âº	-.002893	.0014801	-1.95	0.051	-.0057939	7.92e-06
Gao	.0136889	.0000537	254.77	0.000	.0135836	.0137942
Gombe	.0577486	.002206	26.18	0.000	.0534249	.0620722
GrandKru	-.0100635	.0075918	-1.33	0.185	-.0249431	.0048161
Greater Accra	.0563986	.0013298	42.41	0.000	.0537923	.0590049
Haut-Bassins	-.0043343	.0002027	-21.39	0.000	-.0047315	-.0039371
Imo	-.0338047	.0046484	-7.27	0.000	-.0429154	-.0246939
Jigawa	.0808917	.0022016	36.74	0.000	.0765767	.0852068
Kaduna	.0306054	.00227	13.48	0.000	.0261563	.0350544
Kaffrine	-.0037652	.0008607	-4.37	0.000	-.0054521	-.0020783
Kankan	-.0406824	.0105561	-3.85	0.000	-.061372	-.0199928
Kano	.1084885	.0022352	48.54	0.000	.1041075	.1128695
Kaolack	-.0077988	.000872	-8.94	0.000	-.0095078	-.0060898
Kara	.051798	.0015029	34.47	0.000	.0488524	.0547437
Katsina	.0825908	.0022364	36.93	0.000	.0782076	.0869739
Kayes	.0098879	.0001479	66.87	0.000	.009598	.0101777
Kebbi	.0549611	.0021946	25.04	0.000	.0506598	.0592624
Kidal	.0044446	.0000489	90.95	0.000	.0043488	.0045403
Kindia	-.1329344	.0119322	-11.14	0.000	-.1563212	-.1095477
Kogi	.002675	.0031066	0.86	0.389	-.0034139	.0087638
Kolda	-.0224699	.0009363	-24.00	0.000	-.024305	-.0206348

Koulikoro	.0420869	.0001175	358.19	0.000	.0418566	.0423171
Kwara	.0288865	.0022189	13.02	0.000	.0245375	.0332354
KÃ□Â©dougou	-.023976	.0009713	-24.68	0.000	-.0258797	-.0220722
LabÃ□Â©	.0091097	.0106048	0.86	0.390	-.0116753	.0298947
Lacs	-.0009209	.0011748	-0.78	0.433	-.0032234	.0013816
Lagos	.0700486	.0063741	10.99	0.000	.0575555	.0825417
Lofa	-.073359	.0098466	-7.45	0.000	-.0926581	-.0540599
Louga	.0413939	.0008633	47.95	0.000	.0397018	.043086
Lower River	-.0101782	.0007796	-13.06	0.000	-.0117062	-.0086503
Maccarthy Island	-.0249643	.0006212	-40.18	0.000	-.026182	-.0237467
Maio	.0154992	.0019496	7.95	0.000	.0116781	.0193203
Maradi	-.0197367	.000135	-146.16	0.000	-.0200013	-.019472
Maritime	.1369628	.0019051	71.89	0.000	.1332289	.1406967
Maryland	0	(omitted)				
Matam	.0149896	.0008609	17.41	0.000	.0133023	.0166769
Mopti	.0669032	.0001125	594.77	0.000	.0666827	.0671237
Nassarawa	.0021773	.0022808	0.95	0.340	-.0022929	.0066475
Niamey	.0241212	.0008681	27.79	0.000	.0224198	.0258226
Niger	-.031684	.0021976	-14.42	0.000	-.0359913	-.0273768
Nord	.0338403	.0002994	113.02	0.000	.0332535	.0344272
North Bank	-.0083833	.0007548	-11.11	0.000	-.0098626	-.006904
Northern	-.0428687	.0011834	-36.22	0.000	-.0451882	-.0405492
NzÃ□Â©rÃ□Â©korÃ□Â©	0	(omitted)				
Ogun	.0590166	.0025182	23.44	0.000	.0540809	.0639522
Oio	.0040532	.0011605	3.49	0.000	.0017785	.0063278
Ondo	.0347148	.0116425	2.98	0.003	.0118959	.0575337
Osun	.0520851	.0029348	17.75	0.000	.046333	.0578372
Oyo	.0559763	.0021929	25.53	0.000	.0516782	.0602744
PaÃ□Âºl	.0345183	.0032052	10.77	0.000	.0282363	.0408004
Plateau	.0468579	.0022233	21.08	0.000	.0425003	.0512155
Plateau-Central	.0301874	.0004025	75.00	0.000	.0293985	.0309764
Plateaux	.0644688	.002831	22.77	0.000	.0589201	.0700175
Porto Novo	.077229	.0031644	24.41	0.000	.0710269	.0834312
Praia	-.0068039	.0019608	-3.47	0.001	-.0106469	-.0029609

Quinara	.0060739	.001195	5.08	0.000	.0037318	.008416
Ribeira Brava	.0047771	.0025051	1.91	0.057	-.0001327	.009687
Ribeira Grande	.0461597	.0099966	4.62	0.000	.0265668	.0657526
Ribeira Grande de Santiago	.0025642	.0021452	1.20	0.232	-.0016402	.0067687
Rivers	.0051323	.002559	2.01	0.045	.0001167	.010148
Sahel	.0474845	.0003036	156.38	0.000	.0468894	.0480796
Saint-Louis	.0391217	.00087	44.97	0.000	.0374166	.0408268
Sal	-.0064758	.0018775	-3.45	0.001	-.0101556	-.002796
Santa Catarina	.0012171	.0022281	0.55	0.585	-.00315	.0055841
Santa Catarina do Fogo	.036603	.0018593	19.69	0.000	.0329588	.0402473
Santa Cruz	.0397965	.0024547	16.21	0.000	.0349855	.0446076
Savanes	.0537876	.0017172	31.32	0.000	.0504219	.0571533
Sikasso	.0129925	.0003486	37.27	0.000	.0123092	.0136758
Sokoto	.0659366	.0022205	29.69	0.000	.0615845	.0702888
Southern	-.0624424	.0022905	-27.26	0.000	-.0669317	-.0579531
Sud-Ouest	0	(omitted)				
SÃ□Â£o Domingos	.0014679	.0021741	0.68	0.500	-.0027932	.005729
SÃ□Â£o Filipe	.2534839	.0238487	10.63	0.000	.2067413	.3002265
SÃ□Â£o Miguel	.030318	.004389	6.91	0.000	.0217158	.0389203
SÃ□Â£o Salvador do Mundo	.0073191	.0020224	3.62	0.000	.0033554	.0112829
SÃ□Â£o Vicente	-.0016812	.0018768	-0.90	0.370	-.0053597	.0019973
SÃ□Â©dhiou	-.0163432	.0011731	-13.93	0.000	-.0186425	-.0140438
SÃ□Â©gou	.0473108	.0000854	553.84	0.000	.0471434	.0474783
Tahoua	-.0267817	.0000992	-269.85	0.000	-.0269762	-.0265872
Tambacounda	-.0079056	.0008557	-9.24	0.000	-.0095827	-.0062286
Taraba	.0872707	.0025307	34.48	0.000	.0823106	.0922308
Tarrafal	.0193062	.0027262	7.08	0.000	.013963	.0246493
Tarrafal de SÃ□Â£o Nicolau	0	(omitted)				
ThiÃ□Â¨s	.0259913	.0009416	27.60	0.000	.0241457	.0278368
TillabÃ□Â©ry	-.014742	.000126	-117.02	0.000	-.0149889	-.0144951
Timbuktu	0	(omitted)				
Tombali	0	(omitted)				
Upper East	-.0261397	.0012499	-20.91	0.000	-.0285894	-.02369

Upper River	-.0310344	.0006052	-51.28	0.000	-.0322205	-.0298482
Upper West	-.0164704	.001218	-13.52	0.000	-.0188577	-.0140832
VallÃ□Â©e du Bandama	.0011668	.0013198	0.88	0.377	-.00142	.0037536
Volta	-.009383	.0018096	-5.19	0.000	-.0129299	-.0058362
Western	0	(omitted)				
Woroba	.0101499	.0044366	2.29	0.022	.0014543	.0188456
Yobe	.0892037	.0022186	40.21	0.000	.0848553	.093552
Zamfara	.0755912	.0022213	34.03	0.000	.0712375	.0799449
Zanzan	0	(omitted)				
Ziguinchor	0	(omitted)				
Zinder	0	(omitted)				
Zou	0	(omitted)				
_cons	101.7491	.5257045	193.55	0.000	100.7187	102.7794

Appendix C: Detailed Parabolic regression Output for Solar PV Projects in West Africa

log_lcoe2020	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
log_capaci~q	-.0003884	.0000115	-33.91	0.000	-.0004108	-.0003659
log_capacity	.0066814	.0002108	31.70	0.000	.0062683	.0070945
Country						
Burkina F..	-.1307352	.0028847	-45.32	0.000	-.136389	-.1250813
Cape Verde	-.2114949	.0044025	-48.04	0.000	-.2201236	-.2028662
Cote D'Ivoire	.0143214	.0026942	5.32	0.000	.0090408	.0196019
Gambia	-.1597702	.0025604	-62.40	0.000	-.1647886	-.1547518
Ghana	.0400801	.0046571	8.61	0.000	.0309524	.0492079
Guinea	-.1198476	.0037491	-31.97	0.000	-.1271958	-.1124994
Guinea-Bi~u	-.110367	.002554	-43.21	0.000	-.1153726	-.1053613
Liberia	.0603522	.002772	21.77	0.000	.0549192	.0657853
Mali	-.202333	.0025491	-79.38	0.000	-.2073291	-.1973369
Niger	-.2421379	.0025491	-94.99	0.000	-.247134	-.2371417
Nigeria	.0761267	.0025927	29.36	0.000	.0710451	.0812083
Senegal	-.1478809	.0025552	-57.87	0.000	-.152889	-.1428728
Sierra Leone.	.0421623	.0046665	9.04	0.000	.0330162	.0513083
Togo	-.0332362	.0028799	-11.54	0.000	-.0388807	-.0275918
Region						
Adamawa	-.2427426	.0004915	-493.93	0.000	-.2437058	-.2417793
Agadez	-.0345859	.0000587	-589.61	0.000	-.0347009	-.034471
Akwa Ibom	.0446349	.000593	75.27	0.000	.0434726	.0457971
Alibori	-.1264012	.0025635	-49.31	0.000	-.1314255	-.1213769
Anambra	-.025911	.0005287	-49.01	0.000	-.0269473	-.0248747
Ashanti	-.0521772	.0039007	-13.38	0.000	-.0598224	-.0445321
Atakora	-.1061326	.0025606	-41.45	0.000	-.1111513	-.1011139
BafatĂĄ	-.0244401	.000202	-120.97	0.000	-.0248361	-.0240442
Bamako	.0293431	.0006061	48.42	0.000	.0281552	.030531
Banjul	-.0174823	.0002453	-71.27	0.000	-.0179631	-.0170015
Bas-Sassa~a	.0377169	.0070118	5.38	0.000	.0239741	.0514597
Bauchi	-.2624102	.0004809	-545.61	0.000	-.2633529	-.2614676
Bayelsa	.0436299	.0011598	37.62	0.000	.0413566	.0459032
Benue	-.106428	.0005057	-210.46	0.000	-.1074191	-.1054369
Biombo	-.02777	.0003615	-76.82	0.000	-.0284785	-.0270614
Bissau	-.028756	.0004497	-63.95	0.000	-.0296373	-.0278747
Boa Vista	.0091127	.0036085	2.53	0.012	.0020403	.0161852
BokĂŠ	.0078191	.0031677	2.47	0.014	.0016105	.0140276
Bomi	-.0160983	.0011956	-13.47	0.000	-.0184415	-.013755
Bong	-.0594961	.0010989	-54.14	0.000	-.0616499	-.0573423
Borgou	-.0892876	.0028453	-31.38	0.000	-.0948643	-.0837108
Borno	-.2712795	.0004789	-566.45	0.000	-.2722182	-.2703409

Boucle du..	-.0312635	.0013531	-23.10	0.000	-.0339155	-.0286114
Brava	.0331528	.0065437	5.07	0.000	.0203273	.0459782
Brong Ahafo	-.0645926	.0039079	-16.53	0.000	-.0722519	-.0569333
Cacheu	-.0265061	.0002065	-128.33	0.000	-.0269109	-.0261013
Cascades	.0031718	.0013572	2.34	0.019	.0005118	.0058319
Central	-.0173143	.0064934	-2.67	0.008	-.030041	-.0045875
Centre	-.023359	.0013488	-17.32	0.000	-.0260026	-.0207154
Centre-Est	.0009105	.0013558	0.67	0.502	-.0017467	.0035678
Centre-Nord	-.0298747	.0013534	-22.07	0.000	-.0325273	-.027222
Centre-Ou~t	-.0165748	.0013543	-12.24	0.000	-.0192293	-.0139204
Centre-Sud	-.0082965	.0013575	-6.11	0.000	-.0109572	-.0056358
Collines	-.0077203	.0026714	-2.89	0.004	-.0129562	-.0024845
ComoĂŠ	.0565834	.005563	10.17	0.000	.0456801	.0674867
Conakry	.0424747	.0030245	14.04	0.000	.0365467	.0484027
Cross River	-.0436033	.0006559	-66.48	0.000	-.0448887	-.0423178
Dakar	-.0418044	.000728	-57.43	0.000	-.0432312	-.0403776
Delta	-.0021684	.0005295	-4.09	0.000	-.0032063	-.0011305
DenguĂŠlĂŠ	-.1468625	.0009039	-162.47	0.000	-.1486341	-.1450908
Diffa	-.0063572	.0000737	-86.22	0.000	-.0065017	-.0062126
Diourbel	-.0315738	.000193	-163.58	0.000	-.0319521	-.0311955
Donga	-.0790232	.0025486	-31.01	0.000	-.0840183	-.0740281
Dosso	.0686363	.0001356	506.00	0.000	.0683704	.0689021
Eastern	-.0744592	.0039162	-19.01	0.000	-.0821348	-.0667835
Ebonyi	-.0449591	.0005205	-86.38	0.000	-.0459792	-.043939
Edo	-.0361085	.0005485	-65.83	0.000	-.0371836	-.0350335
Ekiti	-.0901048	.000612	-147.23	0.000	-.0913043	-.0889054
Enugu	-.0428248	.0005255	-81.49	0.000	-.0438548	-.0417949
Est	-.0124487	.0013536	-9.20	0.000	-.0151017	-.0097957
Faranah	-.0397185	.0029665	-13.39	0.000	-.0455328	-.0339043
Fatick	-.0257544	.0002322	-110.93	0.000	-.0262095	-.0252994
Federal C..	-.1232789	.0005087	-242.34	0.000	-.1242759	-.1222818
GabĂş	-.0266267	.0001828	-145.65	0.000	-.026985	-.0262684
Gao	.0069799	.0000433	161.22	0.000	.006895	.0070648
Gbapolu	-.0666502	.0011946	-55.79	0.000	-.0689917	-.0643088
Gombe	-.2542765	.0004896	-519.40	0.000	-.2552361	-.253317
Grand Cap..	-.0304549	.0011844	-25.71	0.000	-.0327763	-.0281335
GrandBassa	-.0201347	.0011551	-17.43	0.000	-.0223986	-.0178708
GrandGedeh	-.0630728	.0011364	-55.50	0.000	-.0653001	-.0608454
GrandKru	.0186032	.0013017	14.29	0.000	.0160519	.0211546
Greater A..	-.0441231	.0044624	-9.89	0.000	-.0528694	-.0353769
GĂ´h-Djib~a	.0065122	.0014093	4.62	0.000	.00375	.0092744
Haut-Bass~s	-.0214989	.0013531	-15.89	0.000	-.0241509	-.018847
Imo	.0010127	.0005098	1.99	0.047	.0000135	.002012
Jigawa	-.2693273	.0004807	-560.24	0.000	-.2702695	-.2683851
Kaduna	-.2194424	.0005098	-430.49	0.000	-.2204415	-.2184433
Kaffrine	-.0183094	.0001929	-94.91	0.000	-.0186875	-.0179313

Kankan	-.0330877	.0028719	-11.52	0.000	-.0387165	-.0274589
Kano	-.2701999	.000479	-564.04	0.000	-.2711388	-.269261
Kaolack	-.0218863	.0002306	-94.92	0.000	-.0223382	-.0214344
Kara	-.0410573	.001349	-30.43	0.000	-.0437014	-.0384133
Katsina	-.27595	.0004812	-573.46	0.000	-.2768931	-.2750068
Kayes	.0351776	.0000403	873.12	0.000	.0350987	.0352566
Kebbi	-.2164678	.0004903	-441.48	0.000	-.2174288	-.2155068
Kidal	-.0057113	.0000495	-115.46	0.000	-.0058082	-.0056143
Kindia	.0553323	.0028696	19.28	0.000	.0497079	.0609566
Kogi	-.0984234	.0005039	-195.33	0.000	-.099411	-.0974358
Kolda	-.001234	.00019	-6.50	0.000	-.0016064	-.0008617
Koulikoro	.0262514	.0000385	681.75	0.000	.0261759	.0263269
Kwara	-.1243313	.0004953	-251.03	0.000	-.1253021	-.1233606
KĂŠdougou	-.0015753	.0001875	-8.40	0.000	-.0019429	-.0012078
LabĂŠ	-.0398103	.0027632	-14.41	0.000	-.0452262	-.0343945
Lacs	.0148644	.0009099	16.34	0.000	.0130811	.0166478
Lagos	-.0367166	.0010383	-35.36	0.000	-.0387516	-.0346816
Lagunes	.0197108	.0036268	5.43	0.000	.0126024	.0268193
Lofa	-.1058385	.0011128	-95.11	0.000	-.1080195	-.1036576
Louga	-.0361991	.0002002	-180.80	0.000	-.0365915	-.0358066
Lower River	.002845	.0002522	11.28	0.000	.0023508	.0033393
Maccarthy..	.0023053	.0002558	9.01	0.000	.0018039	.0028066
Maio	.0306188	.003637	8.42	0.000	.0234905	.0377471
Mamou	-.053094	.0027536	-19.28	0.000	-.0584909	-.047697
Maradi	.0211292	.0002378	88.85	0.000	.0206631	.0215953
Margibi	-.0266488	.0012184	-21.87	0.000	-.0290368	-.0242607
Maritime	.0500738	.0013789	36.31	0.000	.0473711	.0527764
Maryland	-.0017873	.0015966	-1.12	0.263	-.0049166	.0013421
Matam	-.0241193	.0001919	-125.66	0.000	-.0244956	-.0237431
Montagnes	-.0863149	.0048377	-17.84	0.000	-.0957966	-.0768332
Montserrado	-.0093722	.0014068	-6.66	0.000	-.0121295	-.0066149
Mopti	.0195261	.0000828	235.84	0.000	.0193639	.0196884
Nassarawa	-.1351757	.0004931	-274.12	0.000	-.1361422	-.1342091
Niamey	.0800199	.0007896	101.34	0.000	.0784723	.0815675
Niger	-.1638803	.0004912	-333.61	0.000	-.1648431	-.1629175
Nimba	-.0689133	.0011069	-62.26	0.000	-.0710829	-.0667438
Nord	-.0381241	.0013533	-28.17	0.000	-.0407766	-.0354716
North Bank	-.0040022	.0002817	-14.21	0.000	-.0045543	-.0034502
Northern	-.1028143	.0039041	-26.33	0.000	-.1104662	-.0951623
NzĂŠrĂŠko~Š	0	(omitted)				
Ogun	-.0156254	.0005021	-31.12	0.000	-.0166094	-.0146414
Oio	-.0261559	.0001767	-148.07	0.000	-.0265021	-.0258097
Ondo	-.0414355	.0007446	-55.65	0.000	-.042895	-.039976
Osun	-.0425887	.0005711	-74.57	0.000	-.0437081	-.0414692
Oyo	-.0657721	.0005225	-125.88	0.000	-.0667962	-.064748
PaĂşl	-.0668639	.0035996	-18.58	0.000	-.073919	-.0598088

Plateau	-.219832	.0005568	-394.79	0.000	-.2209234	-.2187407
Plateau-C~l	-.0220433	.0013547	-16.27	0.000	-.0246986	-.0193881
Plateaux	.0043057	.0013521	3.18	0.001	.0016556	.0069558
Porto Novo	-.0762708	.0035971	-21.20	0.000	-.083321	-.0692207
Praia	.0137723	.0037186	3.70	0.000	.006484	.0210606
Quinara	-.0137834	.0003171	-43.46	0.000	-.014405	-.0131618
Ribeira B..	.0579915	.0045283	12.81	0.000	.0491162	.0668668
Ribeira G..	-.0722831	.0036396	-19.86	0.000	-.0794166	-.0651496
Ribeira G..	.0024083	.0037466	0.64	0.520	-.0049349	.0097516
River Cess	-.0180334	.001355	-13.31	0.000	-.0206891	-.0153777
River Gee	-.0395045	.0012029	-32.84	0.000	-.0418622	-.0371467
Rivers	.0372733	.0007126	52.31	0.000	.0358767	.0386699
Sahel	-.0302694	.0013559	-22.32	0.000	-.0329269	-.0276119
Saint-Louis	-.0391416	.0002798	-139.89	0.000	-.03969	-.0385932
Sal	.0044299	.0036255	1.22	0.222	-.002676	.0115358
Santa Cat..	.01376	.0042634	3.23	0.001	.0054039	.0221161
Santa Cat..	-.0331184	.0090086	-3.68	0.000	-.0507749	-.0154618
Santa Cruz	.0872054	.0057411	15.19	0.000	.075953	.0984578
Sassandra~Š	-.0147444	.0025302	-5.83	0.000	-.0197035	-.0097854
Savanes	-.0692754	.00133	-52.09	0.000	-.0718821	-.0666686
Sikasso	.0435354	.0000461	943.72	0.000	.043445	.0436259
Sinoe	0	(omitted)				
Sokoto	-.2475202	.0004907	-504.47	0.000	-.2484819	-.2465586
Southern	-.0410664	.0039174	-10.48	0.000	-.0487444	-.0333883
Sud-Ouest	.00927	.0013577	6.83	0.000	.006609	.011931
SĂŁo Domi..	.0343652	.004237	8.11	0.000	.0260608	.0426695
SĂŁo Filipe	-.0124825	.0037452	-3.33	0.001	-.0198229	-.005142
SĂŁo Miguel	.1211998	.0056525	21.44	0.000	.1101211	.1322784
SĂŁo Vi..	-.068799	.0036	-19.11	0.000	-.0758549	-.0617431
SĂŠdhiou	-.0031501	.0001968	-16.00	0.000	-.0035359	-.0027643
SĂŠgou	.0246381	.0000506	486.76	0.000	.0245389	.0247373
Tahoua	.0255842	.000061	419.10	0.000	.0254645	.0257038
Tambacounda	-.0081708	.0001875	-43.58	0.000	-.0085383	-.0078033
Taraba	-.185278	.0004985	-371.66	0.000	-.186255	-.1843009
Tarrafal	.0782484	.0042249	18.52	0.000	.0699677	.0865291
Tarrafal ..	0	(omitted)				
ThiĂ¨s	-.03698	.0002631	-140.56	0.000	-.0374957	-.0364644
TillabĂŠry	.0617084	.0000649	951.46	0.000	.0615813	.0618355
Timbuktu	0	(omitted)				
Tombali	0	(omitted)				
Upper East	-.149458	.0039047	-38.28	0.000	-.1571111	-.1418049
Upper River	.0069494	.0002465	28.19	0.000	.0064663	.0074325
Upper West	-.1501707	.0039022	-38.48	0.000	-.1578189	-.1425225
VallĂŠe d..	-.0299573	.0010377	-28.87	0.000	-.0319912	-.0279234
Volta	-.0452404	.0039418	-11.48	0.000	-.0529662	-.0375145
Western	0	(omitted)				

Woroba	-.116566	.0010252	-113.70	0.000	-.1185754	-.1145566
Yamoussou~o	-.0005995	.0010678	-0.56	0.574	-.0026923	.0014933
Yobe	-.2757981	.0004795	-575.13	0.000	-.2767379	-.2748582
Zamfara	-.2446726	.0004884	-500.95	0.000	-.2456299	-.2437153
Zanzan	0	(omitted)				
Ziguinchor	0	(omitted)				
Zinder	0	(omitted)				
Zou	0	(omitted)				
_cons	-3.125369	.0027168	-1150.38	0.000	-3.130694	-3.120044

Appendix D: Detailed Parabolic regression Output for wind Energy Project in West Africa

log_lcoe2020	Coefficient	Robust std. err.	t	P>|t|	[95% conf. interval]	
log_capacity_sq	1.136997	.007524	151.12	0.000	1.12225	1.151744
log_capacity	-22.00029	.1258485	-174.82	0.000	-22.24695	-21.75364
Country						
Burkina Faso	.0049372	.0007129	6.93	0.000	.0035399	.0063346
Cape Verde	-.0359729	.0020042	-17.95	0.000	-.0399011	-.0320446
CÃ□Â´te d'Ivoire	-.0076566	.0011988	-6.39	0.000	-.0100062	-.005307
Gambia	-.0144174	.0009423	-15.30	0.000	-.0162643	-.0125706
Ghana	.0209538	.0013703	15.29	0.000	.018268	.0236396
Guinea	-.0022924	.0105043	-0.22	0.827	-.0228805	.0182957
Guinea-Bissau	-.0562138	.0012483	-45.03	0.000	-.0586604	-.0537673
Liberia	-.0291067	.0011495	-25.32	0.000	-.0313597	-.0268538
Mali	-.0236582	.00085	-27.83	0.000	-.0253242	-.0219923
Niger	.0349775	.0008611	40.62	0.000	.0332898	.0366652
Nigeria	-.0465932	.0022671	-20.55	0.000	-.0510366	-.0421498
Senegal	-.0245583	.0011374	-21.59	0.000	-.0267875	-.0223291
Sierra Leone	-.1572123	.0009491	-165.64	0.000	-.1590725	-.155352
Togo	-.0543643	.0016208	-33.54	0.000	-.057541	-.0511875
Region						
Adamawa	.0360065	.0022648	15.90	0.000	.0315676	.0404454
Agadez	-.0786793	.0000935	-841.76	0.000	-.0788625	-.0784961
Akwa Ibom	-.0244201	.0055072	-4.43	0.000	-.035214	-.0136262
Alibori	.0447824	.000905	49.48	0.000	.0430086	.0465562
Anambra	-.0362478	.0022946	-15.80	0.000	-.040745	-.0317505
Ashanti	-.0253451	.0013023	-19.46	0.000	-.0278975	-.0227927
Atakora	.037026	.0007509	49.31	0.000	.0355542	.0384977

BafatÃ□Â¡	-.0078113	.0019231	-4.06	0.000	-.0115806	-.0040421
Bauchi	.0804718	.0021934	36.69	0.000	.0761728	.0847707
Bayelsa	.0280788	.0023892	11.75	0.000	.023396	.0327616
Benue	-.0060746	.0022716	-2.67	0.007	-.0105269	-.0016222
Biombo	.0152433	.0012771	11.94	0.000	.0127403	.0177464
Boa Vista	-.0020737	.0018847	-1.10	0.271	-.0057677	.0016203
BokÃ□Â©	-.0823041	.0108647	-7.58	0.000	-.1035986	-.0610096
Bong	-.0731615	.001375	-53.21	0.000	-.0758565	-.0704664
Borgou	.013657	.0012037	11.35	0.000	.0112978	.0160162
Borno	.0948563	.0022021	43.08	0.000	.0905403	.0991723
Boucle du Mouhoun	.0255053	.0002295	111.13	0.000	.0250555	.0259552
Brava	-.0109894	.0039531	-2.78	0.005	-.0187373	-.0032414
Brong Ahafo	-.0478691	.0012898	-37.11	0.000	-.0503972	-.0453411
Cacheu	.0159512	.0011396	14.00	0.000	.0137175	.0181848
Cascades	-.0292354	.0004813	-60.74	0.000	-.0301788	-.028292
Central	.0357999	.0031329	11.43	0.000	.0296596	.0419402
Centre	.0263926	.0006469	40.80	0.000	.0251246	.0276605
Centre-Est	.0114376	.0002905	39.37	0.000	.0108682	.012007
Centre-Ouest	.0205168	.0001979	103.66	0.000	.0201289	.0209047
Centre-Sud	.0225535	.0003442	65.52	0.000	.0218789	.0232282
Collines	-.0463048	.0014761	-31.37	0.000	-.0491978	-.0434117
Conakry	-.2023445	.0111215	-18.19	0.000	-.2241423	-.1805468
Cross River	-.014116	.0028224	-5.00	0.000	-.0196477	-.0085842
Dakar	.0033522	.002364	1.42	0.156	-.0012813	.0079856
Delta	.0290191	.0023122	12.55	0.000	.0244872	.0335509
DenguÃ□Â©lÃ□Â©	-.0367173	.0149255	-2.46	0.014	-.0659706	-.0074639
Diffa	-.0438824	.0001232	-356.09	0.000	-.0441239	-.0436408
Diourbel	.0118091	.0008724	13.54	0.000	.0100993	.0135189
Donga	.000288	.0006703	0.43	0.667	-.0010258	.0016019
Dosso	-.0031914	.0001428	-22.34	0.000	-.0034713	-.0029114

Eastern	-.0870804	.0018434	-47.24	0.000	-.0906935	-.0834674
Ebonyi	-.0174328	.0022547	-7.73	0.000	-.021852	-.0130137
Edo	.0275906	.0028437	9.70	0.000	.022017	.0331642
Ekiti	.0497085	.0023588	21.07	0.000	.0450854	.0543316
Enugu	-.0182144	.0025028	-7.28	0.000	-.0231198	-.0133091
Est	.0444131	.000305	145.64	0.000	.0438154	.0450108
Faranah	.3131783	.0908921	3.45	0.001	.1350329	.4913237
Fatick	.0019989	.0008659	2.31	0.021	.0003017	.0036961
Federal Capital Territory	-.1063829	.0026264	-40.51	0.000	-.1115305	-.1012353
GabÃ□Âº	-.002893	.0014801	-1.95	0.051	-.0057939	7.92e-06
Gao	.0136889	.0000537	254.77	0.000	.0135836	.0137942
Gombe	.0577486	.002206	26.18	0.000	.0534249	.0620722
GrandKru	-.0100635	.0075918	-1.33	0.185	-.0249431	.0048161
Greater Accra	.0563986	.0013298	42.41	0.000	.0537923	.0590049
Haut-Bassins	-.0043343	.0002027	-21.39	0.000	-.0047315	-.0039371
Imo	-.0338047	.0046484	-7.27	0.000	-.0429154	-.0246939
Jigawa	.0808917	.0022016	36.74	0.000	.0765767	.0852068
Kaduna	.0306054	.00227	13.48	0.000	.0261563	.0350544
Kaffrine	-.0037652	.0008607	-4.37	0.000	-.0054521	-.0020783
Kankan	-.0406824	.0105561	-3.85	0.000	-.061372	-.0199928
Kano	.1084885	.0022352	48.54	0.000	.1041075	.1128695
Kaolack	-.0077988	.000872	-8.94	0.000	-.0095078	-.0060898
Kara	.051798	.0015029	34.47	0.000	.0488524	.0547437
Katsina	.0825908	.0022364	36.93	0.000	.0782076	.0869739
Kayes	.0098879	.0001479	66.87	0.000	.009598	.0101777
Kebbi	.0549611	.0021946	25.04	0.000	.0506598	.0592624
Kidal	.0044446	.0000489	90.95	0.000	.0043488	.0045403
Kindia	-.1329344	.0119322	-11.14	0.000	-.1563212	-.1095477
Kogi	.002675	.0031066	0.86	0.389	-.0034139	.0087638
Kolda	-.0224699	.0009363	-24.00	0.000	-.024305	-.0206348
Koulikoro	.0420869	.0001175	358.19	0.000	.0418566	.0423171
Kwara	.0288865	.0022189	13.02	0.000	.0245375	.0332354

KÃ□Â©dougou	-.023976	.0009713	-24.68	0.000	-.0258797	-.0220722
LabÃ□Â©	.0091097	.0106048	0.86	0.390	-.0116753	.0298947
Lacs	-.0009209	.0011748	-0.78	0.433	-.0032234	.0013816
Lagos	.0700486	.0063741	10.99	0.000	.0575555	.0825417
Lofa	-.073359	.0098466	-7.45	0.000	-.0926581	-.0540599
Louga	.0413939	.0008633	47.95	0.000	.0397018	.043086
Lower River	-.0101782	.0007796	-13.06	0.000	-.0117062	-.0086503
Maccarthy Island	-.0249643	.0006212	-40.18	0.000	-.026182	-.0237467
Maio	.0154992	.0019496	7.95	0.000	.0116781	.0193203
Maradi	-.0197367	.000135	-146.16	0.000	-.0200013	-.019472
Maritime	.1369628	.0019051	71.89	0.000	.1332289	.1406967
Maryland	0	(omitted)				
Matam	.0149896	.0008609	17.41	0.000	.0133023	.0166769
Mopti	.0669032	.0001125	594.77	0.000	.0666827	.0671237
Nassarawa	.0021773	.0022808	0.95	0.340	-.0022929	.0066475
Niamey	.0241212	.0008681	27.79	0.000	.0224198	.0258226
Niger	-.031684	.0021976	-14.42	0.000	-.0359913	-.0273768
Nord	.0338403	.0002994	113.02	0.000	.0332535	.0344272
North Bank	-.0083833	.0007548	-11.11	0.000	-.0098626	-.006904
Northern	-.0428687	.0011834	-36.22	0.000	-.0451882	-.0405492
NzÃ□Â©rÃ□Â©korÃ□Â©	0	(omitted)				
Ogun	.0590166	.0025182	23.44	0.000	.0540809	.0639522
Oio	.0040532	.0011605	3.49	0.000	.0017785	.0063278
Ondo	.0347148	.0116425	2.98	0.003	.0118959	.0575337
Osun	.0520851	.0029348	17.75	0.000	.046333	.0578372
Oyo	.0559763	.0021929	25.53	0.000	.0516782	.0602744
PaÃ□Âºl	.0345183	.0032052	10.77	0.000	.0282363	.0408004
Plateau	.0468579	.0022233	21.08	0.000	.0425003	.0512155
Plateau-Central	.0301874	.0004025	75.00	0.000	.0293985	.0309764
Plateaux	.0644688	.002831	22.77	0.000	.0589201	.0700175
Porto Novo	.077229	.0031644	24.41	0.000	.0710269	.0834312
Praia	-.0068039	.0019608	-3.47	0.001	-.0106469	-.0029609
Quinara	.0060739	.001195	5.08	0.000	.0037318	.008416

Ribeira Brava	.0047771	.0025051	1.91	0.057	-.0001327	.009687
Ribeira Grande	.0461597	.0099966	4.62	0.000	.0265668	.0657526
Ribeira Grande de Santiago	.0025642	.0021452	1.20	0.232	-.0016402	.0067687
Rivers	.0051323	.002559	2.01	0.045	.0001167	.010148
Sahel	.0474845	.0003036	156.38	0.000	.0468894	.0480796
Saint-Louis	.0391217	.00087	44.97	0.000	.0374166	.0408268
Sal	-.0064758	.0018775	-3.45	0.001	-.0101556	-.002796
Santa Catarina	.0012171	.0022281	0.55	0.585	-.00315	.0055841
Santa Catarina do Fogo	.036603	.0018593	19.69	0.000	.0329588	.0402473
Santa Cruz	.0397965	.0024547	16.21	0.000	.0349855	.0446076
Savanes	.0537876	.0017172	31.32	0.000	.0504219	.0571533
Sikasso	.0129925	.0003486	37.27	0.000	.0123092	.0136758
Sokoto	.0659366	.0022205	29.69	0.000	.0615845	.0702888
Southern	-.0624424	.0022905	-27.26	0.000	-.0669317	-.0579531
Sud-Ouest	0	(omitted)				
SÃ□Â£o Domingos	.0014679	.0021741	0.68	0.500	-.0027932	.005729
SÃ□Â£o Filipe	.2534839	.0238487	10.63	0.000	.2067413	.3002265
SÃ□Â£o Miguel	.030318	.004389	6.91	0.000	.0217158	.0389203
SÃ□Â£o Salvador do Mundo	.0073191	.0020224	3.62	0.000	.0033554	.0112829
SÃ□Â£o Vicente	-.0016812	.0018768	-0.90	0.370	-.0053597	.0019973
SÃ□Â©dhiou	-.0163432	.0011731	-13.93	0.000	-.0186425	-.0140438
SÃ□Â©gou	.0473108	.0000854	553.84	0.000	.0471434	.0474783
Tahoua	-.0267817	.0000992	-269.85	0.000	-.0269762	-.0265872
Tambacounda	-.0079056	.0008557	-9.24	0.000	-.0095827	-.0062286
Taraba	.0872707	.0025307	34.48	0.000	.0823106	.0922308
Tarrafal	.0193062	.0027262	7.08	0.000	.013963	.0246493
Tarrafal de SÃ□Â£o Nicolau	0	(omitted)				
ThiÃ□Â¨s	.0259913	.0009416	27.60	0.000	.0241457	.0278368
TillabÃ□Â©ry	-.014742	.000126	-117.02	0.000	-.0149889	-.0144951
Timbuktu	0	(omitted)				
Tombali	0	(omitted)				
Upper East	-.0261397	.0012499	-20.91	0.000	-.0285894	-.02369

Upper River	-.0310344	.0006052	-51.28	0.000	- .0322205	- .0298482
Upper West	-.0164704	.001218	-13.52	0.000	- .0188577	- .0140832
VallÃ□Â©e du Bandama	.0011668	.0013198	0.88	0.377	-.00142	.0037536
Volta	-.009383	.0018096	-5.19	0.000	- .0129299	- .0058362
Western	0	(omitted)				
Woroba	.0101499	.0044366	2.29	0.022	.0014543	.0188456
Yobe	.0892037	.0022186	40.21	0.000	.0848553	.093552
Zamfara	.0755912	.0022213	34.03	0.000	.0712375	.0799449
Zanzan	0	(omitted)				
Ziguinchor	0	(omitted)				
Zinder	0	(omitted)				
Zou	0	(omitted)				
_cons	101.7491	.5257045	193.55	0.000	100.7187	102.7794

Appendix E: Logarithmic Turning point of LCOE-Capacity Relationship for PV projects

log $(LCOE_{pv})$	Coefficient	Std. err.	z	P>z	[95% conf. interval]	
_nl_1	8.601578	.0285322	301.47	0.000	8.545656	8.6575

Note: exp(8.601578) = 5440.238 (Table

log_lcoe2020	Coefficient	Std. err.	Z	P>z	[95% conf. interval]	
_nl_1	8.601578	.0285322	301.47	0.000	8.545656	8.6575

Appendix F: Logarithmic Turning point of LCOE-Capacity Relationship for On-shore Wind Projects

log_lcoe2020	Coefficient	Std. err.	Z	P>z	[95% conf. interval]	
_nl_1	9.674738	.008682	1114.35	0.000	9.657722	9.691755

Note: exp(9.674738) = 15910.56

Appendix G: Turning Point

$$\frac{\delta log(LCOE)}{\delta log(capacity)} = \beta_1 + 2\beta_2 log(capacity) = 0$$

$$log(capacity) = -\frac{\beta_1}{2\beta_2}$$

To find actual Optimal capacity,

$$exp(-\frac{\beta_1}{2\beta_2})$$

DECLARATION OF AUTHORSHIP

I, Prince Norgbey, declared that this thesis and the work presented in it are my own and have been generated by me as the result of my original research.

I do solemnly swear that:

1. Where I have consulted the published work of others or myself, this is always clearly attributed.
2. Where I have quoted from work of others or myself, the source is always given. This thesis is entirely my work, except for such quotations.
3. I have acknowledged all major sources of assistance.
4. Where the thesis is based on work done by me jointly with others, I have made clear exactly what was done by others and what I have contributed myself.
5. None of this work has been published before submission.

Date: 12/09/2025 **Signature** 

Declaration of the Use of Artificial Intelligence in Scientific Theses

Norgbey Prince
Surname, First name

20230C7E2
Matriculation Number

I hereby certify that I have written this thesis independently and,

A. with the help of ☑
B. without the help of ☐

an artificial intelligence (AI) program, such as: ChatGPT, DALL-E2, Stable Diffusion, Looka, etc.

If option A has been ticked, the following declaration is also required:

☐ I declare that all AI programs used for this work have been carefully cited in the text and in the bibliography. The screenshots and usage information have also been presented in detail in the appendix "AI-generated content".

☑ I declare that for this document AI assistance was undertaken solely for grammatical improvements. No citations were provided for text generated by an AI, as no content was created or significantly modified.

I have reviewed all the inclusions and modifications made with the assistance of AI in this thesis and take full responsibility for the accuracy of the content.

Dakar, 12/09/2025
Place, Date

Signature