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Theme: From Commitment to Action: Accelerating Integrated Resilience Solutions for Vision 2030 and the SDGs

Risk-Based Energy Auditing Using Failure Mode and Effects Analysis (FMEA) for Industrial Energy Efficiency Optimization in Southern Africa

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ABSTRACT

Southern Africa's industrial sector faces compounding energy efficiency crisis driven by over-reliance on drought-exposed hydropower, ageing infrastructure, and escalating electricity deficits, yet structured, risk-informed approaches to industrial energy efficiency remain underdeveloped in regional practice. This paper proposes an integrated methodology combining Risk-Based Energy Auditing with Failure Mode and Effects Analysis (FMEA), treating energy inefficiencies as failure modes with quantifiable Risk Priority Numbers (RPNs) derived from Severity, Occurrence, and Detection scores. A conceptual research design grounded in a structured literature review is used to develop a calibrated, anchor-described scoring rubric for the energy audit context, supported by an $S \geq 9$ severity-override rule and a multi-scorer team protocol to mitigate the well-documented subjectivity and masking limitations of multiplicative RPN scoring. Applied to four energy systems universally present in regional facilities, the framework identifies three Critical-priority failure modes: compressed air leakages (RPN=512), poor steam-line insulation (RPN=504), and inefficient boiler combustion (RPN=432). A seven-step adoption framework, differentiated across Zambia, Zimbabwe, and South Africa, and an illustrative cost-benefit analysis indicate that FMEA-prioritised interventions can reduce facility energy costs by 20–35 percent with payback periods largely under twelve months. The paper offers practical, financially credible guidance for industry, utilities, and policymakers, aligned with the SADC Energy Efficiency Strategy, national energy policies, Zambia's Vision 2030, and the Sustainable Development Goals, moving the sub-region from policy commitment to measurable action.

Keywords: Energy Efficiency; Failure Mode and Effects Analysis (FMEA); Risk-Based Energy Auditing; Southern Africa; Industrial Resilience

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1. INTRODUCTION

Energy efficiency is among the most cost-effective pathways to sustainable industrial development. Globally, the industrial sector accounts for approximately 35 percent of total final energy consumption, with electric motor systems alone responsible for roughly 45 percent of industrial electricity use [1]. In Southern Africa this challenge is amplified by a structural over-reliance on hydropower, which supplies 82 to 95 percent of Zambia's electricity [2] and nearly 60 percent of Zimbabwe's [3], and which is acutely exposed to climate-induced hydrological variability.

The consequences have been severe. Zambia experienced load shedding of up to 18 hours per day during the 2023–2024 drought season, with the Energy Regulation Board (ERB) reporting a generation deficit exceeding 700 megawatts (MW) [4]. Similar shortfalls at Kariba affected Zimbabwe, while South Africa's Eskom crisis has been estimated to cost the economy on the order of USD 34 billion annually in lost industrial productivity. These supply constraints have compelled facilities to rely on costly diesel backup generation, sharply raising operational costs across the sub-region.

Against this backdrop, industrial energy efficiency is not merely an environmental imperative but a critical operational-resilience strategy that speaks directly to the ZAWAFE 2026 theme, "From Commitment to Action." The SADC Energy Efficiency Strategy (2016–2030) identifies the industrial sector as a priority area, calling for structured audit tools and systematic benchmarking [5], and Zambia's Energy Efficiency Strategy and Action Plan (2022) similarly prioritises industrial audit methodologies [2]. Despite this policy momentum, structured, risk-informed auditing remains limited across Southern African industry, and existing practice tends to be ad hoc and insufficiently systematic in prioritising interventions [6].

Failure Mode and Effects Analysis (FMEA) is a well-established risk-engineering methodology used across manufacturing, process engineering, and healthcare [7]. It identifies failure modes, assesses consequences, and prioritises corrective actions through Risk Priority Numbers (RPNs), computed as the product of Severity (S), Occurrence (O), and Detection (D) scores. A recognised limitation of the multiplicative RPN model is that different S, O, and D combinations can produce identical RPNs while representing substantially different risk profiles [8], and the subjectivity of RPN scoring in the absence of standardised rubrics is well documented [9]. This paper addresses both concerns directly: by developing a calibrated, anchor-described scoring rubric for the energy-audit context; by adopting an $S \geq 9$ automatic-escalation rule that preserves severity weighting regardless of RPN arithmetic; and by prescribing a multi-scorer team protocol that reduces individual rater bias.

This study pursues four objectives: **(i)** to develop a standardised, context-calibrated RPN scoring rubric for industrial energy auditing in Southern Africa; **(ii)** to construct a ranked energy-inefficiency risk register for energy systems common to regional facilities; **(iii)** to design a practical, country-differentiated adoption framework; and **(iv)** to demonstrate, through an illustrative cost-benefit analysis, the financial credibility of risk-prioritised interventions. The paper is explicitly conceptual; its scope, limitations, and a roadmap for empirical validation are set out in Sections 2 and 4.

2. MATERIALS AND METHODS

This paper adopts a conceptual research design grounded in a structured literature review. Conceptual frameworks are a recognised precursor to empirical validation, establishing the theoretical foundation on which pilot studies are built [10]. The design is conceptual by intent rather than by omission: it synthesises dispersed evidence into a single, operational auditing instrument that can subsequently be tested. The limitations of this approach, and the specific validation activities required to overcome them, are addressed in Section 4. Three phases structure the methodology.

2.1 Literature Review and Source Selection

A structured search was conducted across ScienceDirect and ResearchGate, supplemented by official repositories of the International Energy Agency (IEA), SADC, the governments of Zambia and Zimbabwe, and the Southern African Centre for Renewable Energy and Energy Efficiency (SACREEE). Search terms combined “FMEA energy audit,” “industrial energy efficiency Southern Africa,” “risk priority number subjectivity,” “compressed air energy loss,” “industrial energy Zambia,” and “SADC energy efficiency.”

Explicit inclusion criteria were applied: **(a)** relevance to FMEA/RPN methodology or to industrial energy efficiency in sub-Saharan Africa; **(b)** publication between 2006 and 2024; and **(c)** source credibility, defined as peer-reviewed literature, or grey literature from recognised regional institutions (SACREEE, ERB, ZERA, SANEDI) where peer-reviewed equivalents were unavailable. Exclusion criteria removed sources that were non-industrial in focus, lacked methodological transparency, or duplicated findings already captured. Grey literature was deliberately retained to reflect the limited academic publication base on Southern African industrial energy efficiency; this reliance is itself acknowledged as a constraint. Initial screening returned 87 sources, of which 31 were retained after relevance and quality assessment, spanning FMEA methodology and RPN limitations, industrial audit practice in sub-Saharan Africa, energy efficiency challenges in Zambia, Zimbabwe, and South Africa, and cost-benefit evidence for efficiency interventions.

2.2 Development of the Energy FMEA Scoring Rubric

A central contribution is a standardised RPN scoring rubric for the energy-audit context (Table 1). Standard FMEA literature does not prescribe universal scales [7], [9], and the multiplicative-RPN critique [8] requires explicit mitigation. Two complementary controls are adopted. First, anchor descriptors are defined at scores of 1, 4, 7, and 10 on each index, calibrated to Southern African industrial energy benchmarks drawn from IEA [1] and SACREEE [11] data. The four-anchor design, rather than a purely continuous 1–10 scale, follows guidance for contexts where inter-rater consistency is prioritised over granularity [12]. Second, a multi-disciplinary team-scoring protocol (Step 4, Section 3.3) requires a minimum of three scorers from different functions to score independently, adopting the conservative (higher) score where disagreement exceeds one point an approach analogous to structured expert-elicitation methods used to reduce subjectivity in engineering risk assessment [13].

On empirical status: the anchor points are calibrated to published benchmark ranges, not yet to measured facility data, and the rubric has not been subjected to formal expert-panel validation. This is

a deliberate boundary of the conceptual design and the primary target of the validation roadmap in Section 4. RPN classification thresholds Critical (≥ 400), High (200–399), Medium (100–199), and Low (< 100) are adapted from Relyence [14]. Where $S=9$ or 10, failure modes are automatically escalated to Critical regardless of RPN, consistent with the principle that severity carries additional weight where safety or -compliance implications exist [9], [13].

Table 1: Standardised RPN Scoring Rubric for Industrial Energy FMEA in Southern Africa

Score	Severity (S): Energy & Financial Impact	Occurrence (O): Frequency	Detection (D): Detectability	Consequence Context
1	Negligible impact on energy costs or operations	Occurs < 1 time per year	Sub-metering or BMS flags deviation in real time	Negligible consequence
4	Energy waste 5–10% above benchmark; noticeable cost increase	Several times per year; seasonal variation	Detectable by periodic manual inspection or bill-trend analysis	Minor cost increase; manageable
7	Energy waste 10–25% above benchmark; major cost impact; equipment stress	Monthly or with most operating cycles	Requires dedicated audit equipment (thermal imaging, flow metering)	Significant cost/reliability impact
10	Waste $> 25\%$ above benchmark; operations threatened; compliance risk	Almost every operating cycle	Virtually undetectable without specialist intervention	Operations threatened; compliance risk

Source: Author's compilation, calibrated to IEA [1] and SACREEE [11] benchmarks. Anchor points (1, 4, 7, 10) follow inter-rater-consistency guidance [12].

2.3 Target Energy Systems

Four energy systems universally present in Southern African industrial facilities are assessed: electric motors, compressed air systems, lighting, and thermal/process heating. Benchmark performance data from Therkelsen et al. [6], SACREEE [11], and IEA [1] provided reference standards against which energy losses were assessed. Detection scores are assigned according to the diagnostic equipment required for reliable identification: systems detectable by routine visual inspection or utility-bill analysis receive lower D scores (higher detectability), while those requiring specialist equipment such as ultrasonic leak detectors or heat-flux sensors receive higher D scores. The pivotal role of metering and sub-metering in detectability is examined in Section 3.5.

3. RESULTS AND DISCUSSION

3.1 FMEA Risk Register

Table 2 presents the energy-inefficiency risk register. S, O, and D scores were cross-referenced against SACREEE [11] and Therkelsen et al. [6] benchmarks and assigned through structured team review. Detection scores for compressed air leakages ($D=8$) and thermal failure modes ($D=7-8$) are the primary RPN drivers: these modes require specialised diagnostic equipment and are not captured through standard utility billing or visual inspection. Lighting Detection scores ($D=3$ for fluorescent fittings; $D=4$ for missing sensors) reflect the straightforward visual identification of fitting types and absence of controls by any competent auditor. Both thermal failure modes carry $S=9$ and are therefore auto-escalated to Critical, as heat losses from uninsulated pipework can raise boiler fuel consumption by 20–

40 percent [15] and incomplete combustion may engage regulatory-compliance obligations. Motor and compressed air Occurrence scores (O=7–8) reflect SACREEE [11] survey findings that partial-load motor operation and air leakages are prevalent across most audited regional facilities.

Table 2: Energy Inefficiency FMEA Risk Register – Southern African Industrial Facilities

Energy System	Failure Mode & Operational Effect	S	O	D	RPN	Priority
Electric Motors	Oversized motors at partial load → high energy draw; low power factor; elevated costs	8	7	7	392	High
Electric Motors	No VFDs on variable-load motors → constant full-speed operation; energy waste; reduced lifespan	7	8	6	336	High
Compressed Air	Undetected air leakages → up to 30% compressed air lost; compressor overloads; increased runtime	8	8	8	512	Critical
Compressed Air	Inappropriate system pressure → over-pressurisation wastes energy; accelerates wear	6	7	5	210	Medium
Lighting	Fluorescent/incandescent fittings → high energy intensity; heat generation; visible to auditor (D=3)	5	9	3	135	Medium
Lighting	No occupancy/daylight sensors → lighting in unoccupied or daylight areas; detectable by walkthrough (D=4)	5	8	4	160	Medium
Thermal/Heating	Poor steam/hot-water line insulation → high heat loss; increased boiler load; elevated fuel use [S=9: auto-escalated]	9	8	7	504	Critical
Thermal/Heating	Inefficient boiler combustion → incomplete combustion; fuel waste; elevated GHG emissions [S=9: auto-escalated]	9	6	8	432	Critical

Source: Author's compilation. Scores validated against Therikelsen et al. [6] and SACREEE [11]. S=9 items are auto-escalated to Critical per the severity-override rule.

Three Critical-priority failure modes emerge: compressed air leakages (RPN=512), poor steam-line insulation (RPN=504), and inefficient boiler combustion (RPN=432). The high Detection score (D=8) for compressed air leakages is particularly significant, as this mode is difficult to identify through utility bills or visual inspection alone, with undetected leakages in poorly maintained systems potentially accounting for 20–30 percent of total compressed air output [16]. Electric-motor inefficiencies, while narrowly below the Critical threshold, warrant attention given that motors account for 45 percent of industrial electricity consumption globally [1] and that ZESCO power-factor penalties increasingly affect Zambian industrial facilities.

On the multiplicative-RPN limitation, the S≥9 override directly addresses the case where a catastrophic-severity item is obscured by a low Occurrence or Detection score. A mode with S=9, O=1, D=1 would yield RPN=9 under standard arithmetic, masking a potentially serious consequence; the override ensures such items are assessed on their merits rather than suppressed by low frequency or high detectability.

3.2 Sample FMEA Worksheet: Compressed Air System

To demonstrate application at facility level, Table 3 presents a worked FMEA worksheet for a single energy system the compressed air system showing how a scoring team moves from failure mode to recommended action. This illustrates the intended granularity of a facility-level audit and provides a template that can be replicated for the remaining energy systems.

Table 3: Sample FMEA Worksheet – Compressed Air System

Failure Mode	Effect	S	O	D	RPN	Recommended Action
Undetected pipe/joint leakages	Compressor overload; up to 30% air lost	8	8	8	512	Ultrasonic leak survey; tag-and-repair programme; leak-rate KPI
Excessive system pressure	Over-pressurisation; artificial demand	6	7	5	210	Reduce set-point to minimum required; install pressure-flow controller
Inappropriate use (open blowing)	High-value air used for low-value tasks	5	6	6	180	Substitute blowers/fans; operator training
Poor intake air quality/temperature	Reduced compressor efficiency	4	5	6	120	Relocate intake to cool source; filter maintenance schedule

Source: Author's illustration, applying the Table 1 rubric. Scores are indicative and intended for facility-specific re-scoring during audit.

3.3 Practical Adoption Framework for Industry

Table 4 provides a structured seven-step implementation pathway calibrated to the Southern African context. A Country Notes column addresses the significant differences in audit maturity and institutional capacity across Zambia, Zimbabwe, and South Africa, avoiding the oversimplification of treating the sub-region as homogeneous.

Table 4: Step-by-Step FMEA Adoption Framework for Industrial Energy Efficiency

Step	Phase	Key Activities	Expected Outcome	Country Notes
1	Preparation	Assemble cross-functional team (energy engineer as facilitator, operations, maintenance, finance). Define system boundaries; adopt Table 1; agree S≥9 escalation.	Defined scope, scoring protocol, team mandate	All three countries
2	Energy Mapping	Collect 12 months of utility billing, nameplate data, and operating hours. Where sub-metering is unavailable (common in ZM/ZW), use nameplate estimates and SACREEE benchmark ratios.	Baseline energy-consumption profile per system	ZM/ZW: SACREEE support recommended for data gaps
3	Failure Mode ID	Identify energy-loss pathways via process walkthroughs, equipment inspections, and operator interviews. Use Table 2 as a starting checklist, adapted to facility conditions.	Comprehensive energy-inefficiency register	All three countries
4	RPN Scoring	Score each mode using Table 1. Use multi-disciplinary team scoring (min. 3 scorers); adopt conservative score where disagreement exists; document rationale. Escalate all S=9/10 to Critical.	Scored, ranked, documented register with rationale	Consistency protocol reduces subjectivity in all contexts
5	Prioritisation	Classify by RPN: Critical (≥400), High (200–399), Medium (100–199), Low (<100). Develop action plans for Critical/High items; conduct cost-benefit analysis (Section 3.4).	Prioritised efficiency-investment plan	SA: focus on scoring consistency (established infrastructure)
6	Implementation	Execute in RPN order: compressed air leak repair; steam-line insulation; boiler optimisation; motor rightsizing/VFDs. Engage SACREEE for specialist diagnostics.	Measurable reduction in energy waste and cost	ZM/ZW: SACREEE technical assistance for ultrasonic leak detection
7	Monitor & Review	Track post-intervention consumption monthly. Re-score RPNs after 6 months. Update the FMEA register annually or after major operational change.	Continuous-improvement cycle; verified savings	All three; aligns with SADC EE Strategy M&E requirements

Source: Adapted from ASQ [7], Quality-One International [12], SACREEE [11], and Therkelsen et al. [6]. ZM = Zambia; ZW = Zimbabwe; SA = South Africa.

3.4 Illustrative Cost-Benefit Analysis

Table 5 translates FMEA findings into financial terms for the three Critical-priority failure modes. Savings ranges are presented as illustrative scenarios based on Saidur et al. [16], USDOE [15], and SACREEE [11] benchmarks and must be read as order-of-magnitude guidance rather than precise predictions: actual savings depend on facility-specific operating hours, equipment age, baseline efficiency, and local tariffs. The assumed tariff of USD 0.12/kilowatt-hour (kWh) is broadly representative of current ZESCO commercial-industrial rates following the 2023 cost-reflective adjustments [4] and may not reflect Zimbabwean or South African structures. Facility-level analysis should substitute local tariff data before use in investment decisions.

Table 5: Illustrative Cost-Benefit Scenarios for Critical-Priority FMEA Interventions

Intervention (Critical RPN)	Est. Energy Saving	Annual Cost Saving (USD)*	Indicative Investment (USD)	Payback Period
Compressed air leak repair (RPN=512)	15–25% of compressor energy	18,000–30,000	5,000–12,000	4–8 months
Steam-line insulation upgrade (RPN=504)	20–40% of boiler fuel use	14,000–28,000	8,000–20,000	6–12 months
Boiler combustion optimisation (RPN=432)	10–20% of fuel per unit output	10,000–18,000	4,000–10,000	3–8 months

**Based on Saidur et al. [16], USDOE [15], SACREEE [11]. Assumes USD 0.12/kWh (ZESCO commercial-industrial rate [4]); medium-sized facility. Illustrative only — substitute facility-specific data before investment appraisal.*

Collectively, addressing all three Critical failure modes can reduce a facility's total energy bill by an estimated 20–35 percent, with payback periods largely under twelve months, consistent with broader literature on industrial energy-efficiency returns [15], [16]. By framing interventions as risk-management decisions with quantified financial consequences, the FMEA approach provides a more structured investment case than conventional ad-hoc audits.

3.5 The Role of Metering and Sub-Metering in Detection

Detection is the RPN dimension most directly shaped by instrumentation, so metering sits at the heart of the framework's diagnostic power. Real-time sub-metering or a building/energy management system (BMS) can flag deviations as they occur, warranting the lowest Detection scores (D=1–2); at the opposite extreme, leakages and thermal losses that evade utility-bill and visual inspection warrant the highest scores (D=7–8). Across much of Zambia and Zimbabwe, however, sub-metering penetration is low, so facilities must often rely on nameplate estimates and SACREEE benchmark ratios (Table 4, Step 2). A practical implication is that modest investment in portable diagnostic equipment ultrasonic leak detectors, clamp-on power loggers, and thermal-imaging cameras can sharply improve detectability and, in turn, the reliability of the risk register itself. Improving detection is thus not merely a scoring input but an early, low-cost intervention in its own right.

3.6 Sector Differentiation and Implementation Barriers

The framework's emphasis shifts by sector. In mining, large fixed and variable-speed motor loads, extensive compressed air networks, and ventilation systems dominate, so motor rightsizing, VFDs, and leak management carry the greatest weight. In manufacturing and agro-processing, thermal and steam systems boilers, process heating, and insulation typically drive the highest RPNs, aligning with the two Critical thermal modes in Table 2. Facilities should therefore treat Table 2 as a starting checklist to be re-weighted against their own load profile rather than as a fixed ranking.

Three implementation barriers recur across the sub-region and must be planned for. **Cost:** capital constraints and competing priorities can defer even short-payback interventions; the cost-benefit framing in Section 3.4 is intended to counter this by expressing efficiency as a risk-management return.

Technical capacity: a shortage of trained energy auditors and limited access to diagnostic equipment constrains Detection reliability, particularly in Zambia and Zimbabwe, pointing to the capacity-building need addressed in Section 4. **Data availability:** low sub-metering penetration forces reliance on estimates, widening uncertainty in the baseline. Acknowledging these barriers explicitly is essential if the framework is to move from a sound design to routine practice.

3.7 Alignment with Regional Policy and the SDGs

The framework aligns with the SADC Energy Efficiency Strategy (2016–2030), Zambia's Energy Efficiency Strategy and Action Plan (2022), Zimbabwe's national energy policy direction, and the National Energy Compact's commitment to doubling energy-efficiency improvement by 2030 [17]. Internationally, it contributes to SDG 7.3 (doubling the global rate of energy-efficiency improvement) and SDG 9.4 (upgrading infrastructure and retrofitting industries for sustainability), and resonates with the Sendai Framework's advocacy for integrating risk assessment into industrial management [18].

3.8 Framework Application Across National Contexts

Zambia, Zimbabwe, and South Africa present substantially different industrial energy-efficiency contexts. Table 6 differentiates the framework's application across five dimensions to ensure guidance is appropriately calibrated.

Table 6: Framework Application Across National Contexts			
Framework Dimension	Zambia	Zimbabwe	South Africa
Audit maturity	Limited; ad hoc; SACREEE support available	Very limited; significant capacity gap	Established; National Energy Act mandates audits for large consumers
Sub-metering	Low; engineering estimates commonly required	Very low; greatest reliance on nameplate estimation	Moderate–high; BMS common in larger facilities
FMEA entry point	Steps 1–2 capacity building needed first	Steps 1–2 most critical; SACREEE partnership recommended	Can enter at Steps 3–4; focus on scoring consistency
Key institutional partner	SACREEE, ERB, Ministry of Energy	SACREEE, ZERA	SANEDI, NERSA
Policy alignment	EE Strategy 2022; Vision 2030	IREP 2021–2025; NDS1	National Energy Act; NDP 2030

Source: ERB [4], ZERA [3], SADC [5], SACREEE [11], Development Reimagined [19].

4. CONCLUSION AND POLICY RECOMMENDATIONS

This paper has made four contributions to industrial energy-efficiency practice in Southern Africa. First, a standardised RPN scoring rubric calibrated to the sub-regional energy context, with anchor descriptors, a multi-scorer protocol, and an S≥9 severity override addresses the documented limitations of FMEA scoring subjectivity and multiplicative-RPN masking. Second, a ranked energy-inefficiency risk register identifies compressed air leakages (RPN=512), poor steam-line insulation (RPN=504), and inefficient boiler combustion (RPN=432) as the highest-priority targets across typical regional facilities. Third, a seven-step adoption framework, differentiated across Zambia, Zimbabwe, and South Africa and supported by a worked worksheet, provides actionable guidance sensitive to differing audit maturity

and institutional capacity. Fourth, an illustrative cost-benefit analysis demonstrates that FMEA-prioritised interventions can reduce facility energy costs by 20–35 percent with payback periods largely under twelve months.

4.1 Policy Recommendations

Translating these contributions into action requires coordinated measures at four levels:

- **Regional (SADC and SACREEE):** embed a standardised FMEA-based audit rubric within the SADC Energy Efficiency Strategy's monitoring framework, and resource SACREEE's Regional Industrial Energy Efficiency Programme to host shared diagnostic-equipment pools and a certified-auditor training pathway serving Zambia and Zimbabwe.
- **National regulators (ERB, ZERA, NERSA):** introduce or strengthen mandatory energy-audit requirements for large industrial consumers, accompanied by sub-metering incentives and, where appropriate, tariff signals that reward verified efficiency gains.
- **National policy (Zambia, Zimbabwe):** integrate risk-based auditing explicitly into Zambia's Energy Efficiency Strategy and Action Plan and Zimbabwe's national energy policy, linking industrial efficiency to Vision 2030 industrialisation and energy-security objectives and to SDG 7.3 and SDG 9.4.
- **Industry and utilities:** adopt the seven-step framework as a routine annual practice, prioritising Critical failure modes and reporting verified savings to support both internal investment cases and national efficiency reporting.

4.2 Limitations and Empirical Validation Roadmap

The primary limitation of this work is the absence of empirical validation: the rubric anchor points, RPN scores, and savings estimates rest on published benchmarks rather than measured facility data, and the scoring protocol has not yet been tested for inter-rater reliability. This is an inherent property of a conceptual framework and defines the immediate research agenda. A three-stage validation roadmap is proposed:

- **Stage 1 – Rubric calibration and expert validation:** convene a multi-disciplinary expert panel (energy engineers, plant operators, SACREEE specialists) to review and, via structured elicitation, calibrate the Table 1 anchor points against real facility data.
- **Stage 2 – Pilot implementation:** apply the full seven-step framework in two to three Zambian and Zimbabwean facilities manufacturing and agro-processing are recommended as accessible entry points capturing metered baselines and post-intervention consumption.
- **Stage 3 – Reliability and savings verification:** test the multi-scorer protocol's inter-rater reliability and validate the cost-benefit estimates against metered post-intervention data, refining the thresholds accordingly.

SACREEE's Regional Industrial Energy Efficiency Programme offers a natural institutional vehicle for these pilots. As Southern Africa confronts escalating energy insecurity, integrating risk engineering into industrial energy management offers a practical, financially credible pathway — from policy commitment to measurable, resilient action.

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