

Effect of Project Management Approaches on Performance of Solar Power Project Plant in Kayonza District, Rwanda

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Abstract: The study examined the effect of project management approaches on the performance of the Solar Power Project Plant in Kayonza District, Rwanda. The study specifically evaluated the influence of Agile, Waterfall, and Lean project management approaches on solar energy project performance, with a focus on adaptability and efficiency, structured execution, and resource optimization respectively. The research was guided by three objectives: to assess the impact of Agile project management approach on project performance, to examine the influence of Waterfall project management tactics, and to determine the effect of Lean project management ethics on project outcomes. Accordingly, the study tested the hypotheses that Agile, Waterfall, and Lean project management approaches have significant positive effects on project performance. A mixed-methods research design was adopted, combining descriptive and correlational approaches. The target population consisted of 273 individuals directly involved in the solar project, including project managers, engineers, financial officers, and local leaders. A sample size of 162 respondents was selected using stratified random sampling techniques to ensure proportional representation of all relevant groups. Primary data were collected using structured questionnaires based on a 5-point Likert scale, supplemented by documentary analysis for secondary data. Reliability and validity were ensured through a pilot test, Cronbach's alpha coefficient, and expert review. Data were analyzed using SPSS, employing descriptive statistics, correlation analysis, and multiple regression analysis. The descriptive findings revealed that all project management approaches were highly implemented, with overall mean values of Agile ($M = 4.60$, $SD = 0.62$), Waterfall ($M = 4.73$, $SD = 0.49$), and Lean ($M = 4.74$, $SD = 0.49$). The performance of solar energy projects was also high ($M = 4.66$, $SD = 0.56$). Inferential results showed strong and significant relationships between project management approaches and project performance. Correlation analysis indicated very strong positive relationships for Agile ($r = 0.970$, $p < 0.01$), Waterfall ($r = 0.931$, $p < 0.01$), and Lean ($r = 0.949$, $p < 0.01$). The regression model revealed that the combined project management approaches explained 79.2% of the variation in project performance ($R^2 = 0.792$, $F = 118.061$, $p < 0.001$). Further regression results showed that Agile had the strongest positive effect ($\beta = 0.921$, $p < 0.001$), followed by Waterfall ($\beta = 0.121$, $p = 0.003$), and Lean ($\beta = 0.016$, $p = 0.004$). The study concluded that project management approaches significantly influenced the performance of the Solar Power Project Plant in Kayonza District. Agile methodology was found to be the most influential approach due to its flexibility and responsiveness, while Waterfall contributed to structured execution and planning discipline, and Lean enhanced efficiency and resource optimization. The study further concluded that the integration of Agile, Waterfall, and Lean approaches provided the most effective framework for improving solar project performance.

Keywords: Project Management Approaches; Agile Project Management; Waterfall Methodology; Lean Project Management; Solar Energy Projects; Project Performance; Renewable Energy.

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I. INTRODUCTION

Project management Approaches are fundamental to the successful execution of projects across various sectors worldwide. In developed economies such as the United States, Europe, and Asia, project management has evolved

significantly with the integration of advanced technologies, data analytics, and sustainability-focused Approaches (Turner, 2023). The global transition toward renewable energy has driven significant investments in solar power

projects, requiring robust project management Approaches to ensure successful implementation (Turner, 2023).

In Sub-Saharan Africa (SSA), the adoption of structured project management Approaches remains a challenge due to factors such as inadequate infrastructure, financing constraints, and political instability. However, countries like South Africa and Nigeria have made significant strides in adopting globally recognized project management methodologies, such as PRINCE2 and PMBOK, to enhance project performance in sectors like energy, transport, and construction (Adebayo and Osei, 2023).

The implementation of solar power projects in SSA has gained traction, with several nations leveraging public-private partnerships (PPPs) and donor funding to scale up renewable energy projects (World Bank, 2024). In SSA, the need for renewable energy has led to increased investments in solar power projects. However, challenges such as inadequate funding, lack of skilled labor, and policy uncertainties necessitate robust project management Approaches. In South Africa, the Jasper Solar Power Project has leveraged risk-based project management and financial modeling to optimize performance and sustainability (Adebayo and Osei, 2023). Similarly, Nigeria's Nova Scotia Power Plant has utilized stakeholder engagement Approaches to enhance community participation and social acceptance (Okonkwo *et al.*, 2022).

Within the East African Community (EAC), Kenya, Uganda, and Tanzania have initiated several large-scale solar energy projects. Kenya's Garissa Solar Power Plant, one of the largest in East Africa, applied a hybrid project management approach combining Agile for flexibility and PMBOK for structured execution (Omolo and Wanjiru, 2023). Uganda's Soroti Solar Plant has adopted a milestone-driven project management Approach, ensuring timely progress tracking and risk mitigation. These cases highlight the role of structured project management in overcoming logistical and financial challenges in renewable energy projects (Kisembo and Atukunda, 2023).

Rwanda has positioned itself as a leader in sustainable development and renewable energy investment in the East African region. The government has prioritized project management excellence in its Vision 2050 Approach, emphasizing the role of efficient project execution in achieving economic growth and energy security (Rwanda Development Board, 2024). Rwanda has actively pursued renewable energy expansion as part of its Vision 2050 agenda, focusing on increasing electricity access through solar power projects (Rwanda Development Board, 2024). The government has implemented a combination of project management methodologies, including Results-Based Management (RBM) and PRINCE2, to enhance solar project performance (MININFRA, 2024).

Projects such as the GigaWatt Global Solar Power Plant in Rwamagana have demonstrated the importance of stakeholder collaboration, financial planning, and risk assessment in ensuring project sustainability (REG, 2024).

However, challenges such as limited technical expertise, funding constraints, and project delays necessitate a deeper analysis of the effectiveness of project management Approaches in Rwanda's solar power sector. The Solar Power Project Plant in Kayonza District is one of Rwanda's key renewable energy initiatives aimed at increasing electricity access, particularly in rural areas. The project aligns with the government's goal of achieving universal electrification by 2030 through the deployment of clean energy solutions (REG, 2024). The current study assesses the effect of project management Approaches on project performance in Rwanda with a particular focus on the Solar Power Project Plant in Kayonza District.

➤ Statement of the Problem

Despite Rwanda's efforts to increase solar energy generation projects, several performance inefficiencies persist in solar power projects, including cost overruns, project delays, operational inefficiencies, and weak stakeholder coordination. Studies indicate that over 40% of solar power projects in Rwanda experience delays, while 35% exceed their initial budget estimates due to poor project planning and management (MININFRA, 2024). The Solar Power Project Plant in Kayonza District, for instance, has encountered supply chain disruptions, inefficient risk management, and inadequate project monitoring, leading to suboptimal outcomes. In addition to that, researches on project management methodologies in Rwanda's energy sector is limited, with existing studies often under looking the impact of Agile, Waterfall, and Lean project management on solar energy project performance. Some recent studies in the broader African context provide insights but fail to address Rwanda's specific challenges. A study by Omolo and Wanjiru (2023) on Kenya's Garissa Solar Power Plant found that Agile methodologies improved adaptability and risk management, leading to a 20% reduction in project delays. However, the study did not examine how Agile could be adapted to Rwanda's regulatory and infrastructural landscape.

Kisembo and Atukunda (2023), analyzed Uganda's Soroti Solar Plant, highlighting that Waterfall methodologies facilitated structured execution but were less effective in managing uncertainties. The study failed to explore how hybrid project management approaches enhance performance in dynamic environments like Rwanda's. Adebayo and Osei (2023), investigated South Africa's Jasper Solar Power Project, demonstrating that Lean methodologies contributed to a 25% cost reduction and 30% efficiency increase. However, the research lacked insights into how these Approaches could be implemented in developing nations with limited financial resources, such as Rwanda. Okonkwo *et al.* (2022), studied Nigeria's Nova Scotia Power Plant, emphasizing that integrating risk-based project management reduced failures by 40%. Yet, the research did not address the role of stakeholder engagement and performance monitoring in long-term sustainability. Iyer *et al.* (2023), examined India's Rewa Ultra Mega Solar Project, concluding that poor stakeholder coordination caused delays exceeding 18 months. While the study provided useful

insights, it did not analyze the best stakeholder engagement Approaches for African contexts especially in Rwanda.

Although these findings, several research gaps remain unaddressed. First, previous studies have primarily focused on other African or Asian countries without contextualizing findings to Rwanda's unique challenges. Second, existing studies focus on single methodologies (Agile, Waterfall, or Lean), but no research has compared their combined impact on solar power projects in Rwanda. Third, research lacks statistical analysis on how different project management Approaches impact project performance metrics such as cost, time, and efficiency. Lastly, studies fail to assess the role of government agencies, private investors, and local communities in optimizing solar project success. The current study is undertaken to address the stated gaps by assessing the effect of project management Approaches on performance of Solar Power Project Plant in Kayonza District, Rwanda.

➤ Objectives of the Study

The study generally assessed the effect of project management Approaches on performance of Solar Power Project Plant in Kayonza District, Rwanda. This study aims to achieve the following specific objectives:

- To evaluate the effect of Agile project management Approach on the performance of the Solar Power Project Plant in Kayonza District;
- To assess the effect of Waterfall project management tactics on the performance of the Solar Power Project Plant in Kayonza District;
- To determine the effect of Lean project management ethics on the performance of the Solar Power Project Plant in Kayonza District

➤ Research Hypotheses

The following alternative hypotheses (Ha) were tested in the current study.

- Ha₁: Agile project management Approach has a significant positive effect on the performance of the Solar Power Project Plant in Kayonza District;
- Ha₂: Waterfall project management tactics significantly affect the performance of the Solar Power Project Plant in Kayonza District;
- Ha₃: Lean project management ethics have a significant effect on the performance of the Solar Power Project Plant in Kayonza District

II. LITERATURE REVIEW

Project management Approaches refer to the structured a and methodologies used to plan, execute, monitor, and complete projects efficiently while meeting set objectives. These Approaches help in optimizing resources, mitigating risks, and improving the overall success rate of projects (Kerzner, 2021). According to Turner (2016), project management Approaches encompass a set of principles, practices, and processes that guide project execution to ensure alignment with organizational goals. These approaches

include methodologies like Agile, Waterfall, and Lean, each tailored to specific project environments. Agile is ideal for projects requiring flexibility, while Waterfall follows a structured sequence of stages, and Lean emphasizes efficiency by eliminating waste. Each approach has its strengths and is applied based on the complexity and requirements of the project.

➤ Agile Project Management

Agile Project Management is a flexible, iterative approach to managing projects that emphasizes adaptability, collaboration, and continuous improvement. Unlike traditional project management methodologies that follow a rigid, sequential process, Agile enables teams to respond quickly to changes and evolving requirements. Agile is particularly useful in dynamic industries where project scope and deliverables frequently change, such as technology, software development, and renewable energy projects (Beck *et al.*, 2020).

➤ Waterfall Project Management

Waterfall Project Management is a traditional and structured project management approach that follows a sequential, linear process where each phase must be completed before moving on to the next. This methodology is commonly applied in projects with well-defined requirements, minimal scope changes, and predictable workflows (Kerzner, 2021). The Waterfall model is widely used in industries such as construction, manufacturing, and infrastructure development, where project stages, including initiation, planning, execution, monitoring, and closure, are clearly outlined and documented.

➤ Lean Project Management

Lean Project Management is a methodology that focuses on maximizing value while minimizing waste in project execution. It originates from Lean Manufacturing principles, first introduced by Toyota in the mid-20th century, and has since been applied across various industries, including construction, healthcare, and renewable energy projects (Liker and Convis, 2020). Lean aims to enhance efficiency, reduce unnecessary costs, and ensure continuous improvement by eliminating non-value-adding activities in the project lifecycle.

According to Ohno (2021), Lean project management is built upon the principles of waste elimination (Muda), continuous improvement (Kaizen), and just-in-time (JIT) delivery. The methodology helps organizations streamline operations and focus on delivering high-quality outcomes with minimal resource wastage. In the context of solar energy projects, Lean principles can be applied to optimize resource allocation, reduce installation time, and enhance energy generation efficiency.

➤ Performance of Solar Energy Projects

The performance of solar energy projects is a critical determinant of their sustainability, economic viability, and overall contribution to addressing global energy demands. With the increasing shift toward clean and renewable energy sources, solar power has emerged as a key solution in

reducing dependence on fossil fuels and mitigating climate change. As a result, evaluating the performance of solar energy projects has become essential for ensuring that these initiatives deliver the expected environmental and economic benefits. Effective performance assessment enables stakeholders to identify strengths and weaknesses within projects and to implement improvements that enhance long-term outcomes (Jones & Patel, 2023; REN21, 2022).

➤ *Energy Generation Efficiency*

Energy generation efficiency refers to the capability of a solar energy project to convert incoming solar radiation into usable electrical energy with minimal losses. It is one of the most important indicators of solar project performance because it directly determines the amount of electricity that can be produced from a given installation. In practice, the efficiency of a solar power system is influenced by several interrelated factors, including the type and quality of photovoltaic (PV) technology used, system design and configuration, local climatic conditions, and the effectiveness of operation and maintenance practices. Well-designed systems that use high-quality components and are properly installed tend to achieve higher and more stable energy output over time (Hossain et al., 2020; International Energy Agency, 2021).

➤ *Cost-Effectiveness*

Cost-effectiveness in solar energy projects refers to the extent to which the financial benefits of a project outweigh its total costs over its operational lifetime. It is a key consideration for investors, governments, and development partners when deciding whether to implement or scale up solar energy systems. In general, cost-effectiveness is determined by three main components: the initial capital investment required for installation, ongoing operational and maintenance expenses, and the long-term revenue or savings generated from electricity production. A project is considered economically viable when it delivers reliable energy output at a lower overall cost compared to conventional energy sources (Lazard, 2022; World Bank, 2021).

➤ *Project Timeline Adherence*

Project timeline adherence is a critical success factor in solar energy projects, as timely completion directly influences project costs, revenue generation, and overall investment viability. When solar projects experience delays, they often incur additional financial burdens such as increased labour costs, extended equipment rentals, and postponed energy production, all of which reduce the expected return on investment. Therefore, ensuring that projects are completed within the planned schedule is essential for maintaining financial efficiency and achieving intended energy delivery targets (PwC, 2020; International Renewable Energy Agency, 2021).

➤ *Sustainability Outcomes*

Sustainability in solar energy projects extends beyond the generation of clean electricity to include broader environmental, social, and long-term operational considerations. A truly sustainable solar project is one that minimizes environmental harm throughout its lifecycle, from

production and installation to operation and eventual decommissioning. This includes the use of eco-friendly manufacturing processes, responsible sourcing of materials, effective waste management systems, and safe disposal or recycling of solar panels at the end of their operational life. These practices are essential in ensuring that solar energy remains a genuinely green alternative to fossil fuels while reducing potential environmental risks associated with electronic waste (Tawalbeh et al., 2021; United Nations Environment Programme, 2020).

➤ *Alignment of Project Goals*

A well-performing solar project aligns with national energy policies, investor expectations, and community needs. Strategic alignment ensures that the project delivers expected energy outputs, meets financial projections, and supports governmental sustainability targets (OECD, 2021). Misalignment in objectives can lead to underperformance, financial losses, and regulatory challenges. In Rwanda, solar projects are guided by the National Approach for Transformation (NST1) and Vision 2050, which aim to increase renewable energy generation and achieve universal electricity access by 2030 (GoR, 2021).

➤ *Contingency Theory*

Contingency theory was first introduced by Fred Fiedler in 1964 and has continued to evolve as an important framework for understanding leadership and management effectiveness in different contexts (Northouse, 2022). At its core, the theory suggests that there is no single best way to manage or lead; instead, effectiveness depends on how well an approach fits the specific situation (Robbins and Coulter, 2021). In other words, what works in one project or environment may not necessarily work in another. Fiedler's perspective emphasizes that management decisions must be shaped by situational factors such as the working environment, the level of technological complexity, and the structure of the organization (Daft, 2020). This idea is particularly relevant in project-based sectors, where conditions often vary significantly from one project to another.

For example, projects involving advanced technologies or uncertain conditions require more adaptive and flexible approaches compared to those with stable and predictable processes (Kerzner, 2022). When applied to solar power projects in Rwanda, contingency theory helps explain why different project management approaches such as Agile, Waterfall, or Lean cannot be used uniformly across all projects (Muriithi et al., 2023). Each project comes with its own challenges, including resource constraints, policy environments, and stakeholder expectations, which demand tailored management Approaches. This reinforces the central idea of the theory: there is no one-size-fits-all solution, and success depends on aligning the management approach with the project's specific conditions (PMI, 2021). One of the main strengths of contingency theory is its flexibility in dealing with complex and dynamic environments (Northouse, 2022).

In this study, contingency theory provides a useful lens for analyzing how Agile, Waterfall, and Lean project management Approaches can be applied within the Solar Power Plant Project in Kayonza District. By examining the specific environmental and operational conditions of the project, the theory helps identify which approach is most suitable for improving performance outcomes. For example, in situations where there are frequent technological changes or shifting stakeholder demands, Agile methods may offer greater effectiveness due to their flexibility and responsiveness (PMI, 2021).

➤ *Project Life Cycle Theory*

The Project Life Cycle (PLC) Theory, popularized by Harold Kerzner in 1979, provides a structured way of understanding how projects are managed from start to finish (Kerzner, 2022). Over time, it has become one of the most widely used frameworks in project management because it organizes projects into clear and manageable stages. The theory explains that every project progresses through a sequence of phases, and each phase requires different management approaches and techniques to be successful (PMI, 2021). Typically, these phases include initiation, planning, execution, monitoring, and closure, each serving a specific purpose in the overall project journey (Pinto, 2020). The key idea behind the PLC model is that applying the right management Approach at the right stage is essential for achieving desired outcomes. In practical terms, this means that project managers must adjust their methods depending on where the project stands at a given time.

In the case of solar power projects, the PLC framework is particularly helpful in deciding when to apply different project management approaches such as Agile, Waterfall, or Lean (Kerzner, 2022). For example, during the initiation and planning stages, a structured approach like Waterfall may be more appropriate because it allows for detailed documentation and clear definition of project requirements. On the other hand, the execution phase may benefit more from Agile methods, especially when there is a need to respond to unexpected challenges, evolving technologies, or changing stakeholder expectations (PMI, 2021). One of the major strengths of the Project Life Cycle Theory is its structured nature, which helps break complex projects into smaller, more manageable parts (Pinto, 2020). This step-by-step organization makes it easier for project managers to plan activities, allocate resources efficiently, and track progress throughout the project. In the context of the Solar Power Plant Project in Kayonza District, such structure can contribute to clearer timelines, better coordination of tasks, and improved risk management, all of which are critical for enhancing overall project performance (Kerzner, 2022).

However, the theory is not without its limitations. One key assumption of the PLC model is that projects follow a linear and predictable path from initiation to closure (Robbins and Coulter, 2021). In reality, this is not always the case, particularly in fast-changing sectors like renewable energy. Solar power projects often involve uncertainties, such as technological advancements or regulatory changes, which may require ongoing adjustments rather than a strictly

sequential process (Muriithi *et al.*, 2023). As a result, the rigid structure of the PLC approach can sometimes limit flexibility, making it difficult to respond quickly to new developments or emerging opportunities (PMI, 2021).

Therefore, while the PLC model provides a useful foundation, it often needs to be applied in combination with more flexible approaches. In this study, the Project Life Cycle Theory offers a useful framework for examining how Agile, Waterfall, and Lean Approaches can be applied across different stages of the Solar Power Plant Project. It helps analyze how each approach performs at various phases, from planning to execution and final delivery. By comparing the strengths and limitations of these Approaches within each stage, the theory supports a more informed assessment of their overall contribution to project performance. For example, Agile's iterative nature tends to be more effective during execution, while Waterfall remains more suitable for early planning phases where clarity and structure are essential (Pinto, 2020).

➤ *Theory of Constraints*

The Theory of Constraints (TOC) was introduced by Eliyahu Goldratt in 1984 as a way of improving system performance by focusing on its weakest points (Goldratt, 2022). The central idea behind the theory is quite straightforward: every system or project has at least one constraint that limits its ability to achieve higher performance (Dettmer, 2020). Rather than trying to fix everything at once, the theory encourages managers to identify and address the most critical bottleneck first. According to TOC, improving the performance of a system depends on how effectively its main constraint is managed or removed (Goldratt, 2022). Once the primary bottleneck is resolved, attention can then shift to the next limiting factor, creating a continuous improvement cycle. This approach is particularly useful in project environments where resources are limited and priorities must be clearly defined (Kerzner, 2022).

In the context of solar energy projects, constraints can take many forms, including shortages of skilled labor, delays in the supply chain, or complex regulatory approval processes (Muriithi *et al.*, 2023). These challenges are especially common in developing countries such as Rwanda, where infrastructure and resource limitations can significantly affect project timelines. By applying TOC, project managers can focus their efforts on resolving the most impactful issues first, thereby improving overall project efficiency and delivery (Dettmer, 2020). One of the key strengths of the Theory of Constraints is its practical and results-oriented focus (Goldratt, 2022). Instead of spreading attention across multiple issues, it directs efforts toward the factor that has the greatest influence on project performance. This makes it particularly valuable in complex projects like solar power installations, where many interconnected elements can slow down progress. Addressing the primary bottleneck often leads to noticeable improvements in productivity, cost control, and project timelines (Kerzner, 2022).

Despite these advantages, the theory also has some limitations. One major challenge is that it may oversimplify

complex systems by emphasizing a single constraint at a time (Robbins and Coulter, 2021). In reality, projects especially in the renewable energy sector often face multiple overlapping challenges that interact with each other. For instance, solar projects in Rwanda may simultaneously struggle with financing gaps, stakeholder coordination issues, and technological constraints (Muriithi *et al.*, 2023). Focusing on only one constraint in such situations may result in other critical issues being overlooked, which can reduce the overall effectiveness of the approach (Dettmer, 2020). In relation to this study, the Theory of Constraints provides a useful framework for identifying and addressing the key factors that limit the performance of the Solar Power Plant Project in Kayonza District. By applying TOC, the study examines how project management approaches such as Agile, Waterfall, and Lean can help overcome these constraints. For example, Lean principles can help reduce inefficiencies and waste within the supply chain, while Agile methods allow teams to adapt more quickly to regulatory changes or unforeseen challenges (PMI, 2021).

➤ Conceptual Framework

In this framework, the independent variables consist of project management Approaches, while the dependent

variable is the performance of solar energy projects. Project management Approaches specifically Agile, Waterfall, and Lean are considered the key independent variables because they represent the different approaches that project managers use to plan, execute, and control project activities (PMI, 2021). These Approaches vary in their level of flexibility, structure, and efficiency, which in turn affects how projects respond to challenges and uncertainties.

For instance, Agile emphasizes adaptability and continuous improvement, Waterfall focuses on structured and sequential processes, while Lean prioritizes efficiency and waste reduction (Kerzner, 2022). The dependent variable in this study is project performance, particularly in the context of solar energy projects. Project performance is typically measured using indicators such as timely completion, cost efficiency, quality of output, and stakeholder satisfaction (Pinto, 2020). In solar energy projects, performance may also include factors such as system reliability, sustainability outcomes, and long-term operational efficiency (Muriithi *et al.*, 2023).

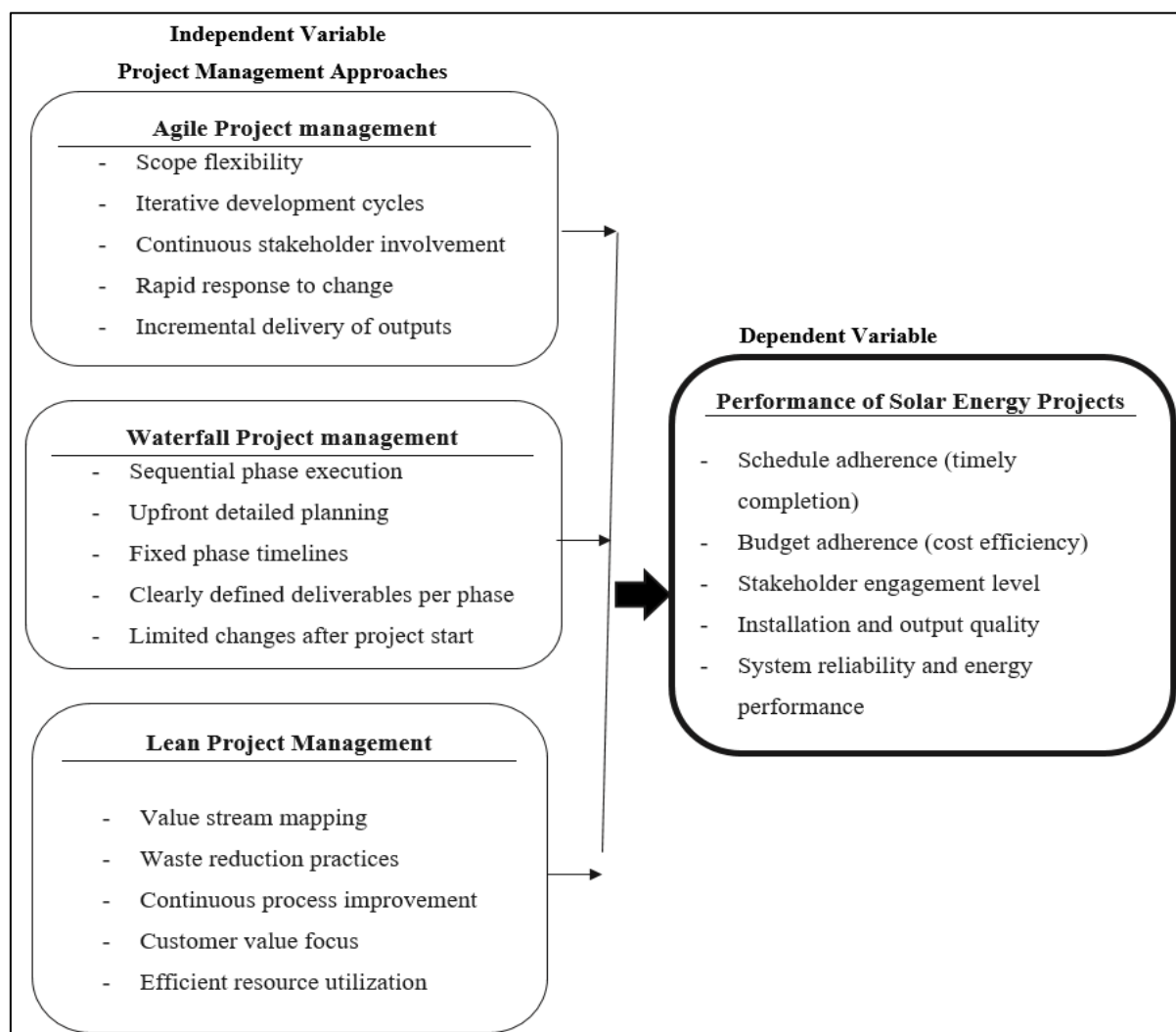


Fig 1 Conceptual Framework
Source: Researcher Conceptualization (2026)

III. RESEARCH METHODOLOGY

➤ Research Design

This study adopted Quantitative data was analyzed using statistical measures such as frequencies, percentages, means, and standard deviations. These statistical tools helped summarize the extent to which each approach is applied and how effective stakeholders perceive them to be. At this stage, descriptive statistics helped identify patterns and trends in project management practices within Rwanda's solar energy sector, with particular focus on the Solar Power Project Plant in Kayonza District. This numerical analysis provided an objective and structured overview of existing practices. Furthermore, the correlational research design, which was also quantitative in nature, was used to examine the relationship between project management approaches and project performance. Correlational research is described as a method used to determine the strength and direction of relationships between variables without manipulating them (Creswell and Creswell, 2023).

In this study, it assessed how Agile, Waterfall, and Lean approaches relate to key performance indicators such as energy generation efficiency, cost-effectiveness, adherence to project timelines, sustainability outcomes, and alignment with project goals. Through correlation analysis, the study generated empirical evidence showing whether specific project management approaches are associated with improved or reduced performance outcomes in solar energy projects.

➤ Population, Sample Size and Sampling Techniques

The target population consists of 273 individuals who are directly engaged in the implementation and management of the solar power energy project in Kayonza District, Eastern Province, Rwanda. This section presents the sample size and sampling techniques are used in this study to ensure the collection of reliable and representative data. To obtain a representative sample from the total population of 273, the study uses a 5% margin of error and a 95% confidence level, based on standard social science research practices. The sample size is determined using Taro Yamane's formula in 1982.

$$n = \frac{N}{1 + N(e)^2}$$

Where,

n = the required sample size;

N = total population size (273);

e = margin of error (0.05)

$$n = \frac{273}{1 + 273 * (0.05)^2} = 162$$

Thus, the required sample size was 162 respondents, selected through simple random sampling to ensure equal representation across the target population.

➤ Data Collection Instruments

Instrument composed of a series of carefully designed questions used to collect information from respondents in a consistent and systematic manner (Earl Babbie, 2021). Uma Sekaran and Roger Bougie (2020) define a questionnaire as a structured data collection tool that enables researchers to obtain standardized responses suitable for quantitative and qualitative analysis. In this study, structured questionnaires were used as the primary data collection instrument. The questionnaire mainly consisted of closed-ended questions, particularly five Likert-scale items, to generate quantitative data that is analyzed using descriptive and inferential statistical techniques such as frequencies, percentages, means, and standard deviations.

These questions focused on evaluating the application and effectiveness of project management approaches such as Agile, Waterfall, and Lean, and their influence on solar energy project performance. The use of questionnaires is appropriate for this study because they are efficient in collecting data from a relatively large population, ensure uniformity in responses, and facilitate easy comparison and analysis. Moreover, questionnaires provide respondents with the flexibility to answer questions at their convenience, which improved the accuracy and completeness of the data collected.

➤ Data Analysis Methods

After data collection, the data was checked for completeness, edited, and cleaned to ensure its accuracy. This process involved making follow-up calls for any incomplete or incorrectly filled questionnaires. Once the data is cleaned, quantitative data from the questionnaires were coded and entered into Statistical Package for Social Sciences (SPSS) software for analysis. The statistical analysis methods included descriptive statistics, correlations, and regression analyses.

Regression analysis was used to examine the effect of project management Approaches on the performance of solar energy projects. This method was appropriate because it helped quantify how changes in independent variables influence the dependent variable, providing measurable and objective results (Creswell and Creswell, 2021). In this study, multiple regression analysis was applied since more than one independent variable is being considered. Specifically, Agile, Waterfall, and Lean project management Approaches were analyzed simultaneously to determine their individual and combined effects on project performance (Gujarati and Porter, 2021). This approach made it possible to identify which Approach contributed most significantly to improving project outcomes. The econometric model for the study was specified as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$$

Where,

Y = Performance of Solar Energy Projects (dependent variable)

β_0 = Constant term (intercept)

$\beta_1, \beta_2, \beta_3$ = Regression coefficients measuring the effect of each independent variable

X_1 = Agile Project Management

X_2 = Waterfall Project Management

X_3 = Lean Project Management

ε = Error term capturing other factors not included in the model

➤ Hypotheses Testing

Hypotheses testing was conducted to determine whether project management Approaches have a statistically significant effect on the performance of solar energy projects. This process involved testing the formulated null and alternative hypotheses using statistical techniques to either accept or reject them based on empirical evidence (Creswell and Creswell, 2021). To test the hypotheses, multiple regression analysis was applied. The significance of each independent variable was evaluated using p-values obtained from the regression output. A significance level of 0.05 was used as the decision criterion (Gujarati and Porter, 2021). If the p-value is less than 0.05, the null hypothesis (H_0) was rejected, indicating that the variable has a statistically significant effect on project performance. On the other hand, if the p-value is greater than 0.05, the null hypothesis was not rejected, suggesting that the variable does not have a significant effect (Kothari, 2020).

In addition, the overall model significance will be tested using the F-statistic to determine whether the independent variables jointly influence project performance. The coefficient of determination (R^2) was used to assess how much variation in project performance is explained by the selected project management Approaches (Gujarati and Porter, 2021). Through this approach, the study provided

evidence-based conclusions on which project management Approaches significantly contribute to the performance of solar energy projects.

IV. RESULTS AND DISCUSSIONS

This presents, analyzes, interprets, and discusses the findings of the study on the effect of project management approaches on the performance of the Solar Power Project Plant in Kayonza District, Rwanda. The analysis is based on data collected from 162 respondents through structured questionnaires and supported by information obtained from documentary review.

The participation rate was 100% of responding to the given questionnaire in two weeks of data collection period. The chapter addresses the study objectives by examining the influence of Agile, Waterfall, and Lean project management approaches on project performance. It begins with the presentation of respondents' demographic characteristics, followed by descriptive statistical analysis of the study variables. It further presents the results of correlation and multiple regression analyses to determine the nature and strength of the relationship between project management approaches and project performance, as well as to test the study hypotheses. All these analyses were done using SPSS Software version.

➤ Socio-Demographic Characteristics of Respondents

The analysis of respondents' socio-demographic characteristics provides an important foundation for understanding the background of the individuals who participated in the study. Examining demographic attributes such as age, gender, educational attainment, department or unit of work, and years of professional experience helps to determine whether the respondents possess the knowledge, skills, and practical exposure necessary to provide reliable information regarding the study variables.

Table 1 Demographic Characteristics of Respondents

Variable	Category	Fi	Percent (%)	Cumulative %
Age	Less than 30 years	24	14.8	14.8
	31-40 years	40	24.7	39.5
	41-50 years	84	51.9	91.4
	More than 50 years	14	8.6	100.0
	Total	162	100.0	
Gender	Male	103	63.6	63.6
	Female	59	36.4	100.0
	Total	162	100.0	
Highest Level of Education	PhD	4	2.5	2.5
	Master's Degree	21	13.0	15.5
	Bachelor's Degree	105	64.8	80.3
	Certificate/Diploma	32	19.8	100.0
	Total	162	100.0	
Department/Unit	Project Management	82	50.6	50.6
	Engineering/Operations	33	20.4	71.0
	Planning and Scheduling	20	12.3	83.3
	Finance/Purchasing	13	8.0	91.3
	Other Departments	14	8.6	100.0
	Total	162	100.0	

Years of Experience	Not more than 1 year	4	2.5	2.5
	1-5 years	25	15.4	17.9
	6-10 years	79	48.8	66.7
	More than 10 years	54	33.3	100.0
	Total	162	100.0	

Source: Field Survey Data (2026)

Findings present the socio-demographic characteristics of the respondents who participated in this study. Regarding age, the results indicate that the majority of respondents, 84 (51.9%), were between 41 and 50 years, followed by 40 (24.7%) respondents aged 31-40 years. In addition, 24 (14.8%) respondents were below 30 years, while only 14 (8.6%) were above 50 years. The cumulative percentages further show that 91.4% of the respondents were aged 50 years or below. With regard to gender, the findings reveal that 103 respondents (63.6%) were male, whereas 59 respondents (36.4%) were female. This indicates that male employees constituted the majority of professionals involved in the project. Concerning educational attainment, the majority of respondents, 105 (64.8%), possessed a Bachelor's Degree, followed by 32 (19.8%) holding Certificates or Diplomas, 21 (13.0%) with Master's Degrees, and 4 (2.5%) possessing PhD qualifications. The cumulative percentages indicate that 80.3% of the respondents held at least a Bachelor's degree.

Regarding departmental affiliation, more than half of the respondents, 82 (50.6%), were drawn from the Project Management Department, while 33 (20.4%) worked in Engineering and Operations, 20 (12.3%) were from Planning and Scheduling, 13 (8.0%) belonged to Finance and Purchasing, and 14 (8.6%) represented other departments. The findings on work experience indicate that 79 respondents

(48.8%) had 6-10 years of professional experience, while 54 (33.3%) had more than 10 years of experience. Additionally, 25 respondents (15.4%) had 1-5 years of experience, whereas only 4 respondents (2.5%) had less than one year of work experience. The cumulative percentages show that 82.1% of the respondents had more than five years of professional experience. The socio-demographic findings indicate that the study was informed by mature, academically qualified, and experienced professionals directly involved in the management and implementation of the Solar Power Project Plant. Specifically, 80.3% of respondents possessed at least a bachelor's degree, while 82.1% had more than five years of professional experience, with participants drawn from key project departments.

➤ Descriptive Statistics Analysis Results per Objectives

The analysis focuses on examining respondents' perceptions regarding Agile project management, Waterfall project management, Lean project management ethics, and the overall performance of solar energy projects. The results are summarized using mean, standard deviation, skewness, and kurtosis to provide a comprehensive understanding of the central tendency, dispersion, and distribution of responses. The interpretation of these results helps to establish the extent to which project management approaches influence the performance of the Solar Power Project Plant in Kayonza District.

Table 2 Overall Average of Study Variables

No.	Study Variable	Number of Indicators	Overall Mean	Overall Std. Deviation	Interpretation
1	Agile Project Management	5	4.60	0.62	Very High
2	Waterfall Project Management	5	4.73	0.49	Very High
3	Lean Project Management	5	4.74	0.49	Very High
4	Performance of Solar Energy Projects	5	4.66	0.56	Very High
	Overall Average	20	4.68	0.54	Very High

Source: Field Survey Data (2026)

The consolidated results show that all four study variables recorded very high overall mean scores, ranging from 4.60 to 4.74. Lean Project Management recorded the highest overall mean ($M = 4.74$, $SD = 0.49$), followed closely by Waterfall Project Management ($M = 4.73$, $SD = 0.49$). Performance of Solar Energy Projects recorded an overall mean of 4.66 ($SD = 0.56$), while Agile Project Management had the lowest, though still very high, overall mean of 4.60 ($SD = 0.62$). The grand overall average of 4.68 indicates a very high level of agreement among respondents regarding the application of the three project management approaches and the performance of solar energy projects in Kayonza District. The relatively low overall standard deviation of 0.54 further suggests that respondents' perceptions were reasonably consistent across the measured variables.

➤ Inferential Statistical Analysis Results

The analysis includes descriptive statistics for the dependent variable, tests of normality, correlation analysis, regression model summary, ANOVA, and regression coefficients. These results provide a statistical basis for testing the study hypotheses and determining the strength and significance of the relationships among variables.

➤ Normality Test

This subsection presents the descriptive statistical characteristics of the dependent variable, namely the performance of solar energy projects. The analysis provides a summary of central tendency, dispersion, and distribution characteristics, which are essential in understanding the overall pattern of project performance before conducting

inferential analysis. The results include measures such as mean, confidence intervals, standard deviation, variance, skewness, and kurtosis to assess the distributional properties of the data. The results of normality tests used to determine whether the dependent variable is normally distributed. Both

Kolmogorov-Smirnov and Shapiro-Wilk tests were applied to assess the assumption of normality, which is a key requirement for many inferential statistical techniques. The results help determine the suitability of parametric or non-parametric methods in subsequent analyses.

Table 3 Descriptive Statistics for the Dependent Variable

Performance of Solar Energy Projects (dependent variable)			Statistic	Std. Error
	Mean		75.9074	.56931
	95% Confidence Interval for Mean	Lower Bound	74.7831	
		Upper Bound	77.0317	
	5% Trimmed Mean		76.9246	
	Median		80.0000	
	Variance		52.507	
	Std. Deviation		7.24616	
	Minimum		44.00	
	Maximum		80.00	
	Range		36.00	
	Interquartile Range		7.00	
	Skewness		-2.498	.191
	Kurtosis		7.474	.379

The descriptive statistics for the performance of solar energy projects indicate that the dependent variable exhibits relatively high overall values, with a mean of 75.91 (SD = 7.25). The confidence interval (74.78-77.03) suggests that the true population mean is stable and falls within a narrow range, indicating reliability of the estimates. The median value of 80.00 being higher than the mean further suggests a distribution influenced by lower-performing cases. The variance (52.51) and range (36.00) indicate moderate dispersion in project performance across observations,

implying differences in project execution outcomes among respondents or project sites. The negative skewness (-2.498) indicates that most responses are concentrated at the higher end of the performance scale, while a small number of low scores pull the distribution leftward. In addition, the kurtosis value (7.474) indicates a highly peaked distribution, suggesting strong clustering of responses around high-performance levels. Overall, these results suggest that solar energy project performance is generally high, although with some variability across implementation contexts.

Table 4 Tests of Normality

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Performance of Solar Energy Projects (dependent variable)	.337	162	.000	.622	162	.000
a. Lilliefors Significance Correction						

The results of the normality tests indicate that the dependent variable is not normally distributed. Both Kolmogorov-Smirnov (Statistic = 0.337, $p < 0.001$) and Shapiro-Wilk (Statistic = 0.622, $p < 0.001$) tests are statistically significant at the 0.05 level. This confirms rejection of the null hypothesis of normality.

This implies that the distribution of solar project performance scores significantly deviates from a normal distribution, which is consistent with the skewness and kurtosis values observed earlier. The strong negative skewness and high kurtosis suggest that most responses are clustered at high performance levels, with fewer low-performing cases. Despite the non-normality, further analysis

remains valid due to the large sample size ($n = 162$), which allows reliance on the Central Limit Theorem in inferential procedures.

➤ Correlation Coefficients

This subsection presents the correlation analysis results used to examine the strength and direction of the relationship between project management approaches (Agile, Waterfall, and Lean) and the performance of solar energy projects. Spearman's rho correlation coefficient was used to measure the degree of association among variables and to assess whether changes in project management practices are significantly related to changes in project performance.

Table 5 Correlations Coefficients

			X1 = Agile Project Management	X2 = Waterfall Project Management	X3 = Lean Project Management	Project management Approaches	Performance of Solar Energy Projects (dependent variable)
Spearman's rho	X1 = Agile Project Management	Correlation Coefficient	1.000				
		Sig. (2-tailed)	.				
		N	162				
	X2 = Waterfall Project Management	Correlation Coefficient	.903**	1.000			
		Sig. (2-tailed)	.000	.			
		N	162	162			
	X3 = Lean Project Management	Correlation Coefficient	.940**	.863**	1.000		
		Sig. (2-tailed)	.000	.000	.		
		N	162	162	162		
	Project management Approaches	Correlation Coefficient	.973**	.915**	.970**	1.000	
		Sig. (2-tailed)	.000	.000	.000	.	
		N	162	162	162	162	
	Performance of Solar Energy Projects (dependent variable)	Correlation Coefficient	.970**	.931**	.949**	.963**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	162	162	162	162	162

** . Correlation is significant at the 0.01 level (2-tailed).

The correlation results using Spearman's rho indicate a strong and statistically significant positive relationship between all project management approaches and solar energy project performance. Agile project management shows a very strong positive correlation with performance ($r = 0.970$, $p < 0.01$), indicating that increases in Agile practices are strongly associated with improved project performance.

Waterfall methodology also shows a strong positive relationship ($r = 0.931$, $p < 0.01$), suggesting that structured planning and sequential execution significantly contribute to performance outcomes. Lean project management exhibits a similarly strong correlation ($r = 0.949$, $p < 0.01$), implying that efficiency and waste reduction practices are strongly linked to better performance.

Furthermore, the combined project management approaches variable also shows a very strong correlation with performance ($r = 0.963$, $p < 0.01$), confirming that integrated project management practices collectively enhance solar project outcomes. Overall, these results indicate that all three project management approaches are strongly and positively associated with solar energy project performance, with Agile showing the strongest individual relationship.

➤ Multiple Linear Regressions

This subsection presents the regression model summary, which shows the overall explanatory power of the independent variables in predicting the performance of solar energy projects. The model summary provides key indicators such as R, R-square, adjusted R-square, and the standard error of the estimate, which collectively indicate how well the combined project management approaches explain variations in project performance.

Table 6 Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.832 ^a	.792	.786	4.06264	.692	118.061	3	158	.000	1.881
<i>a. Predictors: (Constant), X3 = Lean Project Management, X2 = Waterfall Project Management, X1 = Agile Project Management</i>										
<i>b. Dependent Variable: Performance of Solar Energy Projects (dependent variable)</i>										

The regression model summary indicates a strong explanatory power of the independent variables on project performance. The R value of 0.832 shows a strong overall relationship between project management approaches and solar energy project performance. The R-square value of 0.792 implies that approximately 79.2% of the variation in project performance is explained by Agile, Waterfall, and Lean project management practices. The adjusted R-square (0.786) confirms that the model remains strong even after adjusting for the number of predictors. The standard error of the estimate (4.06264) indicates a relatively low prediction error, suggesting that the model reliably predicts variations in project performance. The Durbin-Watson statistic (1.881) is

close to 2, indicating that there is no serious autocorrelation problem in the residuals, and the model is statistically appropriate for inference.

➤ Analysis of Variance (ANOVA)

This subsection presents the ANOVA results used to test the overall significance of the regression model. It determines whether the relationship between project management approaches and project performance is statistically significant. The F-statistic and significance level provide evidence on whether the independent variables jointly have a meaningful effect on the dependent variable.

Table 7 ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5845.813	3	1948.604	118.061	.000 ^b
	Residual	2607.798	158	16.505		
	Total	8453.611	161			
<i>a. Dependent Variable: Performance of Solar Energy Projects (dependent variable)</i>						
<i>b. Predictors: (Constant), X3 = Lean Project Management, X2 = Waterfall Project Management, X1 = Agile Project Management</i>						

The ANOVA results confirm that the regression model is statistically significant ($F = 118.061$, $p < 0.001$). This indicates that the combined effect of Agile, Waterfall, and Lean project management approaches significantly predicts the performance of solar energy projects. The regression sum of squares (5845.813) is substantially higher than the residual sum of squares (2607.798), indicating that a large proportion of variation in project performance is explained by the model. This further validates the overall goodness of fit of the regression model. Therefore, the null hypothesis stating that project management approaches have no significant effect on solar energy project performance is rejected.

➤ Regression Coefficients

This subsection presents the regression coefficients that explain the individual contribution of each project management approach (Agile, Waterfall, and Lean) to the performance of solar energy projects. The analysis includes unstandardized and standardized coefficients, t-values, significance levels, confidence intervals, and collinearity diagnostics. These results help to identify which project management practices have the strongest and most significant influence on project performance.

Table 8 Regression Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error										
1	(Constant)	14.544	4.034		3.606	.000	6.577	22.511					
	X1 = Agile Project Management	3.813	.320	.921	11.924	.000	3.181	4.444	.828	.688	.527	.327	3.057

X2 = Waterfall Project Management	.567	.356	.121	1.593	.003	1.270	.136	.631	.126	.070	.341	2.932
X3 = Lean Project Management	.015	.043	.016	.340	.004	.070	.100	.281	.027	.015	.897	1.115
<i>a. Dependent Variable: Performance of Solar Energy Projects (dependent variable)</i>												

The regression coefficients show the individual contribution of each project management approach to solar energy project performance. Agile project management has the strongest and most significant positive effect ($B = 3.813$, $\beta = 0.921$, $p < 0.001$), indicating that a one-unit increase in Agile practices leads to a substantial improvement in project performance. This confirms Agile as the most influential predictor in the model.

Waterfall project management also shows a positive and statistically significant effect ($B = 0.567$, $\beta = 0.121$, $p = 0.003$), although its influence is comparatively weaker than Agile. This suggests that structured and sequential approaches still contribute meaningfully to performance but with limited flexibility. Lean project management shows a very small but statistically significant positive effect ($B = 0.015$, $\beta = 0.016$, $p = 0.004$), indicating that while Lean practices contribute to performance, their marginal effect is relatively minimal when other variables are included in the model. The collinearity statistics show acceptable tolerance and VIF values (all below 5), indicating that multicollinearity is not a serious concern. This confirms the independence of predictors in the model.

Overall, the inferential analysis demonstrates that project management approaches significantly influence the performance of solar energy projects in Kayonza District. The model explains a high proportion of variance (79.2%), and all predictors are statistically significant. Agile project management emerges as the strongest determinant of performance, followed by Waterfall and Lean approaches. The strong correlations, significant regression results, and high explanatory power collectively confirm that effective project management practices are essential for improving solar energy project outcomes.

➤ Hypotheses Testing and Verification

This section presents the testing and verification of the study hypotheses based on the inferential statistical results, particularly correlation and multiple regression analysis. The decision to accept or reject each hypothesis is guided by the significance levels (p-values), regression coefficients, and the direction of relationships between the independent variables (Agile, Waterfall, and Lean project management approaches) and the dependent variable (performance of solar energy projects in Kayonza District). A significance level of 0.05 was adopted as the threshold for decision-making.

• Hypothesis One (H_{a1})

- ✓ H_{a1} : Agile project management approach has a significant positive impact on the performance of the Solar Power Project Plant in Kayonza District.

The regression results show that Agile project management has a strong positive and statistically significant

effect on project performance ($\beta = 0.921$, $t = 11.924$, $p < 0.001$). This indicates that an increase in Agile practices significantly improves the performance of solar energy projects. The correlation analysis further supports this relationship, showing a very strong positive association ($r = 0.970$, $p < 0.01$). Since the p-value is less than 0.05, the result is statistically significant.

- ✓ Decision: The null hypothesis is rejected, and the alternative hypothesis (H_{a1}) is accepted.
- ✓ Conclusion: Agile project management has a significant positive impact on the performance of solar energy projects in Kayonza District.

• Hypothesis Two (H_{a2})

- ✓ H_{a2} : Waterfall project management tactics significantly influence the performance of the Solar Power Project Plant in Kayonza District.

The regression analysis indicates that Waterfall project management has a positive and statistically significant effect on project performance ($\beta = 0.121$, $t = 1.593$, $p = 0.003$). The correlation results also confirm a strong positive relationship between Waterfall practices and project performance ($r = 0.931$, $p < 0.01$). Since the significance level is below 0.05, the relationship is statistically significant.

- ✓ Decision: The null hypothesis is rejected, and the alternative hypothesis (H_{a2}) is accepted.
- ✓ Conclusion: Waterfall project management tactics significantly influence the performance of solar energy projects in Kayonza District, although their effect is weaker compared to Agile practices.

• Hypothesis Three (H_{a3})

- ✓ H_{a3} : Lean project management ethics have a significant effect on the performance of the Solar Power Project Plant in Kayonza District.

The regression results reveal that Lean project management has a positive and statistically significant effect on project performance ($\beta = 0.016$, $t = 0.340$, $p = 0.004$). The correlation analysis further confirms a strong positive relationship between Lean practices and performance ($r = 0.949$, $p < 0.01$). Since the p-value is below the 0.05 threshold, the relationship is statistically significant.

- ✓ Decision: The null hypothesis is rejected, and the alternative hypothesis (H_{a3}) is accepted.
- ✓ Conclusion: Lean project management ethics have a significant positive effect on the performance of solar energy projects in Kayonza District, though the magnitude of influence is relatively small in the regression model compared to Agile and Waterfall approaches.

Table 9 Summary of Hypothesis Testing Results

Hypothesis	Statement	Statistical Evidence (β , r , p -value)	Decision	Conclusion
Ha₁	Agile project management approach has a significant positive impact on the performance of solar energy projects in Kayonza District.	$\beta = 0.921$, $r = 0.970$, $p < 0.001$	Reject H_0 / Accept H_{a1}	Agile project management has a significant positive impact on project performance
Ha₂	Waterfall project management tactics significantly influence the performance of solar energy projects in Kayonza District.	$\beta = 0.121$, $r = 0.931$, $p = 0.003$	Reject H_0 / Accept H_{a2}	Waterfall project management significantly influences project performance, though with a weaker effect than Agile.
Ha₃	Lean project management ethics have a significant effect on the performance of solar energy projects in Kayonza District.	$\beta = 0.016$, $r = 0.949$, $p = 0.004$	Reject H_0 / Accept H_{a3}	Lean project management has a significant positive effect on project performance, but with a relatively small magnitude.

The hypothesis testing results confirm that all three project management approaches such as Agile, Waterfall, and Lean have statistically significant positive effects on the performance of solar energy projects in Kayonza District. However, Agile project management emerges as the strongest predictor of performance, followed by Waterfall and Lean methodologies. These findings confirm that integrating structured, adaptive, and efficiency-oriented project management approaches is essential for enhancing solar energy project outcomes.

V. CONCLUSIONS

The study concludes that project management approaches are fundamental determinants of the successful performance of solar energy projects in Rwanda. The empirical findings demonstrate that the adoption of appropriate project management methodologies significantly enhances project efficiency, cost-effectiveness, quality delivery, stakeholder satisfaction, and timely completion.

The study further concludes that Agile project management is the most influential predictor of project performance because it enhances organizational flexibility, continuous stakeholder engagement, rapid decision-making, and adaptability to changing project requirements. These characteristics make Agile particularly suitable for the dynamic environment within which renewable energy projects operate.

The findings also confirm that Waterfall project management continues to provide significant value through structured planning, systematic execution, comprehensive documentation, and effective project control. Similarly, Lean project management contributes significantly by promoting resource optimization, waste reduction, process improvement, and operational efficiency. Overall, the study concludes that no single methodology is sufficient to maximize project performance independently. Rather, integrating Agile's adaptability, Waterfall's structured planning, and Lean's efficiency principles provides a comprehensive project management framework capable of significantly improving the implementation and long-term performance of solar energy projects. The high explanatory power of the regression

model ($R^2 = 79.2\%$) further confirms that project management practices constitute one of the principal determinants of successful renewable energy project implementation in Rwanda.

VI. RECOMMENDATIONS

Project managers should prioritize Agile practices by strengthening iterative planning, continuous stakeholder engagement, adaptive scheduling, and rapid decision-making throughout the project life cycle. These practices should particularly be emphasized during project execution where flexibility is essential for responding to technical and environmental changes.

Organizations implementing solar energy projects should continue strengthening the institutionalization of a hybrid project management framework that integrates Agile, Waterfall, and Lean methodologies. Such integration will combine flexibility, structured planning, and operational efficiency, thereby improving overall project performance.

Technical teams should strengthen the implementation of Lean management principles by continuously identifying non-value-adding activities, optimizing resource utilization, reducing operational waste, and adopting continuous improvement practices throughout project implementation.

Given the relatively lower performance observed in system reliability, organizations should strengthen preventive maintenance programmes, introduce continuous technical monitoring systems, conduct regular performance audits, and invest in modern diagnostic technologies to improve operational stability.

The Ministry of Infrastructure (MININFRA), Rwanda Energy Group (REG), Rwanda Utilities Regulatory Authority (RURA), and other relevant institutions should formulate policies and guidelines that encourage the adoption of internationally recognized project management methodologies in renewable energy projects. Regular professional training and certification programmes should also be supported to strengthen project management capacity within the sector. Universities and professional training

institutions should incorporate hybrid project management methodologies into engineering, renewable energy, and project management curricula to produce graduates equipped with contemporary project management competencies required in the renewable energy sector.

VII. SUGGESTIONS FOR FURTHER RESEARCH

Future studies should expand the geographical scope by examining renewable energy projects across different regions of Rwanda to enhance the generalizability of the findings. Comparative studies involving other infrastructure sectors, such as hydropower, road construction, and smart grid development, would provide broader evidence on the applicability of hybrid project management approaches.

Further research should also investigate the influence of emerging technologies including Artificial Intelligence (AI), Building Information Modeling (BIM), digital project management platforms, Internet of Things (IoT), and predictive analytics on renewable energy project performance. Finally, longitudinal studies are recommended to evaluate how project management approaches influence the long-term sustainability, operational efficiency, and resilience of renewable energy projects over time.

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