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Assessing the Effectiveness of Green Technologies in Project Management: A Case Study of the Lusaka-Ndola Dual Carriageway Project in Zambia

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Abstract
This study examines the effectiveness of green technologies in the management of a major infrastructure project in Zambia, using the Lusaka–Ndola Dual Carriageway as a critical case study. Against a backdrop of global and national commitments to sustainable development, the research aimed to: identify the specific green technologies employed, assess their effectiveness across cost, time, quality, and sustainability metrics, and explore the implementation challenges encountered. Employing a mixed-methods research design, the study collected data from 70 key stakeholders, including project managers, engineers, government officials, and community representatives, through structured questionnaires and semi-structured interviews. Quantitative data were analyzed using descriptive and inferential statistics, while qualitative data underwent thematic analysis. The findings reveal a pattern of selective and uneven technology adoption, with widespread use of energy-efficient machinery (52.86%) and recycled materials (42.86%), but minimal implementation of systems for water management, ecosystem integration, and real-time environmental monitoring. While these technologies demonstrated strong positive effectiveness in mitigating environmental impact (72.86% positive rating) and enhancing infrastructure quality (70% positive rating), their effects on budgetary control and schedule adherence were mixed, with significant proportions reporting cost overruns (25.72%) and delays (31.43%). Major implementation barriers were identified, including high upfront costs (81.16%), a shortage of skilled personnel (79.71%), and inadequate regulatory frameworks (72.45%). The study concludes that while green technologies offer substantial environmental and long-term benefits, their full potential in Zambia is constrained by systemic financial, technical, and institutional barriers. It therefore recommends an integrated approach encompassing stronger policy enforcement, targeted financial incentives, comprehensive capacity-building programs, proactive stakeholder engagement, and investment in local green supply chains to foster more effective and sustainable infrastructure project management in Zambia and similar developing contexts.

Keywords: Green Technologies, Project Management, Sustainable Infrastructure, Zambia, Effectiveness

1. Introduction

Globally, the integration of green technologies into project management has transitioned from a niche consideration to a strategic imperative, driven by the urgent need to address climate change, environmental degradation, and resource depletion (United Nations Environment Programme [UNEP], 2022) [26]. Infrastructure development, a significant contributor to carbon emissions and ecological disruption, is at the forefront of this transformation. International frameworks like the Paris Agreement and advocacy from bodies such as the UNEP have catalysed a shift in industry paradigms, compelling project managers to balance traditional objectives of cost, time, and quality with critical dimensions of environmental responsibility and social inclusivity (World Bank, 2021) [27]. Consequently, the adoption of innovations such as renewable energy systems, sustainable building materials, and energy-efficient machinery is redefining best practices in construction and project execution worldwide, moving beyond mere regulatory compliance towards a core component of value creation and long-term viability.

In the African context, this global shift intersects with the pressing need for rapid infrastructure development to foster economic growth and regional integration, as outlined in initiatives like the African Union’s Agenda 2063 (African Union, 2015) [2]. However, the continent faces the dual challenge of accelerating infrastructure rollout while mitigating its environmental footprint. While pioneering nations like South Africa, Kenya, and Rwanda have made strides in incorporating green standards, adoption across much of Sub-Saharan Africa, including Zambia, remains nascent and uneven (World Bank,

2021) [27]. The barriers are pronounced and include high upfront costs, deficits in technical expertise, and underdeveloped policy enforcement mechanisms. This gap highlights a critical need for localized, empirical research to assess the practical application and effectiveness of green technologies within the specific socio-economic and institutional realities of African infrastructure projects.

Within Zambia, road infrastructure is a vital engine for socio-economic development, facilitating trade, connectivity, and industrialization. Recognizing the harmful environmental legacy of conventional construction methods such as deforestation, pollution, and habitat destruction the Zambian government has increasingly prioritized sustainable practices through policies like the Seventh National Development Plan and the establishment of the Ministry of Green Economy and Environment (Ministry of Green Economy and Environment, 2022) [18]. The Lusaka–Ndola Dual Carriageway project, a large-scale Public-Private Partnership (PPP) intended to improve the crucial transport corridor to the Copperbelt Province, embodies this commitment. Its planning documents explicitly advocate for green technologies, including energy-efficient equipment and solar-powered lighting (Ministry of National Development Planning, 2017) [19]. Despite these policy commitments and project-level promises, there is a stark scarcity of empirical studies evaluating the on-ground effectiveness of these technologies in meeting project management objectives related to cost, time, quality, and sustainability within Zambia's unique context, where financial constraints, skilled labour shortages, and regulatory gaps persist (Zulu & Kaliba, 2019; Mwansa & Chanda, 2021) [30, 22]. This study therefore aims to critically investigate this implementation gap, providing an evidence-based assessment that can inform future sustainable infrastructure development in Zambia and the broader region.

1.1 General Objective

The Main objective of this study is to examine the effectiveness of green technologies in the management of the Ndola-Lusaka dual carriageway project in Zambia.

1.1.1 Specific Objectives

1. To identify the specific green technologies being used in the Lusaka-Ndola Dual Carriageway project.
2. To assess how effective these green technologies are in managing the project.
3. To explore the challenges faced in implementing green technologies in this infrastructure project.

1.2 Theoretical Framework

1.2.1 Sustainable Development Theory and Environmental Management Theory

This study is grounded in an integrated theoretical framework combining Sustainable Development Theory (Brundtland, 1987) [5] and Environmental Management Theory (Barrow, 2006) [3] to holistically analyze the role of green technologies. Sustainable Development Theory provides the normative foundation, asserting that development must meet present needs without compromising future generations' capacity, thereby justifying the pursuit of green technologies like solar lighting and recycled materials to harmonize economic progress with ecological preservation, in direct alignment with Zambia's national development plans (MNDP, 2017; UNEP, 2022) [19, 26]. Complementing this, Environmental Management Theory offers the operational lens, focusing on the institutional and procedural mechanisms such as Environmental Impact Assessments (EIAs) and management plans necessary to implement and evaluate these technologies, which is especially critical in contexts like Zambia where institutional capacity and enforcement are pivotal challenges (ZEMA, 2022) [28]. Together, these theories form a cohesive analytical structure where green technologies are the independent variables linked to sustainability outcomes (dependent variables), with their relationship moderated by contextual factors like policy and funding; this dual framework ensures the examination captures both the overarching ethical imperative for sustainable growth and the practical realities of implementation and management within the specific case of the Lusaka-Ndola project.

2. Literature Review

2.1 Identification and Application of Green Technologies in Infrastructure Projects

Globally, the integration of green technologies into infrastructure project management is increasingly recognized as a critical strategy for achieving sustainable development. The discourse, driven by international accords like the Paris Agreement, has evolved from viewing environmental considerations as a cost to understanding them as a source of long-term value and risk mitigation (World Bank, 2021) [27]. The literature identifies a core suite of technologies pivotal to sustainable construction, including renewable energy systems like solar-powered site lighting, energy-efficient and low-emission machinery, and the use of recycled or sustainably sourced materials such as Recycled Asphalt Pavement (RAP) (Zhang *et al*., 2020; UNEP, 2022) [29, 26]. Furthermore, advanced strategies like permeable pavements for stormwater management, ecosystem-integrated design, and real-time environmental monitoring via digital tools represent the frontier of green project execution, promising enhanced resource efficiency and reduced ecological footprints (Hwang & Ng, 2017) [13]. However, a dominant theme in global scholarship is the persistent challenge of balancing the high initial capital costs of these technologies against their long-term operational savings and environmental benefits, a tension that frames much of the economic debate (IEA, 2020) [14].

Within the African regional context, the adoption of green technologies presents a distinct set of opportunities and constraints shaped by developmental imperatives. Continental frameworks like Agenda 2063 explicitly champion sustainable infrastructure, positioning green innovation as essential for climate-resilient growth (African Union, 2015) [2]. Pioneering countries, including South Africa, Kenya, and Rwanda, have demonstrated successful integration through green building standards and renewable energy projects, offering valuable case studies (AfDB, 2021) [1]. However, the literature consistently highlights that widespread adoption across Sub-Saharan Africa is hampered by systemic barriers far more acute than in developed nations. These include severe financing limitations, a scarcity of technical skills and local expertise, fragmented regulatory environments with weak enforcement, and underdeveloped local supply chains for sustainable materials (World Bank, 2021; Owusu & Asiedu, 2020) [27, 23]. Consequently, the implementation of green technologies in the region is often described as selective, project-specific, and heavily reliant on international funding and expertise, rather than being driven by embedded local capacity or markets.

Focusing on Zambia, the literature reveals a clear policy intent for sustainable development, as embodied in the Seventh National Development Plan (7NDP) and the mandates of the Zambia Environmental Management Agency (ZEMA) (MNDP, 2017; ZEMA, 2022) [19, 28]. Scholarly work acknowledges the strategic importance of projects like the Lusaka-Ndola Dual Carriageway and notes the inclusion of environmental sustainability clauses in their planning documents. However, a significant research gap is evident: there is a paucity of empirical, case-study-based research that moves beyond policy rhetoric to critically examine the *de facto* application, performance, and management of specific green technologies within major Zambian infrastructure projects (Zulu & Kaliba, 2019; Mwansa & Chanda, 2021) [30, 22]. Existing studies tend to be either high-level policy analyses or focused on micro-enterprises, leaving a void in understanding the practical realities such as which technologies are genuinely prioritized on site, their operational effectiveness, and the contextual challenges faced during execution. This study directly addresses this gap by investigating the specific technologies employed in the Lusaka-Ndola project, thereby grounding the global and regional discourse in the empirical reality of Zambia's flagship infrastructure endeavour.

2.2 Evaluating the Effectiveness of Green Technologies in Project Management

Globally, the literature presents a nuanced assessment of the effectiveness of green technologies in project management, measured against the traditional iron triangle of cost, time, and quality, and the additional dimension of sustainability. Studies from developed economies indicate that while the upfront capital expenditure for technologies like solar installations, energy-efficient machinery, and advanced recycling systems can be 5-20% higher, they often yield significant long-term operational savings, enhanced asset durability, and reduced lifecycle environmental impact, thereby justifying the initial investment (IEA, 2020; UNEP, 2022) [14, 26]. Effectiveness is frequently documented in terms of improved environmental performance such as quantifiable reductions in carbon emissions, waste diversion from landfills, and better resource efficiency which directly aligns with regulatory and corporate sustainability goals (Zhang *et al*., 2020) [29]. However, the literature also cautions that effectiveness is not automatic; it is heavily contingent on proactive project management, including meticulous planning, stakeholder engagement, and integrated design processes. A recurring finding is that green technologies are most effective when they are not treated as standalone add-ons but are instead woven into the core project strategy from the inception phase, influencing decisions on procurement, scheduling, and risk management (Hwang & Ng, 2017) [13].

In the African regional context, the evaluation of effectiveness becomes more complex, as outcomes are profoundly moderated by local constraints. Case studies from countries like Kenya and South Africa show that green technologies can deliver tangible benefits, such as reduced fuel consumption from efficient equipment and positive community reception towards projects employing solar lighting or noise-reduction measures (Kamau & Mutiso, 2022; AfDB, 2021) [15, 1]. These successes highlight the potential for green practices to enhance project quality and social license to operate. Nevertheless, regional analyses consistently identify a gap between potential and realized effectiveness. This gap is attributed to systemic barriers: high costs can derail project budgets, a lack of skilled personnel leads to improper implementation and maintenance, and weak regulatory enforcement fails to create a consistent demand for high performance (World Bank, 2021; Owusu & Asiedu, 2020) [27, 23]. Consequently, effectiveness is often reported as inconsistent or sub-optimal, with projects experiencing delays due to technology learning curves or failing to capture long-term savings due to a focus on short-term, lowest-bid procurement models.

Focusing on Zambia, the literature reveals a significant empirical void regarding the measured effectiveness of green technologies in large-scale infrastructure. National policies and project Environmental and Social Impact Assessments (ESIAs) presume effectiveness by mandating or recommending certain technologies, but there is a stark lack of published, post-implementation analysis to verify these assumptions (MNDP, 2017; ZEMA, 2022) [19, 28]. Scholarly commentary suggests that the effectiveness observed in global case studies may not directly translate to the Zambian setting, where challenges like erratic funding flows, a reliance on imported technologies with scarce spare parts, and capacity limitations in monitoring and evaluation are acute (Zulu & Kaliba, 2019; Mwansa & Chanda, 2021) [30, 22]. Therefore, while the intent to leverage green technologies for better project outcomes is codified in policy, there is an urgent need for grounded research that systematically assesses their real-world impact on the Lusaka-Ndola project's budget adherence, schedule reliability, infrastructure resilience, and ultimate sustainability footprint. This study aims to provide this critical, localized evidence, moving beyond theoretical benefits to document the practical efficacy and trade-offs experienced on the ground.

2.3 Systemic Challenges in Implementing Green Technologies

Globally, the literature systematically identifies a consistent set of barriers that hinder the seamless implementation of green technologies in infrastructure projects, transcending geographical boundaries but varying in intensity. The most pervasive challenge is the high initial capital investment required for technologies like photovoltaic systems, advanced recycling plants, and low-emission machinery, which creates a significant financial hurdle despite promising long-term returns (IEA, 2020; World Bank, 2021) [14, 27]. Coupled with this are technical and knowledge-based barriers, including the complexity of integrating new systems into existing workflows, a shortage of specialized skills for operation and maintenance, and a lack of proven local case studies that increase perceived risk (Hwang & Ng, 2017) [13]. Furthermore, institutional and regulatory gaps, such as inconsistent policies, sluggish permitting processes, and underdeveloped standards for new materials, create an environment of uncertainty that stifles investment and innovation (UNEP, 2022) [26]. These barriers collectively point to an implementation ecosystem that often lacks the coherence necessary to translate technological potential into widespread, effective practice.

In the African regional context, these global challenges are amplified and compounded by distinct socio-economic and institutional realities. The financial barrier is acutely felt due to constrained public budgets, limited access to affordable green financing, and intense competition for capital with other pressing development needs like healthcare and education (AfDB, 2021) [1]. The technical skills gap is exacerbated by brain drain and educational systems that have not yet fully integrated sustainability and green engineering into their core curricula, leading to a heavy reliance on costly foreign expertise (World Bank, 2021) [27]. Weak regulatory enforcement and fragmented policy landscapes mean that even where progressive laws exist, their on-the-ground application is inconsistent, failing to provide a reliable incentive structure for contractors (Owusu & Asiedu, 2020) [23]. Additionally, logistical and infrastructural constraints, such as unreliable power grids, underdeveloped local supply chains for sustainable materials, and poor transport networks, create fundamental bottlenecks that disrupt procurement and increase costs, making the practical execution of green plans exceptionally difficult (Kamau & Mutiso, 2022) [15].

Zooming in on Zambia, the literature suggests the country embodies the regional challenges with particular acuity, despite a progressive policy facade. While frameworks like the Environmental Management Act and the 7NDP advocate for sustainable construction, studies note a pronounced implementation gap where policy intent rarely translates into enforceable on-site practice (ZEMA, 2022; MNDP, 2017) [28, 19]. The financial constraint is paramount, with both public and private sectors often opting for conventional, lower upfront-cost solutions (Mwansa & Chanda, 2021) [22]. The acute shortage of local skilled professionals in green construction techniques creates a critical dependency on external consultants, undermining knowledge transfer and long-term sustainability (Zulu & Kaliba, 2019) [30]. Moreover, logistical hurdles related to importing specialized equipment and materials, coupled with bureaucratic delays, frequently lead to project slowdowns and cost overruns. This combination of financial, human resource, and systemic institutional challenges creates a complex web that the Lusaka-Ndola project must navigate, making an empirical investigation into these specific barriers not just relevant but essential for understanding the real-world dynamics of sustainable infrastructure delivery in Zambia.

2.4 Literature Gap

While the existing literature effectively outlines the types of green technologies, their potential effectiveness, and the generic challenges to their implementation across global and regional contexts, a significant gap persists in integrated, empirical case-study research within Zambia. Prior studies tend to examine these three themes identification, effectiveness, and challenges in isolation, often relying on theoretical frameworks or aggregated data that lack granular, project-specific detail. There is a critical absence of scholarly work that simultaneously investigates which specific technologies are deployed in a major Zambian infrastructure project, empirically measures their actual impact on core project management metrics (cost, time, quality, sustainability), and diagnoses the interconnected, context-specific barriers that constrain their implementation. This study seeks to bridge this gap by providing a holistic and evidence-based analysis of the green technology ecosystem within the Lusaka-Ndola Dual Carriageway project, thereby generating actionable insights often missing from the current fragmented literature.

3. Methodology

3.1 Research Design

This study employed a mixed-methods research design within a descriptive case study framework (Creswell & Plano Clark, 2017) [8]. This approach facilitated an in-depth, contextual investigation of green technology application in the Lusaka-Ndola Dual Carriageway project, allowing for the integration of quantitative breadth and qualitative depth to comprehensively address the research objectives.

3.2 Target Population

The target population comprised key stakeholders with direct involvement in or impacted by the project, including project managers, engineers, environmental specialists, government officials, contractors, and community leaders. These participants were selected for their expert knowledge, operational role, and capacity to provide reliable insights on the study's core themes (Mugenda & Mugenda, 2003) [20].

3.3 Sampling Design

A dual sampling strategy was used. Purposive sampling selected information-rich participants for qualitative interviews (Etikan *et al*., 2016) [10]. For the quantitative survey, stratified random sampling ensured representation across key stakeholder groups and project segments, enhancing generalizability and reducing bias (Kothari, 2004) [16].

3.4 Sample Size Determination

The quantitative sample size of 70 was determined using Cochran's formula for a known population at a 90% confidence level (Cochran, 1977) [7]. For qualitative data, 15 key informants were purposively selected, a number deemed sufficient to achieve thematic saturation (Guest *et al*., 2006) [12].

3.5 Data Collection Methods

Primary data was collected via structured questionnaires (n=70) and semi-structured interviews (n=15). Secondary data from project reports, EIAs, and policy documents was reviewed. This methodological triangulation strengthened the validity of findings (Bryman, 2016) [6].

3.6 Data Analysis

Quantitative data from questionnaires were analyzed using descriptive and inferential statistics in SPSS (Field, 2013) [11]. Qualitative interview data underwent thematic analysis using NVivo software to identify, code, and interpret recurring patterns (Braun & Clarke, 2006) [4].

3.7 Triangulation

Methodological triangulation synthesizing data from surveys, interviews, and documents—was employed to cross-validate findings, minimize bias, and enhance the credibility and robustness of conclusions (Denzin, 2012) [9].

3.8 Limitations
Limitations included restricted access to sensitive financial data, geographical logistical challenges, potential respondent bias, and resource constraints on site visits. These were mitigated through triangulation, assured anonymity, and purposive sampling (Maxwell, 2013) [17].

3.9 Ethical Considerations
The study received institutional ethical clearance. Informed consent was obtained from all participants, who were assured of anonymity, confidentiality, and their right to withdraw without consequence. Data was stored securely.

4. Findings and Results
4.1 Characteristics of Respondents (Bio Data)
The demographic and professional profile of the study's respondents established a robust foundation for credible and comprehensive insights. The sample exhibited a near-balanced gender representation (54.29% male, 45.71% female) and was predominantly comprised of experienced, middle-aged professionals (70% aged 25-44). Respondents represented all critical stakeholder functions, including Technical Specialists (17.14%), Environmental Management & Compliance officers (17.14%), Project Managers (15.71%), and Site Engineers (14.29%), with a majority possessing substantial industry experience (over 77% had more than two years). Furthermore, the sample included a strategic mix of core project team members (40%), external stakeholders, and regulatory personnel, ensuring the findings encapsulated both operational and oversight perspectives from a well-informed cohort.

4.2 The specific green technologies being used in the Lusaka–Ndola Dual Carriageway project

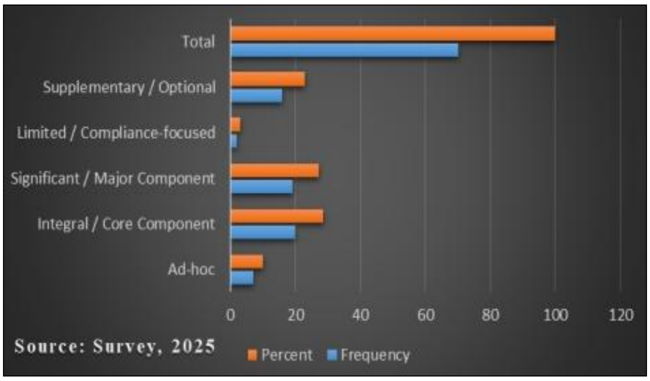

Fig 1: Integration of green technologies within the project's overall execution strategy

The analysis shows that green technologies were integrated at varying levels in the project. About 28.57 percent of respondents indicated that integration was integral or a core component, while 27.14 percent viewed it as significant or a major component. Supplementary or optional integration accounted for 22.86 percent, with smaller proportions reporting ad-hoc (10%) or limited/compliance-focused (2.86%) integration. This suggests that while green technologies were recognized in project planning, their adoption varied in depth and emphasis across different project areas.

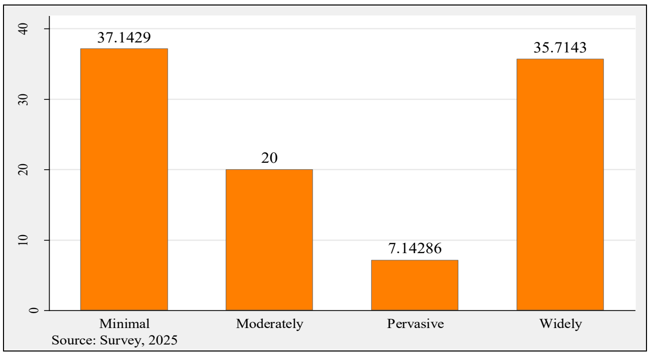

Fig 2: The degree of implementation of solar-powered systems (lighting, site offices) in the project

The data on solar-powered systems shows a varied level of implementation across the project. About 35.71% of respondents reported that solar systems were widely implemented, while 37.14% indicated minimal use. 20.00% reported moderate implementation, and 7.14% noted pervasive or standard practice use.

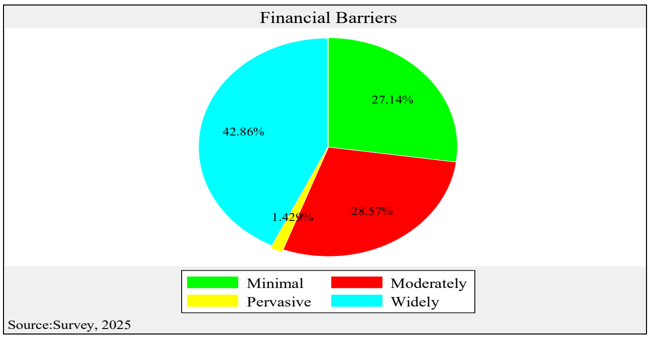

Fig 3: The degree of implementation Recycled or sustainably sourced construction materials in the project

The data on the use of recycled or sustainably sourced construction materials indicates that adoption was generally strong but varied. 42.86% of respondents reported that these materials were widely used, while 28.57% indicated moderate use and 27.14% reported minimal use. Only 1.43% described their use as pervasive or standard practice.

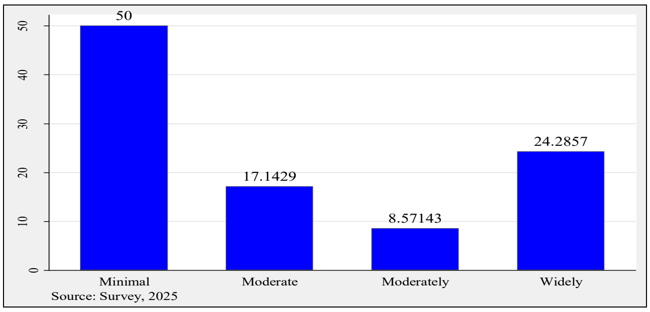

Fig 4: The degree of implementation for Permeable pavements or water management systems in the project

The study found that the implementation of permeable pavements and water management systems was mixed. 50.00% of respondents reported minimal use, while 24.29% indicated wide implementation. Moderate and moderately implemented systems accounted for 17.14% and 8.57%, respectively.

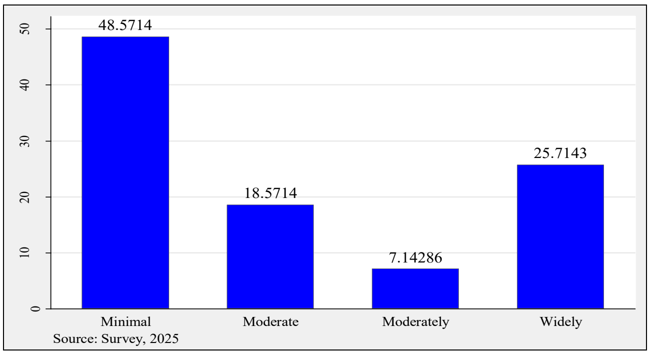

Fig 5: The degree of implementation for Ecosystem integration & carbon-offset vegetation in the project

The study found that the integration of ecosystem-based strategies and carbon-offset vegetation was uneven across the project. 48.57% of respondents reported minimal implementation, while 25.71% indicated wide adoption. Moderate and moderately implemented strategies accounted for 18.57% and 7.14%, respectively.

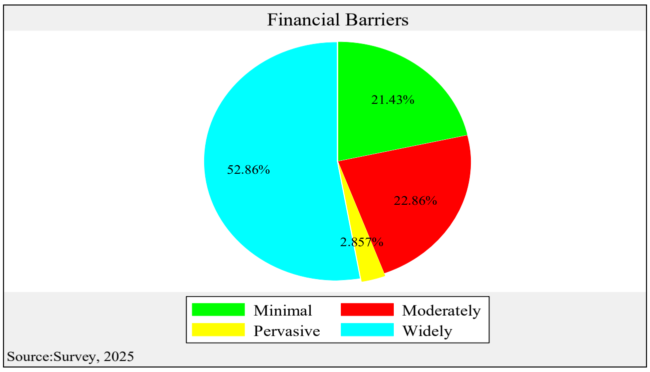

Fig 6: The degree of implementation for Energy-efficient and low-emission machinery in the project

The study found that the use of energy-efficient and low-emission machinery was relatively well adopted across the project. 52.86% of respondents reported wide implementation, while 22.86% indicated moderate use and 21.43% reported minimal use. Only 2.86% described the use as pervasive or standard practice.

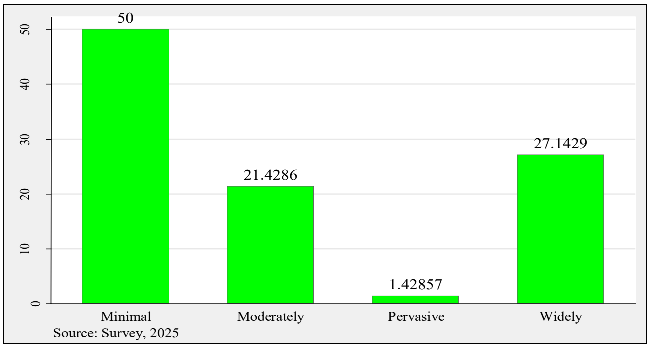

Fig 7: The degree of implementation for Real-time environmental monitoring (dust, noise) in the project

The study found that the implementation of real-time environmental monitoring (dust, noise, and other parameters) was varied. 50.00% of respondents reported minimal use, while 27.14% indicated wide implementation. Moderate and moderately implemented systems accounted for 21.43% and 1.43%, respectively.

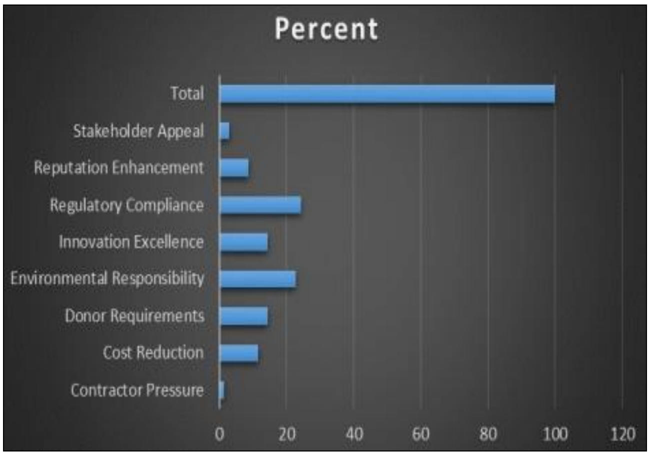

Fig 8: Primary strategic driver for adopting green technologies

The study found that regulatory compliance (24.29%) and environmental responsibility (22.86%) were the primary drivers for adopting green technologies in the project. Other notable motivations included innovation excellence (14.29%), donor requirements (14.29%), and cost reduction (11.43%). Less influential factors were reputation enhancement (8.57%), stakeholder appeal (2.86%), and contractor pressure (1.43%).

4.3 The effectiveness of these green technologies in managing the project

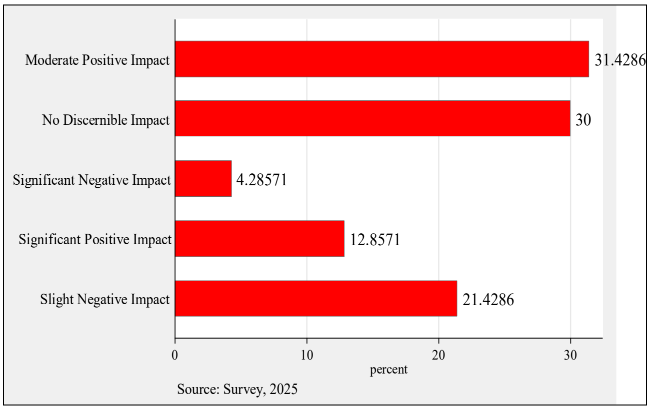

Fig 9: The extent to which the implemented green technologies contributed to adherence to project budget and cost control

The study found that the budgetary effects of green technologies were generally positive but varied across respondents, with 31.43 percent indicating a moderate positive impact and 12.86 percent reporting a significant positive impact, suggesting that these technologies can support cost control through efficiency gains and long-term savings. However, a substantial proportion (30 percent) observed no discernible impact, reflecting mixed experiences depending on project context and implementation quality.

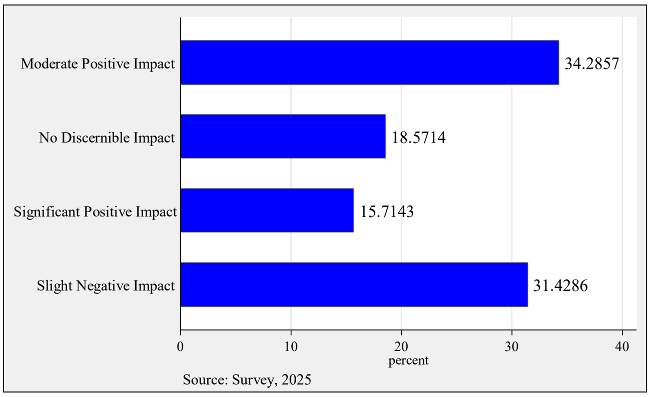

Fig 10: The extent to which the implemented green technologies contributed to adherence to project timelines and schedules

The study shows that green technologies had a mixed but generally positive influence on project timelines, with 34.29 percent of respondents reporting a moderate positive impact and 15.71 percent indicating a significant positive impact. However, 31.43 percent experienced slight delays, and 18.57 percent observed no noticeable change, suggesting that while green technologies can enhance scheduling efficiency and reduce disruptions, they may also introduce adjustment periods or operational learning curves.

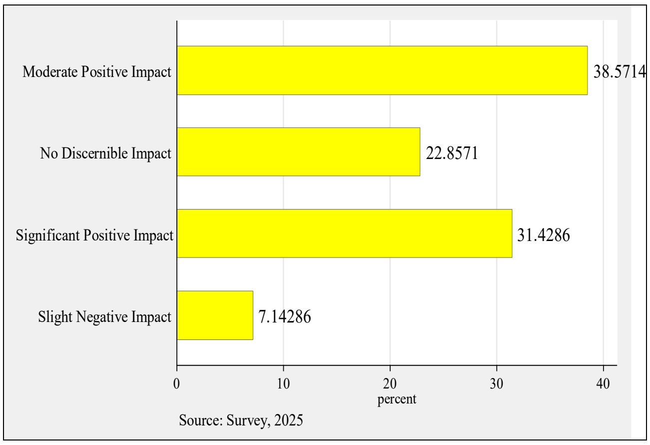

Fig 11: The extent to which the implemented green technologies contributed to quality and durability of the final infrastructure

A combined 70% of respondents reported favorable outcomes, with 38.57% indicating a moderate positive impact and 31.43% reporting a significant positive impact. By contrast, 22.86% observed no discernible change, while only 7.14% experienced slight negative effects.

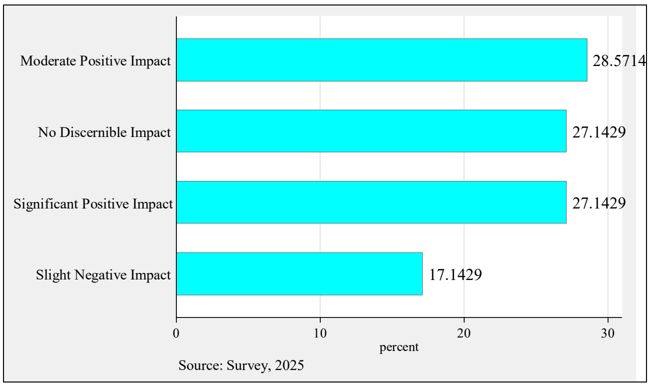

Fig 12: The extent to which the implemented green technologies contributed to on-site health, safety, and working conditions

A combined 55.71% of respondents reported positive outcomes, with 28.57% indicating a moderate positive impact and 27.14% noting a significant positive impact. Meanwhile, 27.14% observed no discernible effect, suggesting neutral experiences among a considerable portion of participants. Only 17.14% reported slight negative impacts.

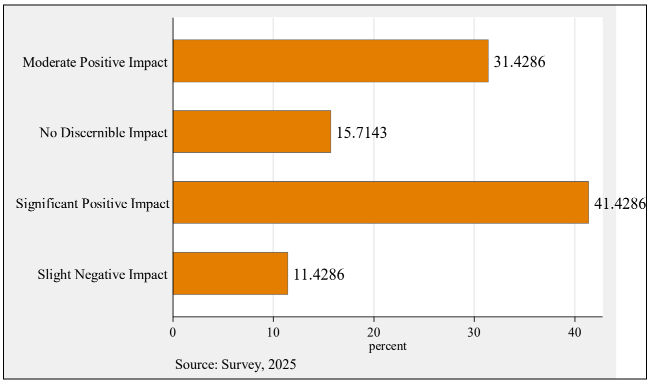

Fig 13: The extent to which the implemented green technologies contributed to mitigation of environmental impact (pollution, waste)

The study shows that green technologies had a strong positive effect on mitigating environmental impacts, with a combined 72.86% of respondents reporting beneficial outcomes. Of these, 31.43% indicated a moderate positive impact, while 41.43% reported a significant positive impact. A smaller share, 15.71%, observed no discernible impact, suggesting neutral experiences for some participants. Only 11.43% reported slight negative effects.

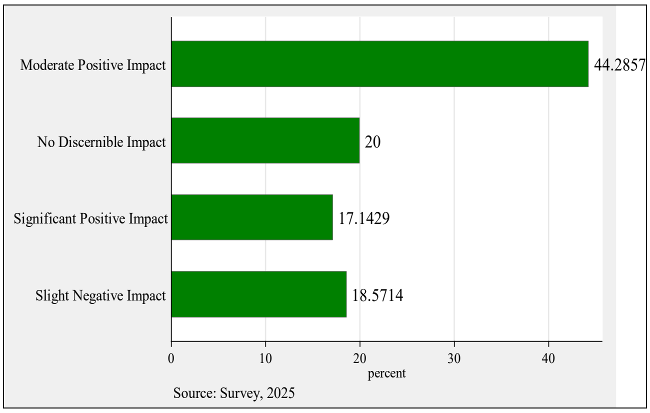

Fig 14: The extent to which the implemented green technologies contributed to community relations and public perception

The study found that the use of green technologies positively influenced community relations, with 44.29% of respondents reporting a moderate positive impact and 17.14% indicating a significant positive impact. This means a combined 61.43% experienced improved engagement, trust, or public perception due to environmentally responsible practices. Meanwhile, 20% observed no discernible impact, suggesting neutral outcomes in some areas, and 18.57% reported slight negative effects.

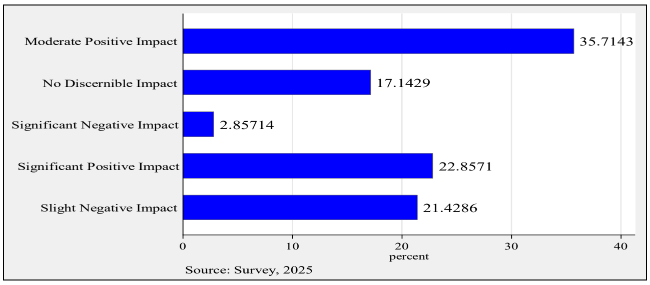

Fig 15: The extent to which the implemented green technologies contributed to team morale and innovative capability

The study shows that green technologies had a generally positive effect on team morale and innovative capability, with 35.71% of respondents reporting a moderate positive impact and 22.86% indicating a significant positive impact, resulting in a combined 58.57% positive perception. However, 17.14% observed no discernible impact, and 21.43% reported slight negative effects, while 2.86% experienced significant negative effects.

Table 1: The most pronounced BENEFIT of using green technologies on this project

Category	Count.	Percent
Environmental Performance & Protection	24	34.78%
Energy Efficiency & Cost Savings	14	20.29%
Sustainability & Resource Management	10	14.49%
Safety & Worker Well-Being	7	10.14%
Stakeholder Trust, Reputation & Acceptance	7	10.14%
Data Quality, Monitoring & Reporting	5	7.25%
Innovation & Project Efficiency	6	8.70%
Total	69	100

Source: Survey, 2025

The study finds that the most pronounced benefits of green technologies were concentrated in environmental performance and protection, which accounted for 34.78% of all responses and highlighted improvements such as reduced emissions, better air quality, and stronger environmental compliance. Energy efficiency and cost savings were the second most cited benefits (20.29%), followed by sustainability and resource management at 14.49%. Safety and worker well-being, as well as stakeholder trust and reputation, each contributed 10.14%, reflecting both internal and external gains. Additional benefits were noted in innovation and project efficiency (8.70%) and data quality and monitoring (7.25%).

4.4 The challenges encountered in implementing green technologies in this infrastructure project

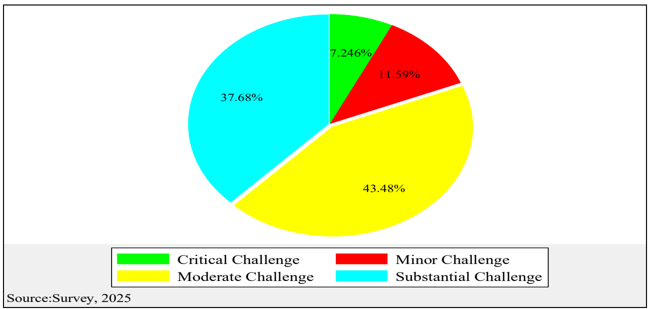

Fig 16: The degree to which higher upfront capital or procurement costs have presented a challenge to the implementation of green technologies

The study indicates that higher upfront capital or procurement costs posed a significant challenge to implementing green technologies, with 43.48% of respondents rating it as a moderate challenge and 37.68% as a substantial challenge, totaling 81.16% experiencing notable difficulty. Additionally, 11.59% considered it a minor challenge, while only 7.25% viewed it as a critical challenge.

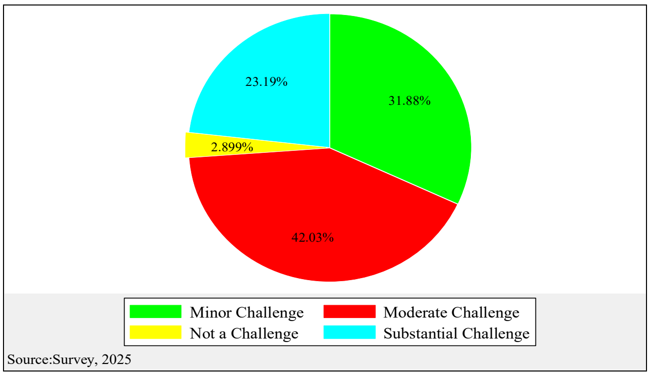

Fig 17: The degree to which technical complexity or lack of proven local case studies have presented a challenge to the implementation of green technologies

The study reveals that technical complexity was a notable challenge for implementing green technologies, with 42.03% of respondents rating it as a moderate challenge and 23.19% as a substantial challenge, together accounting for 65.22% of participants experiencing significant difficulties. Additionally, 31.88% perceived it as a minor challenge, while only 2.90% reported no challenge.

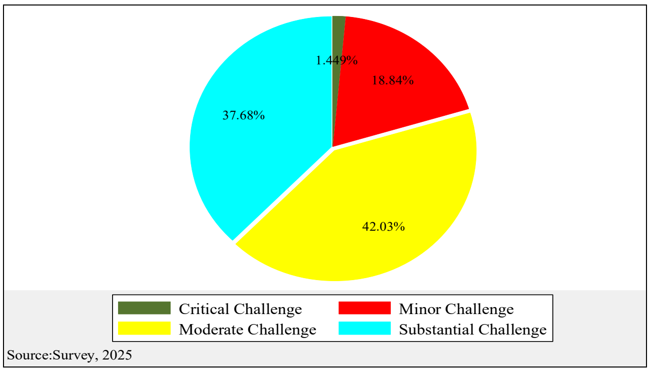

Fig 18: The degree to which shortage of skilled personnel or specialized training have presented a challenge to the implementation of green technologies

The study shows that a shortage of skilled personnel and specialized training was a major challenge for implementing green technologies. Specifically, 42.03% of respondents rated it as a moderate challenge and 37.68% as a substantial challenge, totaling 79.71% experiencing significant impact. An additional 18.84% considered it a minor challenge, while only 1.45% saw it as a critical challenge.

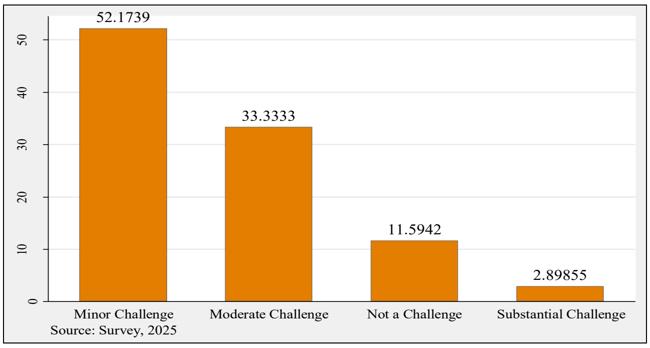

Fig 19: The degree to which Insufficient support from project leadership have presented a challenge to the implementation of green technologies

The study indicates that insufficient support from project leadership posed a moderate challenge to green technology implementation. 52.17% of respondents identified it as a minor challenge, while 33.33% rated it as moderate, totaling 85.50% experiencing some level of difficulty. Only 2.90% viewed it as a substantial challenge, and 11.59% considered it not a challenge, suggesting that while leadership support was generally adequate, gaps still hindered optimal adoption.

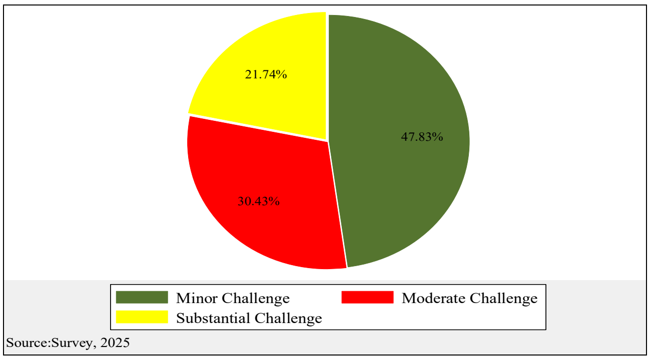

Fig 20: The degree to which Resistance to change from contractors or workforce have presented a challenge to the implementation of green technologies

The study shows that resistance to change from contractors or the workforce was a significant barrier to implementing green technologies. 47.83% of respondents rated it as a minor challenge, 30.43% as moderate, and 21.74% as substantial, indicating that the majority of participants experienced some level of difficulty due to reluctance to adopt new practices or technologies.

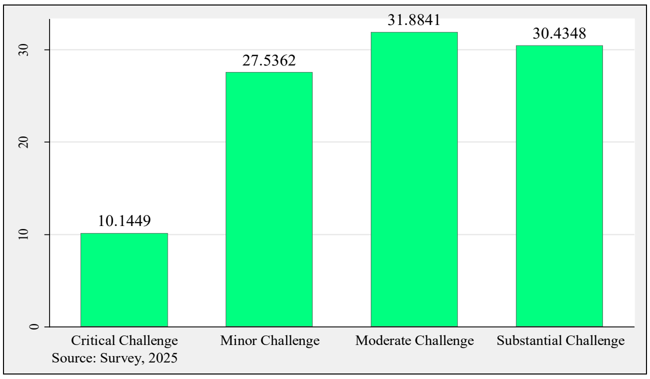

Fig 21: The degree to which Inadequate regulatory frameworks or incentives have presented a challenge to the implementation of green technologies

The study indicates that inadequate regulatory frameworks or incentives posed a considerable challenge to the adoption of green technologies. 31.88% of respondents rated it as a moderate challenge, 30.43% as substantial, and 10.14% as critical, while 27.54% considered it a minor challenge.

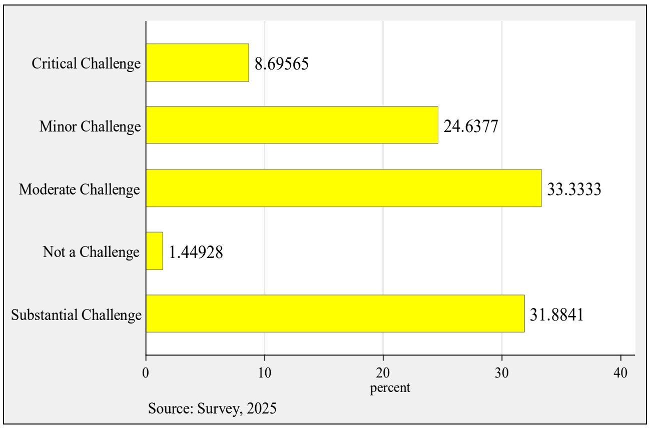

Fig 22: The degree to which Logistical constraints (supply chain, availability) have presented a challenge to the implementation of green technologies

The study reveals that logistical constraints, such as supply chain limitations and availability of materials, were a significant challenge for implementing green technologies. 33.33% of respondents rated it as a moderate challenge, 31.88% as substantial, and 8.70% as critical, while 24.64% considered it a minor challenge and 1.45% saw it as not a challenge.

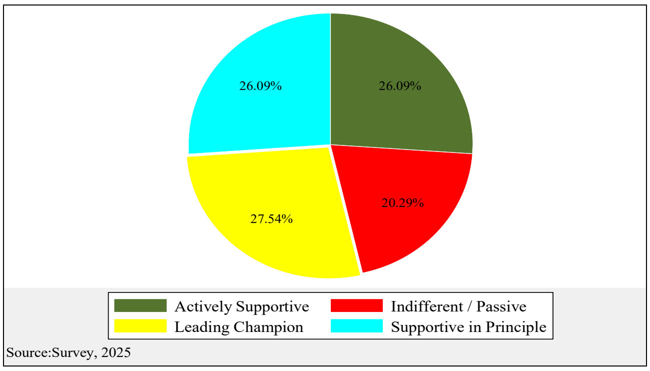

Fig 23: Project Owners / Government Agencies support for green technology adoption

The study shows that government agencies provided strong support for green technology adoption, with 27.54% of respondents identifying them as leading champions and 26.09% as actively supportive. Another 26.09% viewed them as supportive in principle, while 20.29% considered them indifferent or passive.

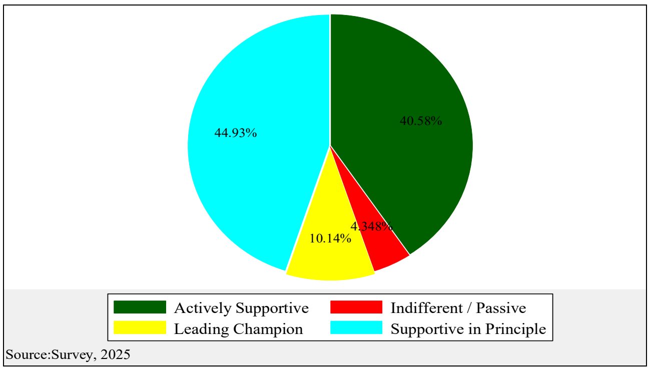

Fig 24: Project Management Team support for green technology adoption

The study indicates that the project management team largely supported green technology adoption. 40.58% of respondents rated them as actively supportive, 10.14% as leading champions, and 44.93% as supportive in principle, while only 4.35% viewed them as indifferent or passive.

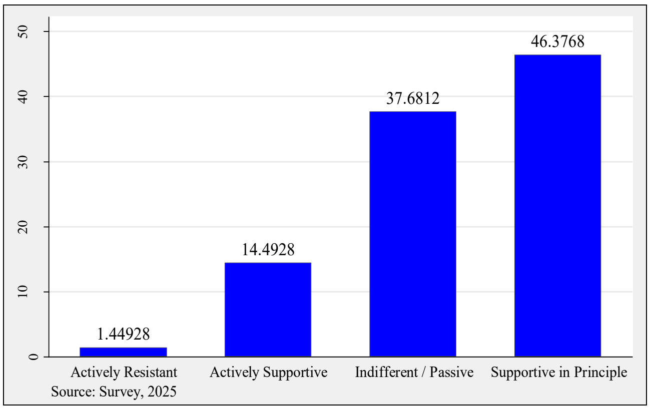

Fig 25: Contractors and Subcontractors support for green technology adoption

The study shows that contractors exhibited mixed support for green technology adoption. 46.38% were supportive in principle, 37.68% were indifferent or passive, and 14.49% were actively supportive, while only 1.45% were actively resistant.

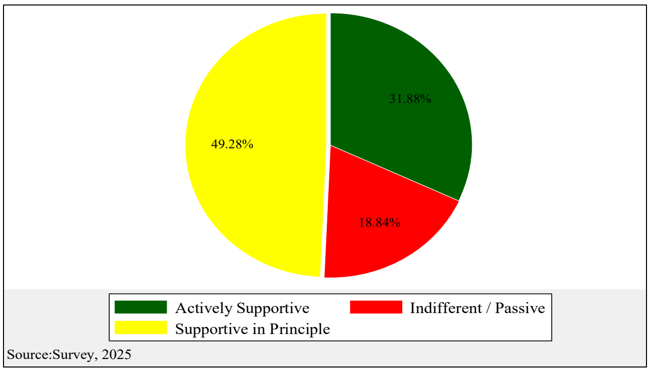

Fig 26: Local Communities support for green technology adoption

The study indicates that local communities generally supported green technology adoption. 49.28% of respondents viewed them as supportive in principle, 31.88% as actively supportive, and 18.84% as indifferent or passive, suggesting that community engagement was largely positive and contributed to project acceptance.

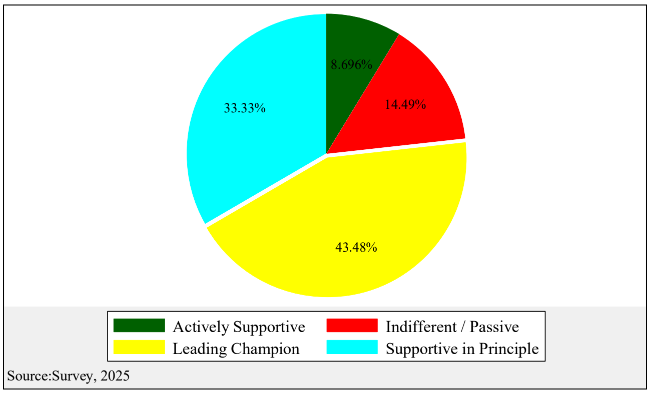

Fig 27: Financial Institutions / Donors support for green technology adoption

The study reveals that donors and financial institutions played a key role in supporting green technology adoption. 43.48% of respondents identified them as leading champions, 33.33% as supportive in principle, 8.70% as actively supportive, and 14.49% as indifferent or passive. This demonstrates that financial stakeholders were largely proactive and instrumental in driving implementation.

Table 2: The single action that would most significantly improve the adoption and effectiveness of green technologies in future Zambian infrastructure projects

Category	Count	Percent
Policy, Regulation & Enforcement	14	20.29%
Financing, Incentives & Cost Reduction	12	17.39%
Capacity Building, Skills & Training	12	17.39%
Infrastructure & Technology Development	10	14.49%
Awareness, Demonstration & Public Engagement	7	10.25%
Data, Monitoring & Reporting	6	8.70%
Collaboration & Partnerships	5	7.25%
Innovation, Research & Development	3	4.35%
Total	69	100%

Source: Survey, 2025

The study shows that improving the adoption and effectiveness of green technologies in Zambian infrastructure projects would be most supported through policy, regulation, and enforcement (20.29%), followed closely by financing and incentives (17.39%) and capacity building and training (17.39%). Other important areas included infrastructure and technology development (14.49%), awareness and public engagement (10.25%), data and monitoring (8.70%), collaboration and partnerships (7.25%), and innovation and research (4.35%), highlighting a multi-faceted approach as critical for successful implementation.

4.5 Discussion of Results

4.5.1 Discussion of Specific Green Technologies Implemented

The implementation landscape for green technologies in the Lusaka-Ndola project was fragmented and strategically selective, revealing a clear prioritization of innovations with immediate economic or compliance payoffs. Widely adopted technologies like energy-efficient machinery (52.86%) and recycled materials (42.86%) align with global trends where cost-benefit rationale drives uptake (Zhang *et al.*, 2020; UNEP, 2022) [29, 26]. Conversely, the minimal deployment of permeable pavements, ecosystem integration, and real-time monitoring (≈50% minimal use) exposes a deficit in investing in holistic environmental management, reflecting the technical and financial hurdles prevalent in developing contexts (Mwaanga & Simukanga, 2022) [21]. This uneven adoption underscores a fundamental disconnect: while policy and project rhetoric advocate for integrated sustainability, execution remains largely reactive and additive. The primary drivers of regulatory compliance (24.29%) and environmental responsibility (22.86%) rather than innovation or cost leadership confirm that green technologies are perceived as an external imposition or risk-mitigation tool, not as a core lever for project optimization (World Bank, 2021; Owusu & Asiedu, 2020) [27, 23]. This reactive posture, exemplified by the underutilization of Zambia's vast solar potential, ultimately restricts the transformative potential of green innovation and perpetuates a cycle of superficial compliance over deep-seated sustainable practice.

4.5.2 Discussion of Effectiveness of Green Technologies

The effectiveness assessment yields a potent but nuanced verdict: green technologies deliver unequivocal environmental and quality dividends, yet their impact on traditional project success metrics remains contested. The strong positive ratings for environmental mitigation (72.86%) and infrastructure quality (70%) empirically validate the core tenets of Sustainable Development and Environmental Management theories, demonstrating that ecological stewardship can directly enhance asset durability and performance (Barrow, 2006; ZEMA, 2022) [3, 28]. However, the project economics narrative is bifurcated. While nearly half of respondents acknowledged positive budgetary impacts, a significant quarter reported cost overruns, crystallizing the central tension between long-term value and prohibitive short-term capital outlays (World Bank, 2021) [27]. Similarly, reported schedule delays (31.43%) highlight the operational learning curves and integration challenges that can negate efficiency gains (Patel & Mehta, 2021) [24]. The notable but less universal social co-benefits—improved community relations (61.43% positive) and team morale (58.57% positive)—reveal that such outcomes are contingent on deliberate engagement strategies and are not automatic byproducts of technical adoption (Silvius & Schipper, 2014) [25]. Crucially, the fact that environmental performance was cited as the foremost benefit (34.78%) reaffirms a compliance-driven mindset, yet the strong secondary recognition of energy efficiency and cost savings (20.29%) signals an emerging, albeit hesitant, appreciation of the economic logic underpinning green technology investment.

4.5.3 Discussion of Challenges in Implementation

The study's findings crystallize a formidable constellation of systemic barriers that critically constrained green technology implementation, affirming and contextualizing the challenges dominant in the literature for developing economies. Financial, human capital, and technical constraints were overwhelmingly severe, with high upfront costs (81.16%), skills shortages (79.71%), and technical complexity (65.22%) acting as primary gatekeepers to adoption (UNEP, 2022; World Bank, 2021) [26, 27]. These barriers were compounded by a significant institutional void; inadequate regulatory frameworks and incentives (a challenge for 72.45% of respondents) expose the stark chasm between Zambia's progressive policies on paper and their weak enforcement on the ground (MNDP, 2017; ZEMA, 2022) [19, 28]. Furthermore, the "soft" infrastructural and social hurdles proved equally consequential. Logistical supply-chain failures (73.91%) and deep-seated resistance to change within the workforce (over 70%) highlight that technological transfer falters without parallel development of local industrial ecosystems and change management protocols (Kamau & Mutiso, 2022) [15]. The tepid, often passive support from contractors the project's execution arm reveals a critical disconnect in the value chain where sustainability mandates are not internalized as performance imperatives. Collectively, these challenges underscore that the failure points are not merely technical or financial but are deeply embedded in institutional, logistical, and cultural frameworks, demanding a holistic systems intervention rather than piecemeal technological solutions.

5. Conclusion

This study concludes that the integration of green technologies in the Lusaka–Ndola Dual Carriageway Project has been selective and uneven, characterized by a reactive, compliance-driven adoption pattern rather than a strategic embrace of sustainability. While technologies offering clearer short-term returns, like energy-efficient machinery (52.86% widely adopted), were prioritized, more holistic solutions such as permeable pavements and ecosystem integration saw minimal use (≈50%). This fragmented approach yielded a mixed effectiveness profile: although the technologies delivered strong positive impacts on environmental mitigation (72.86% positive) and infrastructure quality (70% positive), their influence on core project metrics was ambiguous, with 44.29% reporting positive budget impacts versus 25.72% experiencing cost overruns, and 31.43% noting schedule delays. The implementation was critically hindered by persistent systemic barriers, most severely high upfront costs (81.16%), a shortage of skilled personnel (79.71%), inadequate regulatory frameworks (72.45%), and logistical constraints (73.91%). Consequently, the project's experience underscores that without an integrated enabling environment that simultaneously addresses policy, finance, capacity, and supply-chain gaps, the full potential of green technologies to advance sustainable infrastructure development in Zambia will remain constrained.

6. References

1. African Development Bank (AfDB). Building resilient and sustainable infrastructure in Africa. Abidjan: African Development Bank Group, 2021.
2. African Union. Agenda 2063: The Africa we want. Addis Ababa: African Union Commission, 2015.
3. Barrow CJ. Environmental management for sustainable development. 2nd ed. London: Routledge, 2006.
4. Braun V, Clarke V. Using thematic analysis in psychology. Qualitative Research in Psychology. 2006; 3(2):77-101.
5. Brundtland GH. Our common future: Report of the World Commission on Environment and Development. Oxford: Oxford University Press, 1987.
6. Bryman A. Social research methods. 5th ed. Oxford: Oxford University Press, 2016.
7. Cochran WG. Sampling techniques. 3rd ed. New York: John Wiley & Sons, 1977.
8. Creswell JW, Plano Clark VL. Designing and conducting mixed methods research. 3rd ed. Thousand Oaks, CA: SAGE Publications, 2017.

9. Denzin NK. Triangulation 2.0. Journal of Mixed Methods Research. 2012; 6(2):80-88.
10. Etikan I, Musa SA, Alkassim RS. Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics. 2016; 5(1):1-4.
11. Field A. Discovering statistics using IBM SPSS statistics. 4th ed. London: SAGE Publications, 2013.
12. Guest G, Bunce A, Johnson L. How many interviews are enough? An experiment with data saturation and variability. Field Methods. 2006; 18(1):59-82.
13. Hwang BG, Ng WJ. Project management knowledge and skills for green construction: Overcoming challenges. International Journal of Project Management. 2017; 31(2):272-284.
14. International Energy Agency (IEA). Energy technology perspectives 2020. Paris: IEA Publications, 2020.
15. Kamau J, Mutiso R. Green construction and community acceptance in East Africa: Lessons from Kenya. Journal of Cleaner Production. 2022; 330:129876.
16. Kothari CR. Research methodology: Methods and techniques. 2nd ed. New Delhi: New Age International, 2004.
17. Maxwell JA. Qualitative research design: An interactive approach. 3rd ed. Thousand Oaks, CA: SAGE Publications, 2013.
18. Ministry of Green Economy and Environment, Zambia. National policy on climate change. Lusaka: Government of the Republic of Zambia, 2022.
19. Ministry of National Development Planning (MNDP). Seventh National Development Plan (7NDP) 2017-2021. Lusaka: Government of the Republic of Zambia, 2017.
20. Mugenda OM, Mugenda AG. Research methods: Quantitative and qualitative approaches. Nairobi: Acts Press, 2003.
21. Mwaanga C, Simukanga S. Barriers to sustainable construction in Zambia: A contractor’s perspective. Zambia Journal of Technology & Applied Sciences. 2022; 4(1):45-60.
22. Mwansa L, Chanda J. Financing sustainable infrastructure in Zambia: Challenges and opportunities. African Journal of Economic and Management Studies. 2021; 12(3):345-360.
23. Owusu PA, Asiedu K. Barriers to green building adoption in Sub-Saharan Africa: A review. Construction Innovation. 2020; 20(2):201-218.
24. Patel DA, Mehta Y. Schedule impacts of implementing green technologies in highway projects. Journal of Construction Engineering and Management. 2021; 147(5):04021025.
25. Silvius AJ, Schipper RP. Sustainability in project management: A literature review and impact analysis. Social Business. 2014; 4(1):63-96.
26. United Nations Environment Programme (UNEP). Global status report for buildings and construction. Nairobi: UNEP, 2022.
27. World Bank. Sustainable infrastructure in Africa: A cross-sectoral analysis. Washington, D.C.: World Bank Group, 2021.
28. Zambia Environmental Management Agency (ZEMA). Environmental assessment and management guidelines for infrastructure projects. Lusaka: ZEMA, 2022.
29. Zhang Y, Wang H, Gao W. A review of green technologies in road construction and maintenance. Journal of Cleaner Production. 2020; 259:120790.
30. Zulu S, Kaliba C. Environmental compliance in public infrastructure projects: The case of Zambia. International Journal of Construction Management. 2019; 19(5):405-418.