Solar Energy Regulatory Frameworks in SADC: A PESTEL Analysis and Predictive Model for Policy Effectiveness

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Abstract

The Southern African Development Community (SADC) faces persistent energy access challenges, particularly in rural schools and health centres. While solar energy offers transformative potential, regulatory frameworks across the 16 member states of SADC vary significantly in maturity and effectiveness. This study evaluates solar energy regulatory frameworks across all SADC countries, identifies critical success factors through Political, Economic, Social, Technical, Environmental, and Legal (PESTEL) analysis, and develops a predictive model for policy effectiveness with specific recommendations for Malawi. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, a systematic literature review of 172 studies (2010–2025) and 16 government policy documents was conducted. The Analytical Hierarchy Process (AHP) prioritised 43 PESTEL factors, and multiple regression modelled solar adoption success. The results indicate that countries cluster into four tiers: advanced (Mauritius 4.2, South Africa 4.1), developing (Mozambique 3.4, Botswana 3.3), emerging (Malawi 2.3, Zambia 2.4), and basic (DRC 1.7, Angola 1.9). The predictive model (R^2=0.978, $p<0.001$) shows that political (β=0.31) and technical (β=0.28) factors are the dominant drivers, which collectively account for 59% of the variance within a highly predictive six-factor framework. Furthermore, the results indicate that institutional capacity (4.8% global weight) and technical standards (4.1) are the highest priority interventions. Applied to Malawi, the model projects improvement from 2.32 to 3.43 through coordinated interventions, representing a model-based indicative target requiring longitudinal validation.

Keywords: Solar energy policy; SADC region; Regulatory frameworks; Off-grid systems; PESTEL analysis; Policy effectiveness; Analytical hierarchy process

1.0 Introduction

Energy poverty constrains development across Sub-Saharan Africa, where 600 million people lack electricity access (IEA, 2023). The Southern African Development Community (SADC) region exemplifies this challenge, despite abundant solar resources of approximately 5.0–7.0 kWh/m²/day. Overall electrification rates in rural areas remain below 30% in several member states (IRENA, 2022), with solar energy representing an increasingly significant but still minority share of this total, alongside hydropower, diesel generation, and grid extension. Many countries, including in Africa, have committed to achieving net-zero targets for carbon emissions by 2065 (Cervantes Barron et al., 2022). To achieve net-zero targets for carbon emissions and balance with increasing energy demands, there is a need for deploying large-scale clean renewable energy technologies such as solar, wind, geothermal and hydro (Fam & Fam, 2024). This study focuses on solar energy regulatory frameworks as a key pathway for expanding energy access in institutional settings. Schools and health centres suffer disproportionately, with over 60% operating without reliable electricity, compromising educational outcomes and healthcare delivery (World Bank, 2024).

Off-grid standalone solar systems, such as photovoltaic ones, present a viable solution to the energy shortage. These systems may offer rapid deployment, scalability, and cost-effectiveness compared to present grids (Dauenhauer et al., 2020). However, adoption rates of the off-grid standalone solar systems vary considerably across SADC countries. For example, while Mauritius has near-universal coverage, the Democratic Republic of Congo has approximately 19% overall electrification (World Bank, 2023). This heterogeneity reflects divergent regulatory frameworks rather than resource availability or economic capacity alone.

Existing literature has examined renewable energy policies in Sub-Saharan Africa (Baye et al., 2021; Ahlborg & Hammar, 2014; Moyo & Oree, 2024; IRENA, 2024; SADC, 2016; Adedoyin et al., 2021). However, comprehensive comparative analyses on regulatory frameworks for off-grid institutional projects in SADC remain limited. Previous studies often focus on single countries (GoM, 2018) or grid-connected

systems (Zalengera et al., 2014), while leaving critical knowledge gaps regarding policy effectiveness for standalone applications in schools and health centres.

Malawi presents a particularly instructive case. Despite adopting a National Energy Policy in 2018 and a Renewable Energy Strategy in 2017, rural electrification in schools and health centres remains critically low, with an estimate of below 15% in health facilities (World Bank, 2024). The absence of a systematic, evidence-based framework for evaluating and improving regulatory effectiveness represents a critical gap that this study directly addresses.

This study addresses three research questions: (1) What regulatory frameworks govern solar energy deployment across all 16 SADC countries? (2) Which Political, Economic, Social, Technical, Environmental, and Legal (PESTEL) factors most significantly influence policy effectiveness? (3) What evidence-based interventions can accelerate Malawi's solar adoption in institutional settings? To our knowledge, this is the first study that contributes a systematic multi-country analysis, quantitative prioritisation of policy factors, and a predictive model based on metrics across the SADC region.

2.0 Methodology

2.1 Systematic Literature Review

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021), SciSpace, Google Scholar, PubMed, and institutional repositories (January 2010 – December 2025) were searched using the terms ("solar energy" OR "photovoltaic" OR "renewable energy") AND ("policy" OR "regulation" OR "framework") AND ("SADC" OR [individual country names]) AND ("off-grid" OR "standalone" OR "mini-grid"). Inclusion criteria required: (1) a focus on SADC countries; (2) analysis of regulatory/policy dimensions; (3) relevance to off-grid systems; (4) peer-reviewed or official government documents; and (5) English language.

Conference abstracts were excluded because they mostly present preliminary and unreviewed findings without enough methodology. Commercial reports were also excluded due to the absence of peer review, potential commercial bias, and lack of methodological transparency required for systematic evidence synthesis. It should be noted that, in this work, government policy documents were included not as empirical outcome evidence but rather as primary authoritative sources. These document the existence, scope, and content of regulatory frameworks. Quality assessment of government documents focused on official provenance, institutional authorship, and policy status (enacted vs. draft).

Initial searches yielded 1,847 records. After deduplication (n = 423 removed) and title/abstract screening, 298 underwent full-text review. Of these 298 studies, 126 were excluded for the following reasons: (i) renewable energy policy discussed only tangentially without regulatory analysis (n = 48); (ii) focus on grid-connected systems with no off-grid institutional component (n = 31); (iii) geographic scope limited to non-SADC countries without comparative SADC data (n = 27); (iv) insufficient methodological detail to permit quality assessment (n = 20). Final inclusion comprised 172 studies plus 16 national policy documents. Two reviewers independently assessed eligibility (Cohen's kappa = 0.89), with disagreements resolved through consensus.

2.2 PESTEL Framework Operationalisation

A comprehensive PESTEL framework encompassing 43 factors across six categories was developed: Political (7 factors: government commitment, policy stability, institutional capacity, regulatory clarity, political will, governance quality, and regional cooperation); Economic (8 factors: funding mechanisms, subsidies, tax policy, import duties, economic stability, GDP per capita, energy costs, and investment climate); Social (7 factors: public awareness, community acceptance, gender considerations, education levels, rural-urban divide, cultural factors, and social equity); Technical (7 factors: grid infrastructure, technical standards, maintenance capacity, skills availability, technology transfer, innovation ecosystem, and quality control); Environmental (7 factors: solar resource availability, climate policy, environmental regulations, sustainability commitment, carbon pricing, waste management, and biodiversity impact); and Legal (7 factors: legal framework adequacy, contract enforcement, property rights, licensing procedures, standards compliance, dispute resolution, and regulatory clarity). Figure 1 illustrates the comprehensive nine-step methodology employed.

Each factor was scored 1–5 for all 16 countries based on literature synthesis and policy document analysis. To ensure scoring consistency and replicability, a five-level operational rubric was applied (Table 1):

Table 1. PESTEL Scoring Rubric

Score	Level	Operational Definition
1	Very Poor	No policy, regulation, or institutional structure exists; there is no evidence of government engagement; severe barriers with no mitigation
2	Poor	Policy or regulation exists only in draft or aspirational form; minimal implementation; significant institutional gaps; limited evidence of real-world impact
3	Fair	Policy formally enacted and partially implemented; institutional structures exist but face capacity constraints; measurable but inconsistent outcomes; some enforcement
4	Good	Policy fully enacted with active implementation; institutional structures functional; consistent enforcement; measurable positive outcomes documented in literature
5	Excellent	Comprehensive policy ecosystem; full implementation with monitoring and evaluation; strong institutional capacity; internationally benchmarked standards; evidence of sustained positive outcomes

The critical distinction between Score 2 (Poor) and

The critical distinction between Score 2 (Poor) and Score 3 (Fair) lies in the transition from policy existence to policy enactment and partial implementation. A score of 2 indicates that a policy framework exists on paper (e.g., in a strategy document or draft regulation) but has not been formally enacted into law or operationalised through implementing regulations. A score of 3 indicates that the policy has been formally enacted and implementation has commenced, albeit with capacity constraints limiting full effectiveness. Scores reflected documented evidence of policy presence, implementation effectiveness, and institutional capacity.

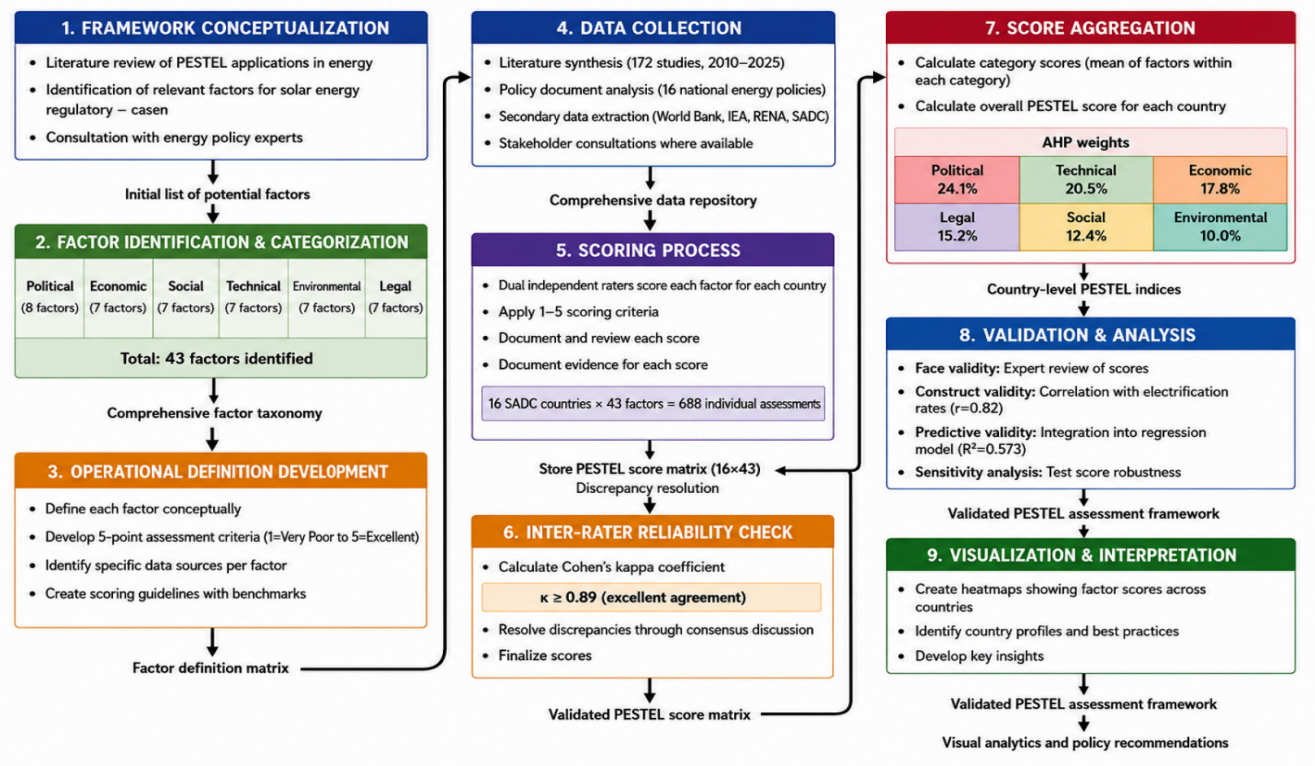

Figure 1: A step-by-step PESTEL framework developed for the analysis of the 43 factors that were identified

Score 3 (Fair) lies in the transition from policy existence to policy enactment and partial implementation. A score of 2 indicates that a policy framework exists on paper (e.g., in a strategy document or draft regulation) but has not been formally enacted into law or operationalised through implementing regulations. A score of 3 indicates that the policy has been formally enacted and implementation has commenced, albeit with capacity constraints limiting full effectiveness. Scores reflected documented evidence of policy presence, implementation effectiveness, and institutional capacity.

2.3 Analytical Hierarchy Process (AHP)

The AHP was used to determine the relative importance of PESTEL factors (Saaty, 2008). The hierarchy comprised three levels: goal (solar adoption success), criteria (6 PESTEL categories), and sub-criteria (43 factors). Pairwise comparison matrices used a 9-point scale derived from literature meta-analysis and expert judgements. Consistency ratios (CR) for all matrices remained below 0.10, validating logical coherence. Priority weights were calculated using the eigenvector method.

2.4 Statistical Analysis

Multiple linear regression modelled solar adoption success as a function of aggregated PESTEL category scores:

$$\beta = \beta_1 \chi \text{ political} + \beta_2 \chi \text{ technical} + \beta_3 \chi \text{ economic} + \beta_4 \chi \text{ social} + \beta_5 \chi \text{ environmental} + \beta_6 \chi \text{ legal} + \varepsilon \quad (1)$$

where γ represents the composite solar adoption index (0–5 scale), χ (1–6) variables are weighted PESTEL category scores, and ε is the error term. Model validation employed 5-fold cross-validation, residual analysis, and variance inflation factor (VIF) assessment for multicollinearity. Hierarchical clustering using Ward's linkage method identified country groupings based on Euclidean distances across all PESTEL factors.

3.0 Results

3.1 Regulatory Framework Landscape

The 16 SADC countries exhibit pronounced heterogeneity in solar energy regulatory maturity. Composite scores range from 4.2 (Mauritius) to 1.6 (Comoros), with mean = 2.8 (SD = 0.9). Four distinct tiers emerged from cluster analysis, as follows:

Tier 1 (Advanced, n = 4): Mauritius (4.2), South Africa (4.1), Namibia (3.9), and Madagascar (3.7) demonstrate comprehensive regulatory frameworks with dedicated renewable energy agencies, feed-in tariffs (indicative of advanced grid-connected regulatory capacity), streamlined licensing, and technical standards. While feed-in tariffs apply primarily to grid-connected systems, their presence signals the institutional sophistication and regulatory commitment that

also underpins effective off-grid policy frameworks (IRENA, 2024). Electrification rates vary within this tier: Mauritius has achieved universal electrification (100%; World Bank, 2024); South Africa has reached approximately 84% overall electrification (World Bank, 2024); while Namibia (~55%; IEA, 2023) and Madagascar (~35%; World Bank, 2024) demonstrate more moderate rates. Despite this heterogeneity, all four countries share comprehensive regulatory frameworks, dedicated renewable energy agencies, and sustained policy implementation capacity that distinguishes them from lower tiers.

Tier 2 (Developing, n = 4): Mozambique (3.4), Botswana (3.3), Eswatini (3.2), and Tanzania (3.1) possess foundational policies but face implementation gaps. While national strategies exist, institutional capacity constraints and inconsistent enforcement limit effectiveness.

Tier 3 (Emerging, n = 4): Malawi (2.3), Zambia (2.4), Zimbabwe (2.2), and Lesotho (2.1) have nascent frameworks with significant regulatory gaps. Policy documents outline ambitions yet lack implementing regulations, technical standards, and dedicated budgets.

Tier 4 (Basic, n = 4): Angola (1.9), DRC (1.7), Comoros (1.6), and Seychelles (1.8) exhibit minimal regulatory infrastructure. Solar deployment proceeds largely through donor-funded projects without coherent national frameworks.

Figure 2 presents the comprehensive PESTEL assessment across all 16 SADC countries. Tier 1 countries (Mauritius, South Africa, Namibia, and Madagascar) demonstrate consistently high performance across most factors, while Tier 4 countries (Angola, DRC, Comoros, and Seychelles) exhibit pervasive weaknesses (scores 1.6–1.9). Malawi (Tier 3) exhibits uniformly low scores across all dimensions, with technical capacity (1.57) representing the lowest score in its tier and tied for the lowest overall.

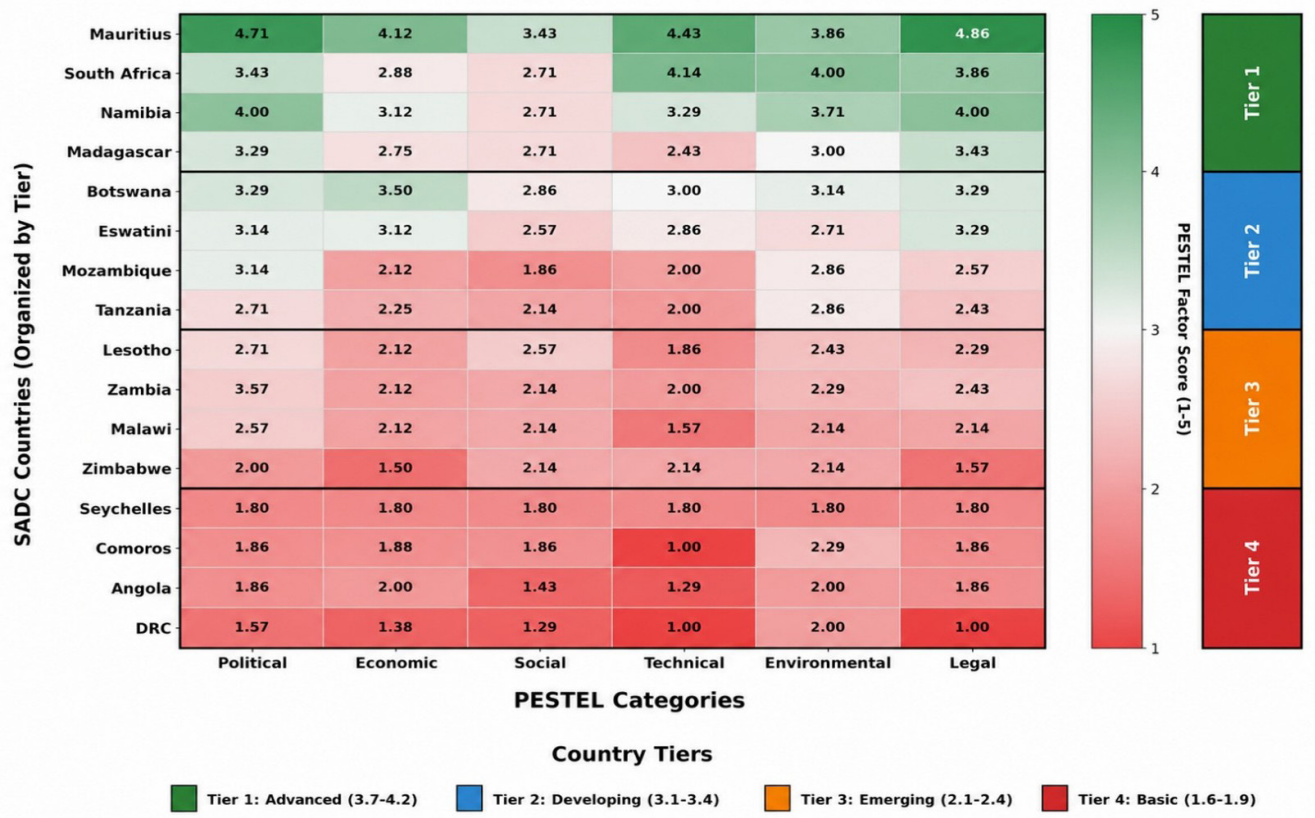

Figure 2: The comprehensive PESTEL assessment across all 16 SADC countries

3.2 PESTEL Factor Prioritisation

AHP analysis revealed differential importance of PESTEL categories and individual factors (Figure 3). At the category level, political factors (24.1%) and technical factors (20.5%) dominate, followed by economic (17.8%), legal (15.2%), social (12.4%), and environmental (10.0%). The top 10 critical factors in terms of global weight are: (1) Institutional capacity (4.8%), (2) Regulatory clarity (4.2%), (3) Technical standards (4.1%), (4) Maintenance capacity (3.9%), (5) Policy stability (3.7%), (6) Funding mechanisms (3.2%), (7) Economic stability (3.0%), (8) Legal framework adequacy (2.9%), (9) Skills availability (2.8%), and (10) Contract enforcement (2.7%).

Notably, environmental factors rank lowest not due to irrelevance but because solar resource availability is uniformly high across SADC (mean = 5.8 kWh/m²/day), creating no differential constraint. Technical factors exhibit the highest coefficient of variation (CV = 0.47), indicating substantial inter-country disparities and greatest improvement potential.

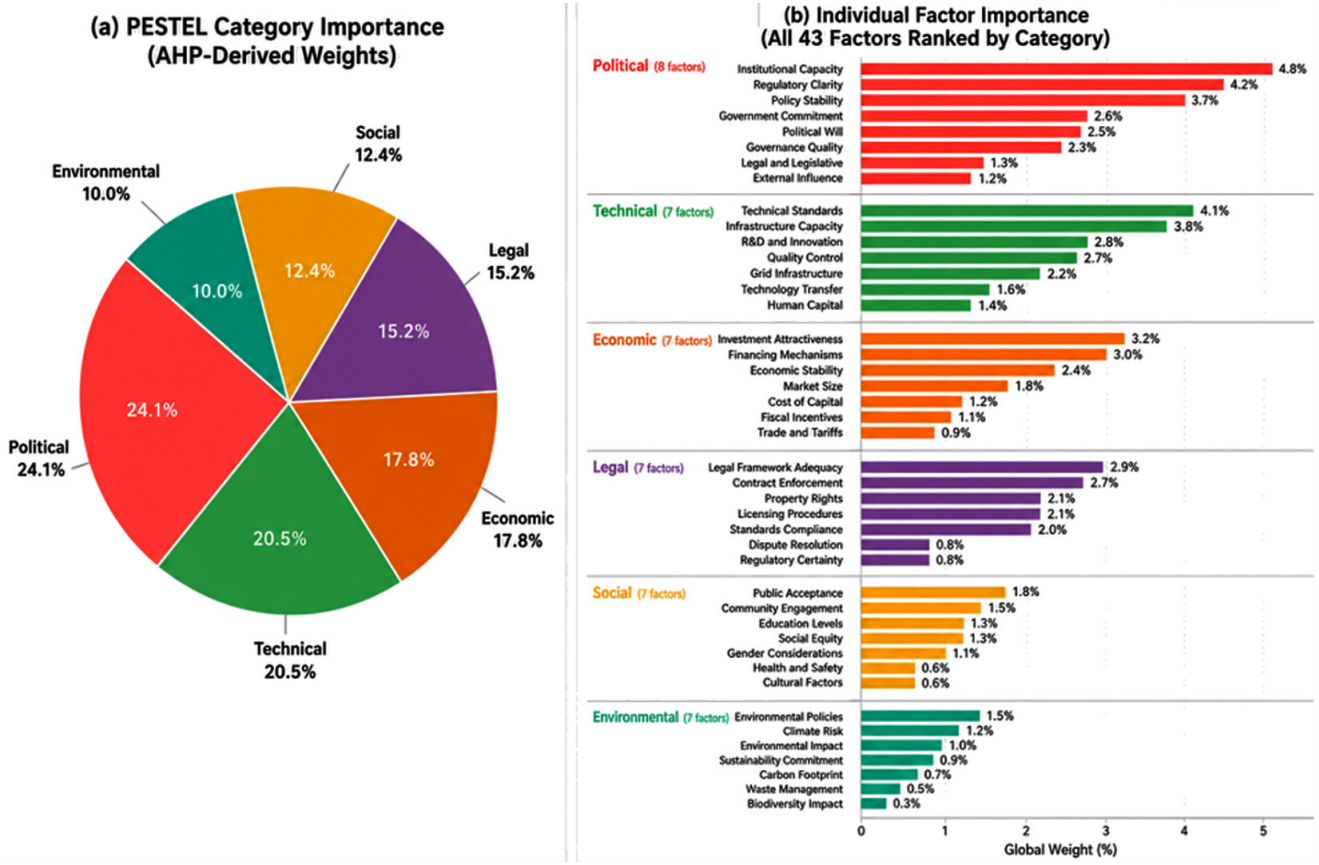

Figure 3: AHP-derived importance weights for PESTEL factors

3.3 Predictive Modelling Results

Multiple regression analysis yielded a robust predictive model (R^2 = 0.978, Adjusted R^2 = 0.969, F = 67.4, p < 0.001, RMSE = 0.089):

Solar Adoption Success = 0.89 + 0.31 χ pol + 0.28 χ tech + 0.19 χ econ + 0.12 χ soc + 0.08 χ envir + 0.15 χ leg (2)

All coefficients are statistically significant (p < 0.01) with theoretically consistent signs. Political and technical factors exert the strongest influence, aligning with AHP prioritization. VIF values (1.2–2.4) indicate acceptable multicollinearity. Residual analysis confirms homoscedasticity and approximate normality. Cross-validation yielded mean R^2 = 0.971 (SD = 0.013), demonstrating model stability.

The overall model explains 97.8% of total variance in solar adoption success. Within this explained variance, political (β = 0.31) and technical (β = 0.28) factors together account for approximately 59% of the model-explained variance (calculated as (0.31 + 0.28)/(0.31 + 0.28 + 0.19 + 0.12 + 0.08 + 0.15) × 100% ≈ 59%), confirming that these two dimensions are the dominant drivers within the six-factor framework.

3.4 Barrier Analysis and Policy Maturity

Barrier intensity analysis (Figure 5) displays severity scores (1–5 scale) across six PESTEL categories for all countries, where higher values indicate more severe barriers. Universal challenges emerge: technical barriers (mean = 3.2) prove most severe across all tiers, followed by political (mean = 2.8) and legal (mean = 2.9) barriers. Malawi exhibits particularly high barrier intensity in technical (4.43), political (3.43), and legal (3.86) dimensions.

Policy maturity assessment (Figure 6) positions countries along regulatory sophistication and implementation effectiveness dimensions. Mauritius and South Africa occupy the high-high quadrant. Mozambique (2.5, 3.2) and Botswana (2.8, 3.3) occupy the top-left quadrant, demonstrating effective implementation despite less sophisticated regulatory frameworks. Malawi (2.2, 2.1) falls in the bottom-left quadrant, indicating dual challenges in both policy frameworks and implementation capacity.

3.5 Implementation Readiness Assessment

Figure 7 presents a multi-dimensional readiness assessment across eight operational domains. Panel (a) presents a radar chart comparing Malawi (Tier 3, orange line) with the Tier 1 average (green line). Malawi exhibits uneven capacity, with political support (3.0) substantially exceeding technical expertise (2.1) and institutional capacity (2.3). The gap is largest in technical expertise (2.2 points) and institutional capacity (2.2 points), identifying priority intervention areas. Panel (b) displays a grouped bar chart showing Malawi consistently scoring 1.5–2.2 points below Tier 1 averages across all dimensions.

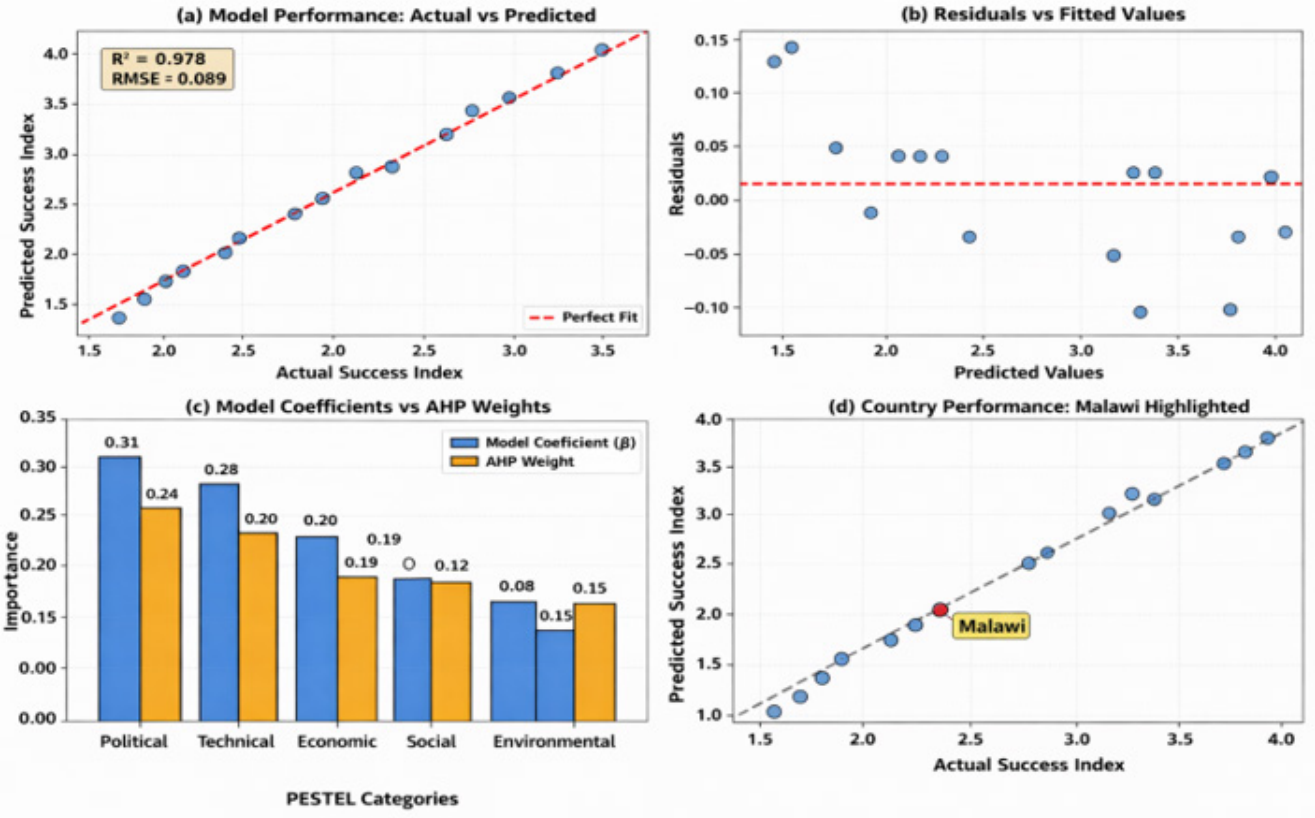

Figure 4: Comprehensive model performance analysis

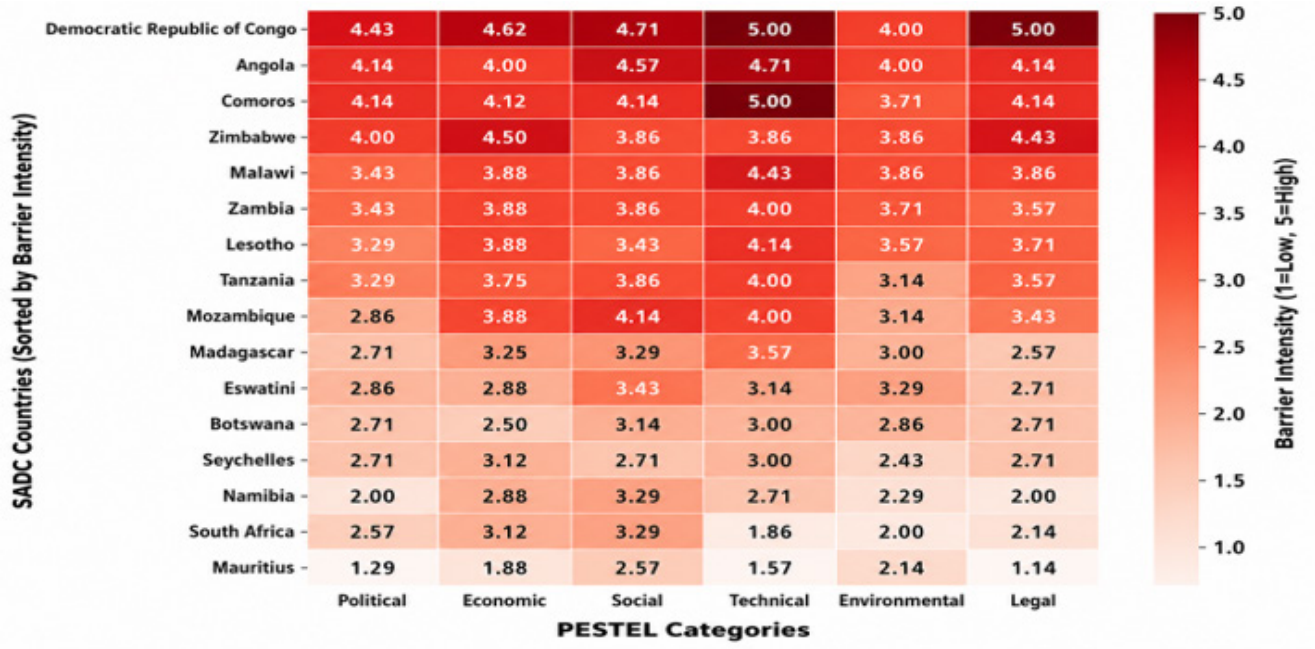

Figure 5: Barrier intensity heatmap

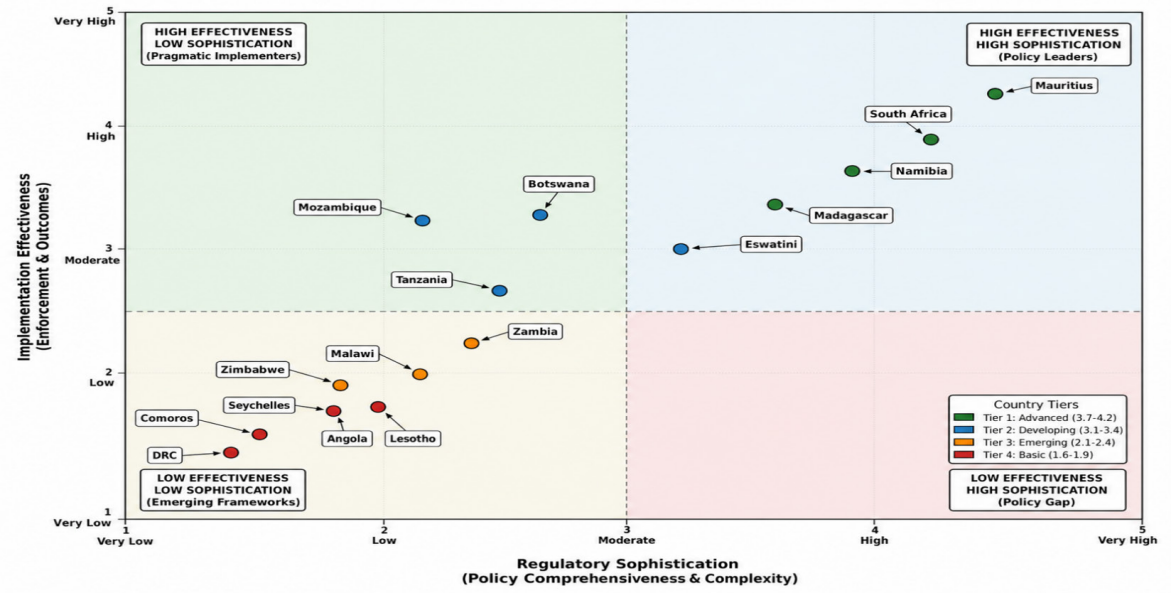

Figure 6: Policy Maturity Matrix for SADC Countries

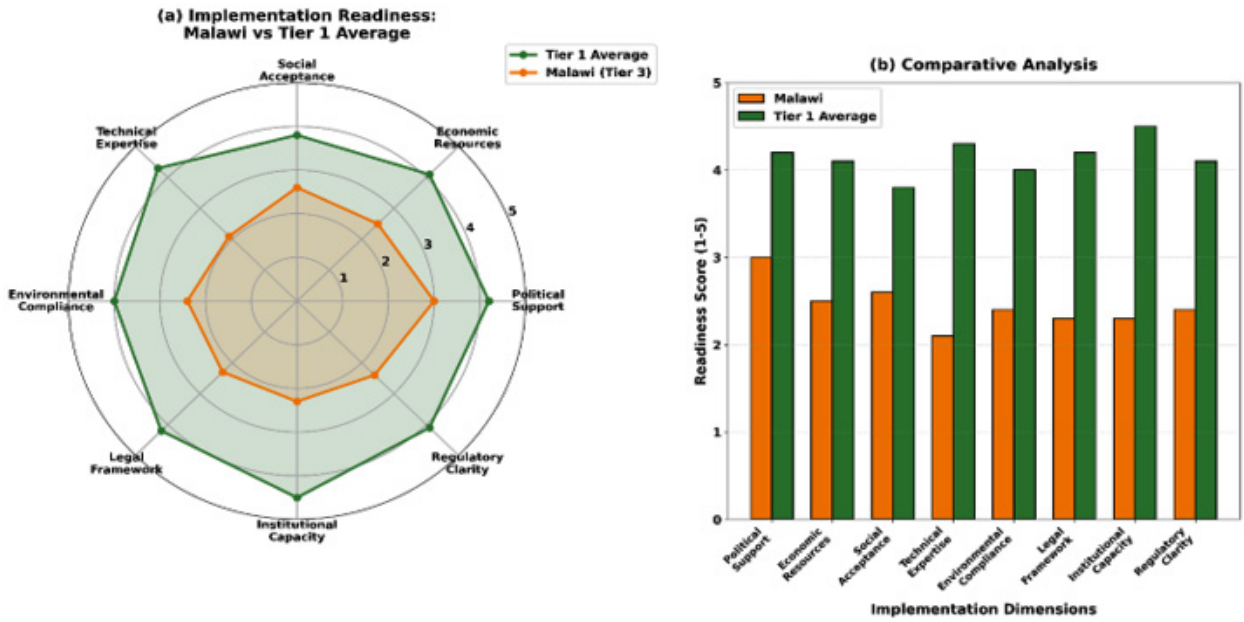

Figure 7: Multidimensional readiness assessment

4.0 Discussion

4.1 Interpretation of Findings

The analysis reveals that solar energy regulatory effectiveness in the SADC region is primarily constrained by institutional and technical factors rather than resource availability or economic capacity alone. The strong predictive power of political (β = 0.31) and technical (β = 0.28) variables confirms that governance quality and implementation capacity determine outcomes more than policy existence. This finding aligns with institutional theory (North, 2012) and challenges assumptions that financial resources constitute the primary barrier.

The four-tier country classification reflects not merely economic development but deliberate policy choices and institutional investments. Mauritius and South Africa achieved advanced status through sustained commitment to regulatory clarity, technical standards, and coordinated implementation. Conversely, resource-rich Angola remains in Tier 4, illustrating that natural endowments cannot substitute for institutional development.

The prominence of maintenance capacity (3.9% global weight) and technical standards (4.1%) as critical factors underscores a frequently overlooked dimension: post-installation sustainability. Many SADC countries have focused on initial deployment through donor-funded projects, neglecting long-term operational frameworks. This explains the proliferation of non-functional solar systems in schools and health

centres across the region (Cook & Elliott, 2022).

4.2 Malawi-Specific Implications

Malawi's position in Tier 3 (index = 2.3) reflects a transitional state — foundational policies exist, as evidenced by the National Energy Policy 2018 and the 2017 Renewable Energy Strategy, yet implementation mechanisms remain underdeveloped. The regression model indicates that Malawi's current performance aligns with its PESTEL profile, suggesting an accurate diagnosis. The regression model projects achievable improvements to 3.43 through coordinated interventions, representing a 48% enhancement in the composite index. It is important to note that this projection is derived entirely from the model's coefficients and assumes that the relationships identified in the cross-sectional data hold under real-world implementation conditions. As noted in the study limitations (Section 5.3), the model has not yet been validated longitudinally, and actual outcomes may differ based on implementation quality, resource constraints, and contextual factors not captured in the PESTEL framework. The projection should therefore be interpreted as an indicative target range rather than a deterministic forecast.

Three strategic priorities emerge for Malawi:

First, institutional capacity building through establishment of a dedicated Renewable Energy Unit (REU) within the Malawi Energy Regulatory Authority (MERA), mandated under the Energy Regulation Act (Cap. 73:01) and the National Energy Policy 2018 (GoM, 2018). The REU's specific functions should include: (i) licensing and certification of off-grid solar system installers and equipment suppliers; (ii) development and enforcement of technical standards for standalone solar systems in institutional settings (schools and health centres), aligned with IEC 62257 standards for rural electrification; (iii) monitoring and evaluation of solar deployment outcomes against national targets; and (iv) coordination of donor-funded projects to ensure alignment with national regulatory frameworks. The Malawi Renewable Energy Strategy 2017 provides the policy mandate for these functions, while the Electricity Act 2004 (as amended) provides the legal framework for licensing and enforcement. Establishing this unit with adequate technical staffing (minimum 5 qualified engineers) and operational budget would directly address the institutional capacity gap identified as the highest-priority intervention (AHP weight: 4.8%).

Second, the development of implementing regulations is necessary to translate policy ambitions into operational procedures, including licensing standards, quality certification, and maintenance protocols.

Third, pilot demonstration projects in schools and health centres to validate technical approaches and build stakeholder confidence.

The model suggests that incremental improvements across all PESTEL dimensions yield greater impact than focusing exclusively on high-weight factors. Simultaneously enhancing political (2.4 to 3.2), technical (2.1 to 3.0), and economic (2.5 to 3.1) factors produces synergistic effects.

4.3 Regional Cooperation Opportunities

The clustering analysis reveals natural partnerships: Tier 3 countries (Malawi, Zambia, Zimbabwe, and Lesotho) face similar challenges and could benefit from coordinated capacity building. Regional cooperation mechanisms could include (1) the SADC Solar Energy Technical Training Center for workforce development; (2) harmonised technical standards reducing equipment costs through economies of scale; (3) a regional financing facility leveraging collective bargaining power; and (4) a knowledge-sharing platform documenting best practices and lessons learned.

Tier 1 countries could provide technical assistance through South-South cooperation, with Mauritius offering regulatory expertise and South Africa contributing technical training infrastructure.

5.0 Conclusions and Recommendations

5.1 Key Findings

This study developed and validated a comprehensive 43-factor PESTEL framework for assessing solar energy regulatory effectiveness across 16 SADC countries. The predictive model (R^2 = 0.978, 5-fold cross-validation R^2 = 0.971) demonstrates that political and technical factors account for 59% of the model-explained variance in solar adoption success, substantially outweighing economic factors (17.8%). Institutional capacity (4.8% global weight), regulatory clarity (4.2%), and technical standards (4.1%) emerge as the highest priority interventions. Countries cluster into 4 distinct regulatory maturity tiers, with a widening gap between advanced performers (Tier 1: scores 3.7–4.2) and basic performers (Tier 4: scores 1.6–1.9), indicating divergent development trajectories rather than convergence.

5.2 Policy Implications

The findings challenge conventional emphasis on economic incentives, revealing that institutional development and technical capacity building yield higher marginal returns than financial subsidies alone. The validated framework enables evidence-based scenario planning, allowing countries to quantify expected outcomes from specific interventions. For Malawi, coordinated improvements in institutional capacity (current score 2.3), technical standards (2.1), and regulatory clarity (2.4) could advance the country from Tier 3 to Tier 2 within 3 to 5 years, accelerating off-grid deployment in schools and health centres. The projected improvement trajectory (2.32–3.43) requires investment likely to be lower than the economic costs of continued energy poverty in lost productivity and health impacts. Regional cooperation through knowledge sharing, technical assistance, and harmonised standards could accelerate progress for lower-tier countries while reducing implementation costs through economies of scale.

5.3 Study Limitations and Future Research Directions

Several limitations warrant consideration. First, PESTEL scoring involved subjective judgements despite systematic literature grounding. Future research could employ Delphi methods with regional expert panels for enhanced validity. Second, the cross-sectional design captures current status but not temporal dynamics. Longitudinal studies tracking policy evolution would elucidate causal

pathways. Third, the model aggregates diverse off-grid applications; system-specific analyses (schools vs. health centres) might reveal differential policy requirements. Fourth, stakeholder perspectives (particularly community beneficiaries) remain under-represented in the literature, suggesting a need for primary qualitative research. Fifth, the projected improvement trajectory for Malawi (from 2.32 to 3.43) is a model-based projection derived from cross-sectional regression coefficients. This projection assumes that the empirical relationships identified in the 16-country dataset will hold under dynamic real-world implementation conditions, an assumption that requires longitudinal validation. Real-world validation through Malawi's implementation of recommended interventions will provide critical evidence on the model's predictive utility and enable refinement of intervention strategies based on observed outcomes.

Authors Data Availability

Data will be made available upon reasonable request from the corresponding author.

Ethics Statement

This research involves no human subjects or animal experiments. All data used are from publicly available sources, including published literature (172 peer-reviewed studies), government policy documents, and international databases (World Bank, International Energy Agency, International Renewable Energy Agency, and SADC Secretariat). No ethical approval was required for this secondary data analysis. The study complies with all ethical guidelines for desk-based research and systematic literature reviews as outlined in the PRISMA 2020 statement.

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Author Contributions

CT – Conceptualisation, methodology, formal analysis, data curation, writing – original draft, writing – review and editing, and visualisations. HM – Validation, writing review and editing, and supervision. MC – methodology, validation, writing review and editing, and supervision. FT – Formal analysis, writing – review and editing, literature eligibility assessment, visualisations.

All authors have read and approved the final version of the manuscript. All authors agree to be accountable for all aspects of the work and to ensure that questions related to the accuracy or integrity of any part of it are appropriately investigated and resolved.

References

Adedoyin, F.F., Ozturk, I., Agboola, M.O., Agboola, P.O. and Bekun, F.V. 2021. The implications of renewable and non-renewable energy generation in Sub-Saharan Africa: The role of economic policy uncertainties. Energy Policy, Volume 150, 112115. https://doi.org/10.1016/j.enpol.2020.112115

Ahlborg, H. and Hammar, L. 2014. Drivers and barriers to rural electrification in Tanzania and Mozambique – Grid extension, off-grid, and renewable energy technologies. Renewable Energy, Volume 61, Pages 117–124. https://doi.org/10.1016/j.renene.2012.09.057

Baye, R.S., Ahenkan, A. and Darkwah, S. 2021. Renewable energy output in sub-Saharan Africa. Renewable Energy, Volume 174, Pages 705–714. https://doi.org/10.1016/j.renene.2021.01.144

Cervantes Barron, K., Hakker, M. E., & Cullen, J. M. 2022. Material Requirements for Future Low-Carbon Electricity Projections in Africa. Journal of Energy Strategy Reviews (Vol. 44). Elsevier Ltd. https://doi.org/10.1016/j.esr.2022.100890

Cook, T. and Elliott, D. 2022. Key Challenges for Solar Electrification of Rural Schools and Health Facilities in Sub-Saharan Africa. In: Sayigh, A. (eds) Sustainable Energy Development and Innovation. Innovative Renewable Energy. Springer, Cham. https://doi.org/10.1007/978-3-030-76221-6_86

Dauenhauer, P.M., Frame, D., Eales, A. et al. 2020. Sustainability evaluation of community-based, solar photovoltaic projects in Malawi. Energy, Sustainability and Society, 10, 12. https://doi.org/10.1186/s13705-020-0241-0

Fam, A., & Fam, S. 2024. Review of the US 2050 Long-Term Strategy to Reach Net Zero Carbon Emissions. Journal of Energy Reports (Vol. 12, pp. 845–860). Elsevier Ltd. https://doi.org/10.1016/j.egyr.2024.06.031

Government of Malawi. 2018. Malawi National Energy Policy. Ministry of Natural Resources, Energy and Mining, Lilongwe. URL: npc.mw/wp-content/uploads/2020/07/National-Energy-Policy-2018.pdf

International Energy Agency. 2023. Africa Energy Outlook 2023. World Energy Outlook Special Report, Pages 1–180. URL: https://www.iea.org/reports/africa-energy-outlook-2023

International Renewable Energy Agency. 2022. Renewable Energy Statistics 2022: Southern Africa Regional Analysis. IRENA Statistical Review, 12:45–59. URL: https://www.irena.org/publications/2022/Jul/Renewable-Energy-Statistics-2022

IRENA. 2024. Sub-Saharan Africa: Policies and Finance for Renewable Energy Deployment. International Renewable Energy Agency, Abu Dhabi. afsiasolar.com/wp-content/uploads/2024/10/IRENA_SS_Africa_policies_finance_RE_2024.pdf

Moyo, B. and Oree, V. 2024. Renewable Energy Policies in Sub-Saharan Africa: An Analysis of Strategies, Challenges, and Pathways to Sustainable Development. 1st International Conference on Smart Energy Systems and Artificial Intelligence (SESAI), Mauritius, 2024, pp. 1–6. doi:10.1109/SESAI61023.2024.10599404

North, D.C. 2012. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511808678

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., et al. 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372: n71. https://doi.org/10.1136/bmj.n71

Saaty, T.L. 2008. Decision-making with the analytic hierarchy process. International Journal of Services Sciences, Vol. 1, No. 1, pp. 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

SADC. 2016. Renewable Energy and Energy Efficiency Action Plan 2016–2030. URL: https://www.sacreee.org/sites/default/files/2023-11/REEESAP_Report_2016-2030.pdf

World Bank Group. 2023. Data360. URL: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?end=2023&locations=CD&start=2000

World Bank Group. 2024. Energy Access in Sub-Saharan Africa: Progress and Challenges. URL: https://openknowledge.worldbank.org/handle/10986/41234

World Bank 2024. Malawi Electricity Access Project (P164331) Implementation Support Mission Aide-Mémoire. World Bank. Accessed on March 1, 2026. Available on: https://documents1.worldbank.org/curated/en/099021025103520011/pdf/P164331-7cfb844e-b560-4f81-8054-8c74d7dc8419.pdf

Zalengera, C., Blanchard, R.E., Eames, P.C., Juma, A.M., Chitawo, M.L. and Gondwe, K.T. 2014. Overview of the Malawi energy situation and a PESTLE analysis for sustainable development of renewable energy. Renewable and Sustainable Energy Reviews, Vol. 38: 335–347. https://doi.org/10.1016/j.rser.2014.05.050