



Sustainable environmental and tourism development: a multivariate regression analysis of selected tourism enterprises, Livingstone Zambia

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Abstract

This study examines the relationship between electricity infrastructure, environmental considerations, and sustainable tourism development in Livingstone, Zambia, where tourism growth around Victoria Falls continues to increase pressure on energy systems and local environmental management. The purpose of the study is to assess how electricity reliability, solar energy adoption, energy costs, firm size, and facility type influence sustainable tourism performance among tourism enterprises in the area. A mixed-methods research design is adopted in order to generate both statistical and contextual evidence on the role of energy systems in tourism sustainability. The target population comprised 150 tourism-related facilities, including hotels, lodges, guesthouses and tour operators, with stratified random sampling used to ensure representation across sub-sectors. Data were collected through structured questionnaires and key informant interviews. Quantitative data were analyzed using multivariate regression to estimate the effect of electricity reliability, solar energy adoption, energy costs, firm size and facility type on a composite Sustainable Tourism Index (STI), while qualitative data were analyzed thematically. Results show that electricity reliability has a positive and statistically significant effect on sustainability performance ($\beta = 0.152$; $p = 0.001$), while solar energy adoption emerges as the strongest predictor of improved outcomes. Energy costs display a negative relationship with sustainability indicating that higher electricity expenses constrain investment in environmental initiatives. Firm size shows a positive association with sustainability, whereas lodges perform relatively lower than hotels. The study recommends that government and private sector should improve electricity reliability, expand access to affordable renewable energy particularly solar power and support smaller or resource-constrained tourism enterprises aimed at strengthening sustainable tourism development in Livingstone.

Keywords: Sustainable tourism development, environmental sustainability, tourism enterprises, Livingstone Zambia

Introduction

Electricity infrastructure plays a major role in supporting sustainable tourism development in Zambia. Access to reliable and renewable sources of energy can significantly contribute to the quality of tourism attractions in Zambia, while reducing the negative environmental impact that is associated with energy consumption. In many developing countries including Zambia, tourism is seen as an essential sector which can contribute positively to the economic growth of Zambia, but its environment footprint has been a significant concern (Mubanga *et al.*, 2021)^[22]. There is a strong relationship between electricity infrastructure and sustainable tourism development in Zambia and further research into this relationship is necessary to determine how best to improve the use of energy in tourism centers (Tembo *et al.*, 2022)^[29].

The need for an integrated approach to sustainable tourism and energy management in Livingstone is further supported by the shift toward renewable energy solution. The Tourism sector in Livingstone is over reliance on traditional sources of energy such as hydroelectric power and coal can exacerbate environment degradation. Livingstone is vulnerable to the effect of climate change (Nchito *et al.*, 2021)^[23].

Livingstone is the tourist capital of Zambia and a well-renowned tourism destination in Africa and the world beyond. Livingstone is the home to the Victoria Falls, a UNESCO world heritage site. Livingstone attracts millions of tourists annually, contributing massively to the GDP and economic growth of Zambia (Chileshe *et al.*, 2021)^[7]. However, Livingstone faces several environmental challenges

such as inadequate infrastructure development which hampers sustainable development initiatives.

There is limited or scarce research of the relationship between electricity infrastructure, environment sustainability, and tourism development in Zambia. While much has been written about the importance of sustainable tourism in developed nations, there is limited understanding of how these practices can be applied to developed countries like Zambia (Tantoh *et al.*, 2022)^[28]. Understanding the role of energy in sustainable tourism development is critical for informing policies that can contribute to economic growth and environment stewardship. Livingstone, as a key tourism destination, provide a unique case for exploring the impact of energy infrastructure on sustainable tourism practices and to determining how energy solutions can be tailored to fit the local content.

Increasing tourism brings one of the biggest challenges, which is achieving balance between expansion and consumption of electricity resources in a sustainable way. There are certain challenges faced by Livingstone, such as an unreliable supply of power, limited renewable energy resources, and low capacity to meet increasing demand (Mofya *et al.*, 2022)^[21]. These are compounded by poor investment in green energy technology like solar energy, which would be a greener and more environmentally friendly alternative to traditional means of energy (Chomba *et al.*, 2023)^[10]. This leaves the tourism enterprises in Livingstone with no option but to utilize energy-intensive and ecologically harmful forms of energy, which undermines their capacity to sell sustainability in the industry.

Sustainability issues take center stage globally when it comes to discussing tourism, and Zambia is no exception. The growth of the country's tourism sector requires a holistic approach that balances the environmental impacts of tourism activities with economic benefits. Sustainable tourism development involves not just minimizing environmental degradation but also ensuring effective and responsible use of resources (Wang *et al.*, 2020) [30]. Livingstone is an insightful case study of the challenges faced by centers of tourism; therefore, it is imperative to develop a research framework that can assess the complex interactions among energy infrastructure, tourism development, and environmental sustainability

Statement of a problem

The rapid growth of the tourism sector in Livingstone, Zambia, has subjected the local electricity grid to greater strain, thereby presenting challenges to the sustainable growth of the sector. Low and unstable energy supply levels, coupled with environmental impacts of conventional energy consumption, reduce prospects for incorporating sustainable tourism interventions. Zambia's tourism recovery places renewed pressure on Livingstone's energy-dependent visitor economy especially as international arrivals reach 1.2 million by June 2025, while hotel occupancy in Livingstone is reported at about 70% and average tourist stay lengthens to roughly five days conditions that raise the daily electricity load required to keep accommodation, catering, transport support services and visitor facilities operating reliably.

Chitandula *et al* (2024) [8], characterise Zambia's solar resource as strong with average irradiation reported around 5.5 kWh/m²/day, which positions solar technologies as a plausible complement to conventional supply in high-demand service locations such as tourism hubs. Despite the existence of renewable energy sources such as solar power, which presents a viable solution for these issues, the integration of these technologies into the tourism sector in Livingstone has moved at a slow and insufficient rate. Thus, there is an urgent need for scholarly research analyzing the inter linkages between electricity infrastructure, sustainable tourism growth, and environmental sustainability in Livingstone, Zambia with the aim of ascertaining methods of improving the area's energy systems and more sustainable forms of tourism. The objective of this research is to fill this gap by conducting a detailed examination of the Livingstone electricity infrastructure and its effect on the tourism industry's sustainability based on the use of multivariate regression analysis to guide policy development and sustainable tourism growth strategies in the area.

Research objectives

The following objectives guided the study:

1. General objectives

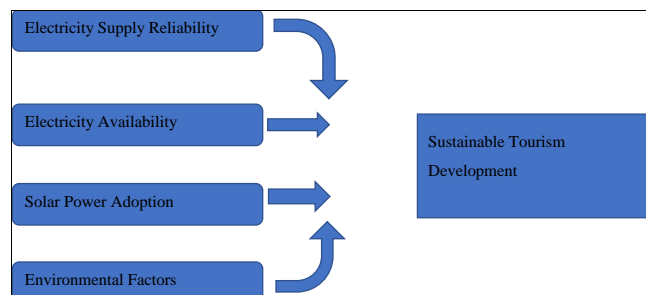
The primary objective of this study is to examine the effect of electricity infrastructure and environmental factors on sustainable tourism development in selected tourist centres in Livingstone, Zambia.

2. Specific objectives

1. To assess the current status of sustainable tourism development in selected tourist centres in Livingstone, Zambia.
2. To determine the effect of electricity supply on sustainable tourism development in the area of study.
3. To identify the challenges contributing to the slow adoption of solar power in selected tourist centres in Livingstone.
4. To examine the influence of environmental factors on sustainable tourism development in Livingstone, Zambia.

Theoretical and Conceptual Framework

The study draws on Sustainable Development Theory and the Energy–Growth Nexus Theory to explain how electricity infrastructure affects sustainable tourism development in Livingstone. Sustainable Development Theory frames tourism growth as a process that must protect ecological systems while still meeting present economic needs, a point that matters in destinations where environmental quality is itself part of the tourism product (Brundtland, 2007) [4]. But tourism does not function in the abstract. Hotels, lodges, restaurants, booking systems, cold storage, water pumping, lighting, and visitor security all depend on reliable electricity. From the perspective of the Energy–Growth Nexus, this makes energy supply a direct input into service performance and local economic activity rather than a passive background condition (Stern, 2011) [7]. In practical terms, unstable electricity can disrupt operations, raise maintenance and fuel costs, reduce service quality, and weaken destination competitiveness, while solar adoption may offer a more resilient energy pathway where grid supply remains erratic. On that basis, the conceptual framework treats sustainable tourism development as the dependent variable and electricity reliability, electricity availability, solar power adoption, and environmental factors as the explanatory variables, since each is expected to shape tourism efficiency, visitor experience, and the long-term viability of the sector (Miles & Huberman, 1994; Bramwell & Lane, 2013) [11, 2].



This diagram illustrates the independent and dependent variable in the current study.

Literature Review

The literature review will highlight global, regional and local studies on women participation in entrepreneurship. Below is a summary

No.	Author	Title	Findings	Gap
1	Ibnou-Laaroussi <i>et al.</i> (2020)	Environmental Sustainability in Tourism	Sustainability in tourism is framed around reducing environmental degradation, including soil, air, and water pollution, while maintaining biodiversity and ecological landscapes.	Limited attention to how energy infrastructure constraints affect environmental sustainability outcomes in tourism settings.
2	Mihalic (2016)	Economic Dimensions of Sustainable Tourism	Economic sustainability enhances destination competitiveness, revenue generation, and long-term viability of tourism markets.	Does not sufficiently examine how unreliable electricity supply undermines economic sustainability in tourism-dependent regions.
3	Söderholm (2020)	Approaches to Tourism Sustainability	Common sustainability practices include waste management, water conservation, and community welfare improvement, with emphasis on social and environmental balance.	Lacks focus on energy systems as a central determinant of sustainable practice implementation.
4	Agyeiwaah <i>et al.</i> (2017)	Conceptualizing Sustainable Tourism	Sustainable tourism integrates environmental protection, social equity, and economic continuity to preserve tourism resources for future generations.	Provides limited empirical linkage between sustainability principles and operational constraints such as energy reliability.
5	Chomba <i>et al.</i> (2023)	Sustainable Practices in Livingstone Tourism	Tourism operators show awareness of sustainability through adoption of eco-friendly practices such as renewable energy and waste reduction.	Adoption remains uneven due to high costs and limited access to energy-efficient infrastructure.
6	Tembo <i>et al.</i> (2022)	Renewable Energy Infrastructure in Zambia	Renewable energy potential exists, but infrastructure for large-scale solar and wind deployment remains underdeveloped.	Does not directly connect infrastructure gaps to tourism sector performance and sustainability outcomes.
7	Eberhard <i>et al.</i> (2011)	Electricity Infrastructure and Investment	Weak electricity systems discourage investment, increase operational costs, and favour larger firms with capital to absorb energy risks.	Limited sector-specific analysis of tourism and its sensitivity to electricity reliability.
8	Seetanah <i>et al.</i> (2011)	Infrastructure and Tourism Development	Infrastructure, including electricity, drives tourism performance, with power supply affecting service delivery, pricing, and visitor experience.	Does not isolate electricity as a distinct constraint nor explore its cascading effects in unstable supply contexts.

Research methodology

This Chapter explains the methodological approach used to examine how electricity infrastructure affects sustainable tourism development in Livingstone, Zambia. The study adopts a quantitative design supported by descriptive elements because the research seeks both to measure relationships among variables and to document the current condition of electricity reliability, renewable energy integration and sustainability practices in tourism enterprises. A multivariate approach is appropriate since the study investigates the combined effects of electricity supply reliability, energy consumption patterns and renewable energy integration on tourism and environmental outcomes, rather than treating these factors in isolation (Gujarati & Porter, 2009; Saunders *et al.*, 2019) [12, 24].

The target population consists of tourism-related enterprises in Livingstone, including hotels, lodges, guesthouses, tour operators, travel agencies, and transport providers. Stratified random sampling is used to ensure that each major category of tourism service is represented, which improves the representativeness of the sample and reduces sampling bias (Saunders *et al.*, 2019) [24]. Using Fisher's formula,

The formula used is:

$$\text{Sample Size} = \frac{(Z\text{-score})^2 \times \text{StdDev} \times (1\text{-StdDev})}{(\text{confidence interval})^2}$$

Where:

n = required sample size

Z = Z-score corresponding to the desired confidence level

p = estimated population proportion

e = margin of error

$$STI_i = \beta_0 + \beta_1 ER_i + \beta_2 SS_i + \beta_3 EC_i + \beta_4 FS_i + \beta_5 LOD_i + \beta_6 TOUR_i + \beta_7 GH_i + \varepsilon_i$$

For this study, the following parameters are adopted:

- Confidence level = 95%
- Z-score at 95% confidence = 1.96
- Estimated population proportion (p) = 0.5
- Margin of error (e) = 0.08 (8%)
- Substituting into the formula:

$$n = (1.96^2 \times 0.5(1 - 0.5)) / (0.08^2)$$

Step-by-step calculation:

$$(1.96)^2 = 3.8416$$

$$0.5(1 - 0.5) = 0.25$$

$$\text{Numerator} = 3.8416 \times 0.25 = 0.9604$$

$$\text{Denominator} = (0.08)^2 = 0.0064$$

$$n = 0.9604 / 0.0064$$

$$n = 150.06$$

Therefore, the required sample size is approximately 150 participants. Data are collected through surveys and semi-structured interviews with business owners, managers, and relevant stakeholders, while secondary data from government reports, sector publications, and prior studies provide contextual support for the primary findings (Kvale, 1996) [17].

Data analysis relies mainly on multivariate regression to test how electricity-related factors influence sustainable tourism development, while thematic analysis is applied to interview data in order to identify recurring issues, perceptions and operational challenges connected to sustainable energy use (Wooldridge, 2016; Braun & Clarke, 2006) [31, 3]. Ethical safeguards include informed consent, confidentiality, voluntary participation, and secure handling of data, while the study acknowledges limits linked to self-reported data and its focus on Livingstone alone, even though that scope allows closer examination of a major tourism destination in Zambia (Bryman, 2016) [5].

Presentation of Findings

This chapter presents the empirical findings of the study, based on data collected from tourism enterprises across Livingstone. The analysis focuses on examining how electricity infrastructure, specifically reliability of supply, renewable energy adoption, and the cost of electricity influence sustainable tourism performance.

1. Characteristics of the sample

The study involved 150 tourism facilities, including hotels, lodges, guesthouses, and tour operators. The sample represented the structure of Livingstone's tourism sector, with hotels and lodges accounting for the majority of respondents. The facility sizes ranged greatly, ranging from small family-owned guesthouses to major hotels with over 100 employees. Variability was also seen in electricity consumption patterns, reliance on solar energy, generator use, and the implementation of environmental policies.

2. Regression Analysis

A multivariate linear regression model was used to identify the elements that influence sustainable tourism performance. The Sustainable Tourism Index (STI) was used as the dependent variable. The independent factors were power reliability, solar energy share, monthly energy cost, business size, and firm type. The model was statistically significant ($F = 11.28$; $p < 0.001$) and accounted for 42% of the variation in sustainable tourism performance. To determine the factors influencing sustainable tourism performance in Livingstone, a multivariate linear regression model was estimated. The Sustainable Tourism Index (STI) was specified as the dependent variable. The independent variables included electricity reliability, solar energy share, monthly energy cost, firm size, and firm type. The general econometric model is specified as:

Where:

STI_i = Sustainable Tourism Index

ER_i = Electricity reliability

SS_i = Solar energy share

EC_i = Monthly energy cost

FS_i = Firm size

LOD_i = Lodge dummy variable

TOUR_i = Tour operator dummy variable

GH_i = Guesthouse dummy variable

ϵ_i = Error term

The overall model is statistically significant ($F = 11.28$; $p < 0.001$). The R-squared value of 0.42 indicates that 42 percent of the variation in sustainable tourism performance is explained by the independent variables. The adjusted R-squared of 0.39 confirms that the model remains stable after adjusting for the number of predictors.

Table 1: Multivariate Regression Results on Sustainable Tourism Index

Variable	Coefficient	Std. Error	t-Statistic	P-Value
Electricity reliability	0.152	0.045	3.38	0.001
Solar energy share	0.421	0.128	3.29	0.002
Energy cost (ZMW/month)	-0.0031	0.0014	-2.21	0.031
Firm size (employees)	0.0098	0.0041	2.39	0.022
Firm type: Lodge	-0.214	0.102	-2.10	0.041
Firm type: Tour operator	-0.067	0.088	-0.76	0.453
Firm type: Guesthouse	-0.112	0.091	-1.23	0.221
Constant	0.486	0.217	2.24	0.027

Table 2: Model Summary Statistics

Statistic	Value
Number of observations	150
R-squared	0.42
Adjusted R-squared	0.39
F-statistic	11.28
Prob > F	0.000
Statistic	Value

3. Interpretation of Regression Results

The regression results indicate that electricity reliability has a positive and statistically significant effect on sustainable tourism performance ($\beta = 0.152$; $p = 0.001$). This implies that improvements in power stability contribute directly to better environmental management and sustainability outcomes. Reliable electricity reduces dependence on diesel generators and improves operational planning, which supports sustainable practices. Solar energy share exhibits the strongest positive coefficient among the energy-related variables ($\beta = 0.421$; $p = 0.002$). This suggests that enterprises integrating higher levels of renewable energy achieve stronger sustainability performance. The magnitude of this coefficient indicates that renewable adoption plays a central role in enhancing environmental outcomes within tourism operations.

Energy cost shows a negative and statistically significant relationship with sustainability ($\beta = -0.0031$; $p = 0.031$). Higher electricity expenditure appears to constrain the ability of firms to invest in environmental improvements. Rising costs may divert financial resources away from sustainability initiatives, thereby weakening overall performance. Firm size demonstrates a positive and significant association ($\beta = 0.0098$; $p = 0.022$), suggesting that larger enterprises are better positioned to implement sustainable practices. Larger firms may benefit from economies of scale, stronger financial capacity, and structured management systems that support environmental compliance.

With respect to firm type, lodge establishments show a statistically significant negative coefficient ($\beta = -0.214$; $p = 0.041$) relative to the reference category. This indicates that, holding other factors constant, lodge-type enterprises exhibit lower sustainability performance compared to the base group. In contrast, tour operators and guesthouses do not display statistically significant differences, suggesting that their sustainability performance does not vary meaningfully from the reference category when other variables are controlled. The regression findings confirm that electricity infrastructure variables, particularly reliability and renewable energy integration, play a decisive role in shaping sustainable tourism performance in Livingstone. The joint significance of the model further supports the conclusion that energy-related factors and firm characteristics collectively influence sustainability outcomes.

3.1 Electricity Reliability

Electricity reliability shows a positive and statistically significant relationship with sustainable tourism performance ($\beta = 0.152$; $p = 0.001$). This result indicates that improvements in the stability and consistency of grid supply are associated with measurable gains in sustainability outcomes among tourism enterprises in Livingstone. Firms that experience fewer outages and voltage fluctuations tend to perform better on environmental indicators captured in

the Sustainable Tourism Index. Reliable electricity reduces dependence on diesel generators, which are often used as backup during load shedding or power interruptions. Generator use increases fuel consumption and carbon emissions while also raising operational costs. When grid supply is stable, tourism facilities are less likely to rely on such emergency systems, leading to lower emissions and improved environmental performance. In addition, consistent power supply supports energy-efficient technologies such as automated lighting systems, refrigeration units, and water heating systems, all of which require steady electricity flow to function optimally.

3.2 Solar Energy Adoption

Solar energy share exhibits the strongest positive effect among all explanatory variables ($\beta = 0.421$; $p = 0.002$). The magnitude of this coefficient suggests that renewable energy integration plays a central role in improving sustainable tourism performance in Livingstone. Facilities that generate a larger proportion of their electricity from solar sources demonstrate stronger environmental practices and higher sustainability scores. This relationship indicates that solar adoption contributes not only to carbon reduction but also to operational resilience. Tourism enterprises that rely less on unstable grid supply or diesel generators reduce emissions and enhance energy security. Solar systems lower long-term operating costs and reduce exposure to energy price volatility. These combined effects strengthen both environmental and economic sustainability. The statistical significance of this variable reinforces the argument that renewable integration is not a marginal adjustment but a structural determinant of sustainability performance. The results suggest that expanding solar penetration across tourism facilities may produce measurable improvements in environmental outcomes within the sector.

3.3 Energy Costs

Energy cost displays a negative and statistically significant relationship with sustainable tourism performance ($\beta = -0.0031$; $p = 0.031$). Although the magnitude of the coefficient appears small, the direction of the relationship is meaningful. Rising electricity expenses reduce firms' ability to allocate financial resources toward sustainability initiatives such as renewable installations, energy audits, or environmental certifications. Higher operational costs may compel businesses to prioritize short-term survival over long-term environmental investments. Enterprises facing elevated electricity bills may postpone capital expenditures related to sustainability. This financial constraint limits the adoption of efficient technologies and restricts environmental improvement efforts. The negative coefficient also suggests that affordability plays a decisive role in environmental performance. When energy systems become costly or unpredictable, firms may revert to coping mechanisms that are not environmentally optimal. This reinforces the importance of stable and cost-efficient electricity infrastructure in promoting sustainable tourism development.

3.4 Firm Size

Firm size shows a positive and statistically significant association with sustainability performance ($\beta = 0.0098$; $p = 0.022$). Larger enterprises tend to score higher on the Sustainable Tourism Index. This outcome implies that scale

provides structural advantages in implementing sustainability practices. Larger firms often possess stronger managerial capacity, formalized operational systems, and greater financial resources. These characteristics increase the likelihood of investing in renewable energy systems, staff training, environmental audits, and certification programs. Economies of scale may also reduce the per-unit cost of adopting sustainable technologies. The positive coefficient suggests that smaller enterprises may face structural constraints in adopting sustainability measures. Limited capital, technical knowledge gaps, and operational pressures may slow their transition toward environmentally responsible practices. This finding highlights the need for targeted policy support aimed at small and medium tourism enterprises.

Firm Type

Firm type reveals variations in sustainability performance across categories of tourism establishments. Lodges exhibit a statistically significant negative coefficient ($\beta = -0.214$; $p = 0.041$) relative to the reference group. This indicates that, holding other factors constant, lodge-type enterprises demonstrate lower sustainability scores compared to hotels. One possible explanation is the operational structure and geographical positioning of lodges. Many lodges operate in remote or semi-rural environments where grid reliability may be weaker and renewable installations may face logistical challenges. Their infrastructure may also rely more heavily on diesel generation, which affects environmental performance. Guesthouses and tour operators also display negative coefficients; however, these results are not statistically significant. This suggests that their sustainability performance does not differ meaningfully from the base category once other variables are controlled for. The absence of statistical significance implies that differences among these categories may be influenced more by firm-level practices than by structural type alone.

Discussion

This chapter discusses the findings presented in Chapter Four in relation to the study objectives and existing literature. The purpose is to interpret the significance of the results, highlight their implications for sustainable tourism development, and provide practical recommendations for tourism enterprises and policymakers.

1. Electricity reliability and sustainable tourism

Electricity reliability demonstrates a positive and statistically significant association with the Sustainable Tourism Index ($\beta = 0.152$; $p = 0.001$), confirming that stable grid supply is a foundational condition for environmentally responsible tourism operations. Enterprises that experience fewer outages are better positioned to maintain energy-efficient systems, reduce diesel generator use, and manage operational processes in a consistent manner. Reliable electricity lowers fuel combustion emissions and stabilizes operational planning, both of which contribute directly to sustainability performance.

This finding aligns with Chola, Chirwa, and Banda (2021)^[9], who argue that dependable electricity infrastructure strengthens service quality and reduces reliance on costly and polluting backup systems in Zambia's tourism sector. Mubanga *et al.* (2021)^[22] also emphasize that weaknesses in electricity distribution constrain tourism enterprises from

transitioning toward low-carbon practices. The present study advances that argument by providing quantitative evidence that reliability exerts a measurable and statistically significant influence on a composite sustainability index. Beyond environmental implications, reliable electricity improves investor confidence and operational stability. When power supply is predictable, firms can invest in renewable integration and efficiency technologies without fear of system incompatibility or operational disruptions. These results suggest that infrastructure upgrades aimed at minimizing outages and voltage instability are not merely technical improvements but central policy instruments for promoting sustainable tourism development in Livingstone.

2. Solar Energy Adoption

Solar energy share records the strongest positive coefficient in the regression model ($\beta = 0.421$; $p = 0.002$), indicating that renewable energy integration substantially enhances sustainability performance. Tourism facilities that generate a higher proportion of their electricity from solar systems demonstrate stronger environmental outcomes and reduced carbon intensity. The magnitude of this coefficient suggests that solar adoption is not incremental but transformative in shaping sustainability performance. Nchito, Nyirenda, and Chirwa (2021)^[23] argue that Zambia's high solar irradiance creates favorable conditions for photovoltaic investment within the tourism industry. Mofya *et al.* (2022)^[21] further contend that solar energy reduces generator dependence and lowers long-term operating costs. The present findings provide empirical confirmation of these claims by statistically linking solar share to improvements in a structured sustainability index.

Tembo *et al.* (2022)^[29] emphasize the importance of bridging energy access gaps with renewable systems to enhance tourism resilience. The results of this study extend that perspective by quantifying the relationship between renewable penetration and sustainability performance. Solar adoption appears to strengthen both environmental responsibility and operational stability. These outcomes support policy measures such as tax incentives, concessional financing, and targeted subsidies designed to accelerate photovoltaic adoption within tourism enterprises.

3. Energy costs as a barrier to sustainability.

Monthly energy cost exhibits a negative and statistically significant relationship with sustainability performance ($\beta = -0.0031$; $p = 0.031$). As electricity expenses increase, tourism enterprises show reduced capacity to invest in environmentally responsible practices. Although the coefficient magnitude appears small, its statistical significance confirms that affordability plays a meaningful role in shaping sustainability outcomes. Mofya (2023)^[20] observe that high operational and capital costs constrain small and medium tourism enterprises from adopting energy-efficient technologies. Chileshe (2020)^[6] similarly notes that financial limitations restrict sustainability transitions within Zambia's tourism sector. The regression findings in this study quantify that relationship by demonstrating that rising energy costs correspond with measurable declines in sustainability index scores.

Elevated electricity expenditures may force firms to prioritize immediate operational expenses over long-term environmental investments. Financial pressure can delay the adoption of LED systems, renewable installations, waste

management upgrades, and certification processes. This reinforces the need for financial mechanisms that lower entry barriers to sustainable technology adoption. Policy instruments such as subsidized credit lines, tax deductions for renewable systems, and on-bill financing arrangements may reduce cost constraints and improve sector-wide sustainability performance.

4. Organizational capability and firm size

Firm size shows a positive and statistically significant relationship with the Sustainable Tourism Index ($\beta = 0.0098$; $p = 0.022$), indicating that larger tourism enterprises tend to perform better on sustainability indicators. This suggests that organizational scale strengthens the ability of firms to adopt environmentally responsible practices and maintain structured sustainability systems. Larger enterprises often possess stronger financial reserves, formal management systems, and internal monitoring mechanisms that support environmental investments (Wang *et al.*, 2020)^[30]. Structured governance and strategic planning within larger firms create conditions that support systematic sustainability integration rather than isolated interventions (Hassan *et al.*, 2020)^[13]. The empirical findings of this study confirm that organizational capability translates into measurable sustainability performance advantages. Firms with greater human and financial resources are more likely to invest in renewable technologies, energy audits, staff training, and environmental certifications.

Uneven adoption of energy-efficient technologies across Zambia's tourism industry has been documented, with better-resourced operators demonstrating higher uptake levels (Chomba *et al.*, 2023)^[10]. The regression results quantify that disparity by showing that firm size exerts a statistically significant influence on sustainability outcomes. Smaller enterprises may face financial and informational constraints that limit their participation in sustainability transitions. These findings suggest that targeted interventions such as technical assistance, concessional financing, and pooled procurement mechanisms are necessary to reduce structural disparities in sustainability adoption (Chomba *et al.*, 2023)^[10].

5. Differences by facility type (lodges worse than hotels)

The results indicate that lodges perform significantly worse than hotels in sustainability outcomes ($\beta = -0.214$; $p = 0.041$). This suggests that structural and locational factors may influence environmental performance across facility types. Lodges are often located in remote or semi-rural areas where electricity infrastructure is weaker and renewable integration may face logistical challenges (Jere *et al.*, 2022)^[16]. Higher transportation costs, limited grid connectivity, and dependence on diesel generation create operational barriers that restrict sustainability performance in remote facilities (Tembo *et al.*, 2022)^[29]. The empirical findings of this study align with these observations, as lodge-type establishments show statistically lower sustainability scores compared to the reference category.

Sustainability adoption in Zambia's tourism sector has been described as uneven across sub-sectors, with variations influenced by both resource endowment and operational context (Chomba *et al.*, 2023)^[10]. The present results reinforce that conclusion by demonstrating that differences are not solely explained by firm size but also by facility

classification and geographic positioning. These findings indicate that uniform policy measures may not be sufficient. Spatially differentiated approaches, including rural renewable subsidies, micro-grid support, and community-based energy initiatives, may be more effective in addressing sustainability gaps across tourism facility types (Jere *et al.*, 2022; Tembo *et al.*, 2022) ^[29, 16].

Conclusion and Recommendation

This study examined the influence of electricity infrastructure on sustainable tourism development in Livingstone, with particular attention to electricity reliability, renewable energy adoption, and energy costs. Using data from 150 tourism enterprises and applying a composite Sustainable Tourism Index (STI), the research provided empirical insights into how energy conditions shape sustainability outcomes within the tourism sector.

Conclusion

The findings demonstrate that electricity reliability is a significant enabler of sustainable tourism performance in Livingstone. Enterprises that experience stable and consistent grid supply report stronger environmental outcomes and higher sustainability index scores. Reliable electricity reduces dependence on diesel generators, limits carbon emissions, and supports the effective functioning of energy-efficient technologies. This confirms existing scholarship which emphasizes that tourism operations are structurally dependent on stable energy systems for both service delivery and environmental performance (Chola *et al.*, 2021) ^[10]. Without dependable infrastructure, sustainability initiatives remain constrained by operational uncertainty.

Solar energy adoption emerged as the strongest predictor of sustainability within the regression model. Facilities that generate a greater proportion of their electricity from solar systems achieve markedly higher sustainability performance. This result supports arguments that renewable integration strengthens both environmental protection and economic resilience in tourism enterprises (Nchito *et al.*, 2021). Solar energy reduces fuel consumption, lowers emissions, and shields firms from volatility in electricity supply and pricing. In a high-insolation environment such as Zambia, renewable systems provide not only environmental gains but also long-term operational stability (Mofya *et al.*, 2022) ^[21]. The statistical strength of the solar coefficient underscores that renewable energy is not merely complementary but central to sustainable tourism development. By quantifying the relationship between solar share and a composite sustainability index, this study extends prior conceptual discussions and provides measurable evidence that renewable integration translates into improved sustainability performance. These findings reinforce the view that renewable energy systems form a core pillar of sustainable tourism strategy in developing economies (Tembo *et al.*, 2022) ^[29].

Energy affordability also emerged as a critical factor shaping sustainability outcomes. Higher electricity costs were associated with reduced sustainability performance, suggesting that financial constraints limit firms' capacity to invest in environmental improvements. This supports previous research highlighting affordability as a structural barrier to green investment within Zambia's tourism sector (Chomba *et al.*, 2023) ^[10]. When energy costs rise,

enterprises may prioritize short-term operational needs over long-term sustainability investments. Addressing cost barriers therefore becomes essential for expanding adoption of clean technologies.

Firm size and facility type further reveal structural disparities within the tourism industry. Larger enterprises demonstrate stronger sustainability performance, indicating that organizational capacity and resource availability influence environmental outcomes (Wang *et al.*, 2020) ^[30]. Lodge-type facilities, particularly those located in remote areas, exhibit lower sustainability scores, reflecting infrastructural and logistical challenges (Jere *et al.*, 2022) ^[16]. These patterns suggest that sustainability performance is shaped by both internal organizational factors and external infrastructural conditions. The study concludes that improvements in electricity reliability and renewable energy adoption are central to advancing sustainable tourism in Livingstone. Infrastructure stability, renewable integration, and financial accessibility operate together to determine environmental performance within the sector. The findings provide empirical support for policy interventions focused on grid modernization, solar energy incentives, and targeted support for smaller and remote tourism enterprises. Strengthening these areas will contribute to a more resilient, environmentally responsible, and economically sustainable tourism industry in Zambia.

Recommendations

Sustainable tourism in Livingstone is closely influenced by the reliability, affordability, and source of energy available to tourism enterprises. Based on the findings of this study, government and policy makers should introduce targeted incentives that encourage tourism businesses to invest in alternative energy systems, particularly solar power. These incentives may include grants, tax reductions, low-interest loans, and subsidy schemes that reduce the high initial cost of renewable energy installation. Financial support mechanisms would help enterprises overcome cost barriers that currently limit adoption, especially among small and medium-sized operators with constrained capital.

There is also a need to strengthen electricity infrastructure within Livingstone's tourism corridor. Government, working through institutions such as Zesco and other energy authorities, should prioritize improvements in grid stability, maintenance of distribution systems, and reduction of power interruptions affecting tourism facilities. Stable and predictable electricity supply reduces dependence on diesel generators, lowers operational risk, and supports the consistent functioning of energy-efficient systems. Improving grid reliability should therefore be treated as a strategic component of tourism sustainability rather than only as an energy sector concern.

Access to affordable renewable energy solutions should be expanded through partnerships between public institutions, private investors, and development agencies. Tourism enterprises require not only financing but also technical guidance to adopt and manage renewable systems effectively. Capacity-building initiatives should be introduced to train managers and staff in energy management, system maintenance, and sustainability reporting. Strengthening technical knowledge will increase confidence in renewable technologies and promote wider adoption across the sector. Policy measures should also reflect differences among facility types and locations.

lodges operating in remote areas may face unique infrastructural and logistical challenges that limit their ability to adopt renewable systems. targeted support such as rural energy subsidies, small-scale micro-grid projects, and community-based renewable initiatives would help address spatial inequalities. a differentiated policy approach is more likely to close sustainability gaps than a uniform incentive structure applied across all facility types.

Finally, continuous monitoring and evaluation mechanisms should be established to track progress in renewable energy integration and electricity reliability within the tourism sector. future research should examine long-term trends in energy adoption, assess the economic returns of sustainability investments, and evaluate the effectiveness of government incentive programs. evidence generated from such research will support more precise and responsive policy interventions, ultimately strengthening the environmental and economic sustainability of tourism development in Livingstone.

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