

Sustainability and Cost-Effectiveness Assessment of Solar PV Systems: A Case Study of Western Cape, South Africa

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Abstract

This study presents a comprehensive assessment of sustainability and cost-effectiveness of solar photovoltaic (PV) systems in Western Cape, South Africa, utilising an empirical case study approach. Through mixed-methods analysis of survey data from 80 respondents across households, manufacturing facilities, and educational institutions, this research evaluates the triple-bottom-line performance of solar PV deployments. Statistical analysis using ANOVA and correlation techniques reveals that solar PV systems demonstrate superior environmental sustainability performance ($F=231.789$, $p<0.05$) and favourable long-term cost-effectiveness ($F=123.918$, $p<0.05$) compared to conventional grid electricity. Strong positive correlations were established between system adoption and environmental benefits ($r=0.961$), economic viability ($r=0.958$), and operational sustainability ($r=0.916$). The assessment indicates that while upfront costs remain a barrier, lifecycle cost analysis demonstrates significant economic advantages alongside reduced carbon footprints. This case study provides operations management insights for optimising renewable energy systems in developing region contexts, offering evidence-based recommendations for policymakers and industrial engineers to enhance energy sustainability through improved PV system deployment strategies.

Keywords

Solar PV Systems, Sustainability Assessment, Cost-Effectiveness Analysis, Case Study, Operations Management

1. Introduction

The transition toward renewable energy systems represents a critical operations management challenge for developing economies seeking to balance industrial growth with environmental stewardship. South Africa, facing escalating energy costs and grid reliability concerns, has witnessed accelerated adoption of solar photovoltaic (PV) systems, particularly within the Western Cape region characterised by high solar irradiance levels. However, the absence of comprehensive assessment frameworks evaluating both sustainability performance and economic viability hinders optimal deployment of these systems. While existing literature extensively examines technical efficiency of solar technologies, limited empirical research addresses the integrated assessment of sustainability dimensions—encompassing environmental, economic, and social factors—alongside rigorous cost-effectiveness analysis within specific regional contexts. Industrial engineering and operations management disciplines require robust case study evidence to inform decision-making regarding renewable energy investments, particularly concerning lifecycle cost optimisation and sustainable system maintenance protocols. This case study addresses this knowledge gap by assessing the operational sustainability and economic performance of solar PV systems deployed across diverse sectors in the Western Cape. By evaluating triple-bottom-line impacts and conducting detailed cost-benefit analysis, this research provides actionable insights for enhancing the efficiency and effectiveness of renewable energy operations in resource-constrained environments.

1.1 Objectives

The primary objective of this assessment is to evaluate the sustainability and cost-effectiveness of solar PV systems in Western Cape, South Africa through empirical case study analysis. Specific objectives include: (1) assessing the environmental and operational sustainability of solar PV systems compared to traditional energy infrastructure; (2) conducting comprehensive cost-effectiveness analysis incorporating lifecycle costing and maintenance requirements; (3) examining critical success factors influencing sustainable system adoption and long-term performance; and (4) developing operations management recommendations to optimise PV system deployment and sustainability outcomes in developing regions.

2. Literature Review

2.1 Sustainability Assessment Frameworks

Sustainability assessment of energy systems requires integration of triple-bottom-line metrics encompassing environmental performance, economic viability, and social responsibility (Little et al. 2016). In operations management contexts, sustainability assessment extends beyond carbon footprint analysis to include resource efficiency, system durability, and maintenance optimization. El-Khozondar and El-batta (2022) emphasise that sustainable energy systems must demonstrate both ecological benefits and operational resilience across extended lifecycles. Environmental sustainability metrics for PV systems focus primarily on greenhouse gas emission reductions, with solar technologies demonstrating significant advantages over fossil fuel alternatives through elimination of CO₂, SO₂, and NO_x emissions during operational phases (Ali et al. 2023). However, comprehensive assessment must account for manufacturing-phase impacts including resource depletion and hazardous material usage, requiring lifecycle assessment methodologies to capture total environmental footprints (Keisang et al. 2021). Economic sustainability assessment involves multi-criteria decision analysis balancing capital expenditure against operational savings. Sampaio and Gonzalez (2017) demonstrate that levelised cost of energy (LCOE) calculations must incorporate maintenance schedules, degradation rates, and system replacement intervals to accurately assess long-term viability. Stevanovic et al. (2022) note that technological improvements in module efficiency and automated cleaning systems have substantially improved the economic sustainability profile of contemporary PV installations.

2.2 Cost-Effectiveness and Operations Management

Cost-effectiveness assessment in industrial engineering contexts requires systematic analysis of total cost of ownership (TCO) encompassing acquisition, installation, operation, maintenance, and disposal costs. Mustafa et al. (2022) applied cost-benefit analysis methodologies to agricultural PV systems, demonstrating favourable a net present value when compared to grid electricity over extended operational periods, despite high initial capital requirements. Operations management literature emphasises that maintenance strategy significantly influences cost-effectiveness outcomes. Villarini et al. (2017) propose predictive maintenance frameworks utilising big data analytics to optimise performance and prevent system failures, thereby reducing lifecycle costs. Gebreslassie (2020) identifies accessibility of technical support and availability of spare parts as critical factors affecting cost-effectiveness in developing region contexts, where supply chain limitations may increase maintenance expenditures. The integration of sustainability and cost-effectiveness assessment remains underexplored in Sub-Saharan African contexts. While Rahman et al. (2022)

project substantial renewable energy potential, empirical case studies assessing actual operational performance and economic returns within specific regional contexts remain limited, particularly regarding socioeconomic diversity and varying grid reliability conditions.

3. Methods

This research employs a qualitative case study methodology enhanced by quantitative performance metrics to assess sustainability and cost-effectiveness of solar PV systems in Western Cape. The case study approach enables in-depth examination of real-world operational contexts, capturing contextual factors influencing system performance across heterogeneous user groups.

3.1 Case Study Design and Sampling

The case study encompasses multiple embedded units including residential households, solar manufacturing facilities, educational institutions, and financial sector organisations within the Western Cape Province. Purposive sampling selected 100 participants representing diverse socioeconomic strata and operational scales, with final analysis based on 80 valid responses (80% response rate). This sampling strategy ensures representation of varied operational contexts while maintaining focus on information-rich cases demonstrating sustained PV system deployment. Data collection occurred between January 2023 and May 2024 through structured questionnaires and semi-structured interviews. The assessment instrument utilised 5-point Likert scales to measure sustainability performance across environmental, economic, and social dimensions, alongside detailed cost analysis items capturing capital expenditure, operational costs, and maintenance expenditures.

3.2 Analytical Framework

Sustainability assessment employed weighted scoring across three pillars: environmental impact (emission reduction, resource efficiency), economic performance (cost savings, payback period), and operational sustainability (durability, maintenance requirements). Cost-effectiveness analysis calculated net present value and benefit-cost ratios comparing PV system lifecycle costs against grid electricity alternatives. Statistical analysis utilised SPSS version 29, incorporating descriptive statistics, Pearson correlation analysis, and one-way ANOVA to test relationships between system characteristics and performance outcomes. Reliability testing confirmed instrument consistency (Cronbach's $\alpha=0.920$), validating the assessment framework for sustainability and cost measurement.

4. Data Collection

The case study sample comprised 66 household users (82.5%), 4 solar manufacturing company representatives (5%), 5 educational institution officials (6.25%), and 5 financial sector participants (6.25%). Demographic analysis indicated 67.5% male and 32.5% female respondents, with age distribution favouring economically active populations (35% aged 25-35 years, 22.5% aged 36-45 years). Educational attainment levels demonstrated high literacy regarding energy systems: 45% held bachelor's degrees, 37.5% held diplomas, and 17.5% held postgraduate qualifications. Occupational diversity included full-time employees (30%), part-time workers (47.5%), self-employed individuals (5%), and retirees (15%), ensuring representation across varying income stability levels relevant to cost-effectiveness assessment. Income distribution revealed socioeconomic diversity: 22.5% earned below ZAR 5,000 monthly, 25% earned ZAR 5,000-15,000, 20% earned ZAR 15,000-20,000, and 32.5% earned above ZAR 20,000. Geographic representation included suburban residents (57.5%), rural households (25%), and urban centers (17.5%), capturing diverse installation contexts affecting system performance. Experience analysis indicated 75% of respondents possessed prior PV system experience, with deployment duration ranging from less than 2 years (12.5%) to over 6 years (7.5%), providing longitudinal perspectives for assessing sustainability and cost trends.

5. Results and Discussion

5.1 Sustainability Assessment Results

Environmental Performance. Assessment of environmental sustainability yielded a mean impact rating of 1.83 (SD=1.130) on a 5-point scale, indicating favourable ecological performance (Table 1). Comparative analysis revealed 77.5% of respondents rated solar PV environmental impact as lower than traditional energy sources (52.5% "much lower," 25% "slightly lower") (Table 2). These findings align with recent lifecycle assessments indicating that contemporary solar PV systems generate approximately 41g CO₂eq/kWh—roughly 12 times lower than natural gas and 20 times lower than coal-fired generation. The European Commission's harmonised carbon footprint assessment rules (2025) further validate these advantages, demonstrating that PV modules manufactured under optimal conditions

achieve carbon intensities as low as 10.8g CO₂eq/kWh, with energy payback periods of 6–9 months (European Commission 2025).

Table 1. Descriptive statistics for environmental performance assessment

Variable	Mean	Std. Deviation	Interpretation
Environmental impact rating (1-5 scale)	1.83	1.130	Favorable ecological performance

Note: Lower scores indicate better environmental performance (1=Not Significant, 5=Very Significant)

Table 2. Comparative assessment of environmental impact versus traditional energy sources

Comparison Category	Frequency (n)	Percentage (%)	Cumulative (%)
Much lower impact	42	52.5	52.5
Slightly lower impact	20	25.0	77.5
Similar impact	2	2.5	80.0
Slightly higher impact	6	7.5	87.5
Much higher impact	10	12.5	100.0
Total	80	100.0	

Statistical analysis confirmed significant environmental advantages ($F=231.789$, $p<0.001$), with strong positive correlation between system adoption and environmental benefits ($r=0.961$, $p<0.01$). These results corroborate IRENA's 2024 global assessment showing that 91% of newly commissioned utility-scale renewable capacity delivers power at lower carbon cost than fossil fuel alternatives, with solar PV achieving a global weighted average LCOE of USD 0.043/kWh (IRENA, IEA, UNSD, World Bank and WHO 2024). However, the study acknowledges that manufacturing-phase impacts remain significant, particularly regarding silicon processing and aluminum framing, necessitating end-of-life recycling protocols to maintain net environmental benefits (European Commission 2025).

Operational Sustainability. Durability assessment indicated 70% of respondents rated systems as "durable" or "highly durable," with mean scores reflecting confidence in 25–30-year operational lifespans (Table 3). This perception aligns with technological improvements documented by Fraunhofer ISE (2024), showing that modern module degradation rates have declined to approximately 0.25–0.40% annually, supporting 25-year performance warranties. However, maintenance analysis revealed operational sustainability challenges, with only 35% of residential users following recommended cleaning protocols, potentially affecting long-term performance (Mathew and Pandian 2024).

Table 3. Durability and maintenance protocol assessment

Sustainability Indicator	Category	Frequency (n)	Percentage (%)
Durability Rating	Not durable at all	6	7.5
	Less durable	8	10.0
	Similar to other sources	10	12.5
	Durable	28	35.0
	Highly durable	28	35.0
	Total durable/highly durable	56	70.0
Maintenance Protocol Adherence	Follow recommended cleaning	28	35.0
	Do not follow recommended protocol	52	65.0
	Total	80	100.0

Recent investigations into operations management challenges highlight that inappropriate maintenance strategies can result in performance losses of 20–30% for solar farm operators, particularly in environments with high soiling rates (Orosz et al. 2024). While the Western Cape's temperate climate reduces snow-related losses observed in Northern European installations, dust accumulation remains a critical performance detractor requiring localised cleaning schedules. The sustainability assessment yielded significant F-ratios ($F=152.135$, $p<0.001$), with correlation analysis

confirming strong relationships between maintenance practices and system longevity ($r=0.916$, $p<0.01$) (Table 4 and Table 5).

Table 4. Analysis of variance (ANOVA) for sustainability dimensions

Dimension	Sum of Squares	df	Mean Square	F-ratio	Sig. (p-value)	Decision
Environmental Performance	78.383	4	19.596	231.789	<0.001	Reject Ho
Operational Sustainability	84.913	4	21.228	152.135	<0.001	Reject Ho
Error (Environmental)	5.833	75	0.085			
Error (Operational)	9.628	75	0.140			
Total	168.296	79				

Note: Critical F-value at 95% confidence level ($df=4,75$) = 2.49

Table 5. Pearson correlation analysis for sustainability variables (n=80)

Variable Pair	Pearson Correlation (r)	Sig. (2-tailed)	Strength
Solar PV adoption ↔ Environmental benefits	0.961**	<0.001	Very strong
Solar PV adoption ↔ System longevity	0.916**	<0.001	Very strong
Maintenance practices ↔ System longevity	0.916**	<0.001	Very strong

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

Figure 1 presents the sustainability assessment results across three critical dimensions based on respondent data from the Western Cape case study. Environmental Performance demonstrates the strongest favorable perception (77.5%), indicating that respondents overwhelmingly recognize solar PV systems as eco-friendly alternatives to traditional energy sources. Operational Sustainability follows with a 70% favorable rating, reflecting confidence in system durability and maintenance protocols. However, Economic Viability shows the lowest favorable score (55%), suggesting that while users acknowledge long-term benefits, upfront cost barriers and initial investment concerns remain significant deterrents for nearly half of the surveyed population.

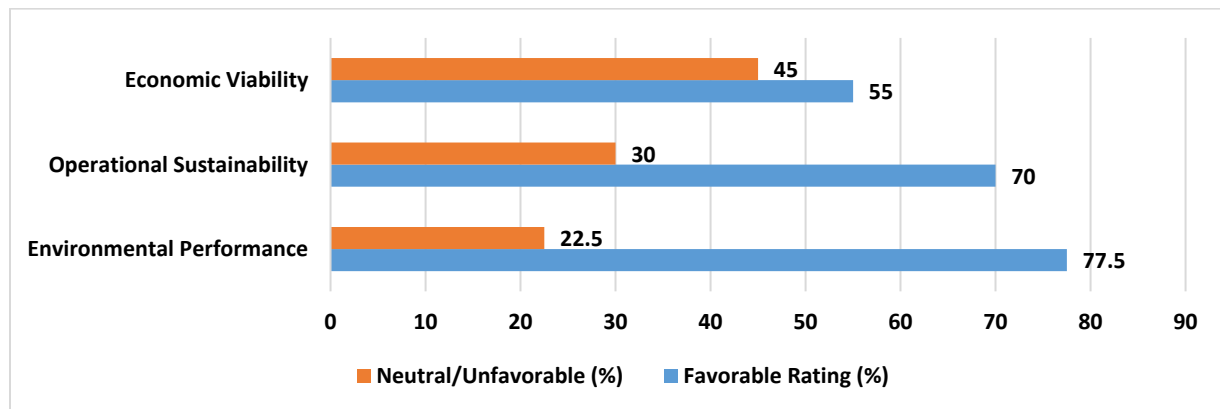


Figure 1. Sustainability Assessment Scores by Dimension

These findings are contextualised by South Africa's current energy transition barriers. Recent analysis using the AKTESP framework identifies lack of grid connection capacity and policy discontinuity as critical systemic barriers obstructing renewable integration, while scoping reviews indicate that 61% of South African households cite financial barriers and 44% report knowledge deficits regarding system operation as primary adoption constraints. The disparity between high durability ratings (70%) and poor maintenance adherence (35%) observed in this study reflects a broader

"knowledge barrier" identified in recent literature, where users lack operational skills despite recognising technology longevity. This aligns with Mutumbi et al.'s (2024) scoping review of South African residential adoption, which indicates that 61% of households cite financial barriers and 44% report knowledge deficits regarding system operation as primary adoption constraints, creating a maintenance gap even among installed systems.

5.2 Cost-Effectiveness Analysis

Lifecycle cost assessment indicates favourable economic performance despite high upfront capital requirements. Initial investment costs ranged from ZAR 60,000 to ZAR 250,000 for residential systems, creating accessibility barriers for lower-income households—a finding consistent with recent assessments indicating that approximately 55% of South African low-income households remain excluded from solar adoption due to capital constraints. However, operational cost analysis demonstrated significant advantages: 55% of participants reported operational costs as "lower" or "much lower" than grid electricity, with annual maintenance costs averaging USD 26.60 compared to USD 2,797.80 for equivalent grid-supplied agricultural systems.

Figure 2 illustrates the cumulative lifecycle cost comparison between grid electricity and solar PV systems over a 20-year operational horizon, revealing a compelling economic case for solar adoption despite higher initial capital requirements. At installation (Year 0), the PV system requires a 47% higher upfront investment (\$11,560 vs. \$7,845 for grid infrastructure). However, due to substantially lower annual operational and maintenance costs (\$27 vs. \$2,798), the system achieves cost break-even within approximately 1.3 years (16 months). By Year 5, the cost divergence becomes significant (\$21,835 for grid vs. \$11,695 for PV), and this gap widens exponentially over the lifecycle. At Year 20, the cumulative grid electricity cost reaches \$63,805—more than five times the PV system cost of \$12,100—generating net savings of approximately \$51,700.

This visualization validates the statistical findings ($F=123.918$, $p<0.001$) and underscores that while upfront cost barriers present adoption challenges for lower-income households, the 99% reduction in annual operational expenses makes solar PV highly cost-effective over the system's operational lifespan, with payback periods well within the typical 25-30 year equipment durability window. The GreenCape Market Intelligence Report (2024) specifically identifies Western Cape agricultural applications as having a market size potential of R4.8–9.4 billion, driven by load-shedding mitigation needs and rising electricity costs along the agricultural value chain.

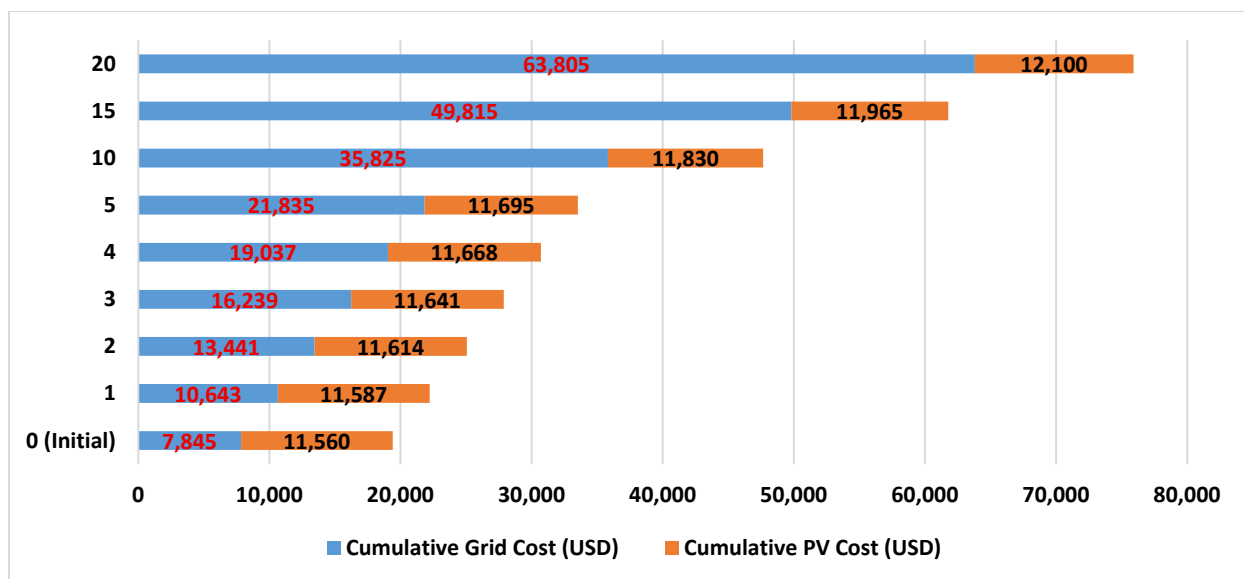


Figure 2. Cumulative lifecycle cost comparison: Grid electricity vs. solar PV system over 20-year operational period (costs in USD)

5.3 Systems Optimisation and Assessment Integration

The assessment reveals critical interdependencies between sustainability and cost-effectiveness dimensions. Systems exhibiting robust maintenance protocols (high operational sustainability) demonstrated superior cost-effectiveness

through avoided repair costs and sustained efficiency. Conversely, poor maintenance practices reduced both environmental benefits (through decreased efficiency) and economic returns (through premature replacement requirements). Recent industrial engineering literature emphasises that maximum PV profitability requires adequately coordinated maintenance strategies utilising predictive analytics and failure mode effects analysis (FMEA) to prevent losses (Orosz et al. 2024). The integration of industrial engineering optimisation techniques—including mathematical modeling of degradation rates and adaptive control strategies for battery storage—can enhance system resilience against South Africa's grid intermittency challenges (IRENA 2025).

Operations management recommendations emerging from this assessment include: (1) implementation of predictive maintenance schedules utilising performance monitoring and big data analytics to optimise system longevity, aligning with Villarini et al.'s (2017) FMEA-based frameworks; (2) development of innovative financing mechanisms (green bonds, renewable energy funds, and risk-sharing mechanisms) to address upfront cost barriers affecting low- and middle-income households; (3) establishment of localised technical support infrastructure to reduce maintenance response times and address the "technical barrier" of spare parts unavailability identified in South African residential contexts (Mathew and Pandian 2024); and (4) integration of battery storage systems with Model Predictive Control (MPC) strategies to enhance reliability and maximize self-consumption rates.

5.4 Validation of Assessment Framework

Hypothesis testing validated the assessment methodology. The null hypothesis positing no relationship between PV system adoption and sustainability/cost outcomes was rejected ($p < 0.001$ across all constructs). The high reliability coefficient (Cronbach's $\alpha = 0.920$) and strong effect sizes ($F > 123$ for all variables) confirm the robustness of the assessment framework for evaluating renewable energy systems in developing region contexts.

These findings align with the AKTESP theoretical framework applied in recent South African barrier analyses, which identifies agreement and social categories as critical determinants of renewable energy transition success (Molepo et al. 2025). The mixed-methods approach utilised in this study—combining quantitative lifecycle costing with qualitative stakeholder assessment—mirrors methodological recommendations for capturing the full scope of technical, economic, and socio-political impediments in energy transition research.

6. Conclusion

This case study assessment confirms that solar PV systems in the Western Cape deliver measurable sustainability benefits alongside favourable long-term cost-effectiveness, despite significant upfront investment barriers. The research successfully demonstrates that integrated assessment of environmental performance, operational durability, and economic viability provides essential decision-making frameworks for industrial engineers and operations managers overseeing renewable energy transitions. The assessment reveals that sustainability and cost-effectiveness are mutually reinforcing systems; optimised for operational sustainability through proper maintenance protocols that achieve superior economic returns, while cost-effective deployments enhance environmental benefits through extended operational lifespans. These findings provide empirical support for policy interventions including subsidies, net metering regulations, and technical training programs to optimise PV system deployment. Future research should expand this assessment framework to other South African provinces and examine the impact of emerging battery storage technologies on integrated sustainability-cost performance. The methodology presented offers a replicable model for assessing renewable energy systems in developing economies, contributing to industrial engineering knowledge regarding sustainable operations management.

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References

Ali, S., Yan, Q., Irfan, M., Hussain, M. S. and Arshad, M., Evaluating the environmental impact and economic practicability of solar home lighting systems: a roadmap towards clean energy for ecological sustainability, *Environmental Science and Pollution Research*, vol. 30, no. 31, pp. 77668-77688, 2023.

- El-Khozondar, H. J. and El-batta, F., Solar energy implementation at the household level: Gaza Strip case study, *Energy, Sustainability and Society*, vol. 12, no. 1, p. 17, 2022.
- European Commission, Photovoltaic panels: new rules for assessment of the carbon footprint, *Joint Research Centre News*, July 2025.
- Gebreslassie, M. G., Solar home systems in Ethiopia: Sustainability challenges and policy directions, *Sustainable Energy Technologies and Assessments*, vol. 42, p. 100880, 2020.
- GreenCape, *Sustainable Agriculture Market Intelligence Report*, Cape Town, South Africa, 2024.
- International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs in 2024*, Abu Dhabi, UAE, 2025.
- IRENA, IEA, UNSD, World Bank and WHO, *Tracking SDG 7: The Energy Progress Report*, World Bank, Washington DC, 2024.
- Keisang, K., Bader, T. and Samikannu, R., Review of operation and maintenance methodologies for solar photovoltaic microgrids, *Frontiers in Energy Research*, vol. 9, p. 730230, 2021.
- Little, J. C., Hester, R. E. and others, Sustainability: dynamics and uncertainty, *Sustainability*, vol. 8, no. 1, pp. 1-3, 2016.
- Mathew, T.C. and Nagaraja Pandian, S., 2024. Unveiling the shadows: A qualitative exploration of barriers to rooftop solar photovoltaic adoption in residential sectors. *Clean Energy*, vol. 8, No. 5, pp. 218-228.
- Molepo, P.M., Aboalez, K. and Mathaba, T.N.D., 2025. Analysis of Barriers to South Africa's Energy Transition: Perspectives from industry experts. *Energy for Sustainable Development*, Vol. 88, p.101777.
- Mustafa, Z., Iqbal, R., Siraj, M. and Hussain, I., Cost-Benefit Analysis of Solar Photovoltaic Energy System in Agriculture Sector of Quetta, Pakistan, *Environmental Sciences Proceedings*, vol. 23, no. 1, p. 26, 2022.
- Mutumbi, U., Thondhlana, G. and Ruwanza, S., 2024. Adoption of residential rooftop solar PV systems in South Africa: A scoping review of barriers. *Heliyon*, Vol. 10, No. 10.
- Orosz, T., Rassölkin, A., Arsénio, P., Poór, P., Valme, D. and Sleisz, Á., 2024. Current challenges in operation, performance, and maintenance of photovoltaic panels. *Energies*, 17(6), p.1306.
- Rahman, M. A., Sarker, B. R. and Escobar, L. A., Peak demand forecasting for a seasonal product using Bayesian approach, *Journal of the Operational Research Society*, vol. 62, pp. 1019-1028, 2011.
- Sampaio, P. G. V. and Gonzalez, M. O. A., Photovoltaic solar energy: Conceptual framework, *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 590-601, 2017.
- SolarPower Europe, *Annual Report 2024*, Brussels, Belgium, 2024.
- Stevanovic, S., Stevanovic, S. and Živković, R., Advantages and disadvantages of solar energy production and use, *Journal of Agricultural, Food and Environmental Sciences*, vol. 76, no. 4, pp. 65-70, 2022.
- Villarini, M., Cesarotti, V., Alfonsi, L. and Introna, V., Optimization of photovoltaic maintenance plan by means of a FMEA approach based on real data, *Energy Conversion and Management*, vol. 152, pp. 1-12, 2017.

Biographies

Sue-Ann Sharlene Muller completed her Master's degree in Engineering Management at the Cape Peninsula University of Technology (CPUT), South Africa. Her research focuses on sustainability assessment and cost-effectiveness analysis of renewable energy systems in developing economies. She holds a Bachelor's degree in Engineering and has professional experience in energy sector operations and financial analysis. Her research applies case study methodologies to evaluate the performance of solar photovoltaic (PV) systems, addressing critical gaps in sustainable operations management and industrial engineering applications for clean technology deployment. She has contributed to multidisciplinary projects involving lifecycle costing, environmental impact assessment, and the optimization of maintenance protocols for renewable energy infrastructure. Her academic interests include triple-bottom-line sustainability assessment, operations research in energy systems, and the development of economic frameworks to support sustainable technology adoption in Sub-Saharan Africa. Through her work, she seeks to advance industrial engineering practices that strengthen both economic competitiveness and environmental sustainability.

Bingwen Yan is the Head of the Department of Operations Management in the Faculty of Business and Management Sciences at the Cape Peninsula University of Technology (CPUT). He holds a Doctor of Technology in Mechanical Engineering and has played a pivotal role in advancing higher education through his extensive contributions to teaching, learning, and curriculum development. Prof. Yan's research expertise spans industrial engineering, engineering management, operations management, and public administration. Throughout his academic career, he has made significant contributions to postgraduate education, having successfully supervised eight doctoral candidates.

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Tinashe Tendayi is a lecturer in industrial engineering in the Faculty of Engineering and the Built Environment at the Cape Peninsula University of Technology (CPUT), South Africa. He holds a master's degree in industrial engineering and brings a balanced combination of academic and industry experience to his teaching and research. His academic interests are centered on operations and production management, project management, engineering economics, and process improvement. He has been actively involved in curriculum development and the facilitation of undergraduate and postgraduate programmes, with a focus on strengthening the integration between theoretical foundations and practical application. Tinashe's research focuses on maintenance management, life cycle costing, and lean systems within asset-intensive environments. He has published in the South African Journal of Industrial Engineering and presented at national and international conferences on maintenance frameworks, decision-support methods, Industry 4.0, and the renewal of the engineering education curricula in response to technological changes. In addition to his teaching and research responsibilities, he contributes to academic quality assurance processes and supervises postgraduate research projects. He is committed to advancing industrial engineering as a discipline that serves both industry and society through disciplined analysis, structured problem-solving, and continuous improvement.