Design and Development of a Smart Remote Energy Assessment Framework: A Technology-Driven Approach for Education and Industrial Application

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Dr. Vora is leading efforts to enhance the ITAC Program and the GPCoE at OSU, which supports clean energy workforce development and energy efficiency improvements for small and medium-sized enterprises (SMEs) across 13 Great Plains states. Under his leadership, the ITAC has performed over 1,140 energy assessments at no cost to clients, saving more than $139 million in energy costs.

A dedicated educator, Dr. Vora, teaches courses related to Energy Management, Smart Manufacturing, Additive Manufacturing, Modeling and Simulations, preparing the next generation of engineers. His research focuses on improving energy efficiency in SMEs, and he has secured over $13 million in federal funding from agencies like the DOE, USDA, and Oklahoma Department of Commerce.

In addition to his academic and research roles, Dr. Vora was recently appointed as a Regional Vice President of the Association of Energy Engineers (AEE) South Central Regions (13-states). He is also an Executive Board Member and Student Chapter Director for the Association of Energy Engineers – Oklahoma Chapter (AEEOK). In addition, he is also a faculty advisor for the AEEOK OSU Student Chapter and the Society of Manufacturing Engineers (SME OSU Student Chapter).

Dr. Vora is committed to the land-grant mission of OSU by training students through real-world energy assessments, ensuring the region's SMEs achieve significant energy savings, which further boosts regional economic development.

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I am an energy engineer and researcher specializing in digital twins for industrial energy management, building energy modeling, and decarbonization of manufacturing and commercial systems. I hold a Master's degree in Industrial Engineering from Oklahoma State University and a Bachelor's degree in Mechanical Engineering. I have published a peer-reviewed review article in the AEE Journal titled "Decarbonization for a Sustainable Energy Future," which synthesizes practical and scalable pathways for industrial decarbonization, energy transition planning, and carbon reduction strategies across industrial sectors. My research focuses on integrating digital twin architectures, industrial process design with emphasis on energy efficiency, building energy modeling, HVAC and BAS optimization, and data-driven performance analytics. I am particularly interested in specific energy consumption (SEC) modeling, grid-interactive efficient systems, energy grid management, sustainability metrics, CO-weighted renewable integration, and quantitative evaluation of industrial energy performance improvements. In addition to my research, I am currently working with ES2, where I contribute to applied energy engineering projects focused on energy efficiency, system optimization, and performance analysis. This work strengthens my ability to translate theoretical models into practical, real-world energy solutions across industrial and commercial environments. My work bridges applied engineering practice and research methodology to develop scalable, data-driven frameworks for energy optimization and emissions reduction.

Kritika Bhandari, Oklahoma State University

Kritika Bhandari is an energy engineer with a strong background in industrial engineering, mechanical engineering, energy management, and sustainability. She earned her master's degree in industrial engineering and management and her bachelor's degree in mechanical engineering. Her work focuses on industrial energy management, building energy modeling, decarbonization of manufacturing and commercial systems, HVAC and building automation system optimization, and data-driven performance analytics. She has

published a paper titled ”Decarbonization for a Sustainable Energy Future” in the International Journal of Strategic Energy and Environmental Planning – Journal of the Association of Energy Engineers. The paper emphasizes practical and scalable strategies for energy transition planning, carbon reduction, and improved energy management across industrial sectors. Driven by her passion for clean energy systems, supply chain optimization, and industrial sustainability, Kritika bridges applied engineering practice with research-based methodologies. Her work supports the development of scalable, data-driven frameworks for energy optimization, emissions reduction, and the transition toward clean, equitable, and resilient energy systems.

Kyle Robison, Oklahoma State University

Kyle Robison currently serves as a Senior Research Engineer at Oklahoma State University (OSU). He supports the Industrial Training and Assessment Center (ITAC) and the Rural Energy Assessment Center (REAC). In this role he recruits clients and supervises on-site energy audits at small to medium-sized industrial and commercial companies. Kyle not only works closely with clients, but he also manages 8 to 10 graduate and undergraduate engineering students as they collect energy site data and prepare reports. Kyle holds a master’s in business administration from Friends University in Wichita, Kansas and a bachelor’s degree in electrical engineering from OSU.

DESIGN AND DEVELOPMENT OF A SMART REMOTE ENERGY ASSESSMENT FRAMEWORK: A TECHNOLOGY-DRIVEN APPROACH FOR EDUCATION AND INDUSTRIAL APPLICATIONS

Abstract

Small- and medium-sized enterprises (SMEs) increasingly need actionable energy-efficiency guidance but often face barriers to accessing high-quality onsite audits due to travel cost, limited staffing, and disruption to operations. Remote energy assessments offer a scalable alternative, yet their effectiveness depends on disciplined workflow design, data-quality controls, and explicit treatment of uncertainty. This paper presents a Smart Remote Energy Assessment Framework that integrates (i) a Skill Matrix to screen which audit activities can be executed remotely with appropriate competency levels, and (ii) a Risk Matrix to classify data sources by reliability and trigger conservative assumptions or targeted onsite verification when needed. The framework was developed using mixed-methods inputs from practitioners and validated through case-based comparisons between remote reconstructions and traditional walkthrough audits. The framework is structured for engineering education and Industrial Training and Assessment Center (IAC/ITAC)-style workforce training, enabling competency-based learning outcomes in data interpretation, savings calculations, and decision-making under uncertainty.

Keywords: Remote energy audit, Industrial energy assessment, SME accessibility, Skill matrix, Risk matrix, Engineering education

1. Introduction

Energy assessments are a practical mechanism for identifying operational and capital improvements that reduce energy use, cost, and emissions. Facilities in the built environment and industrial sector represent a large share of total energy consumption and operating expenditure. Evidence from audit-driven initiatives indicates that well-scoped energy assessments can yield measurable reductions in energy intensity through both equipment retrofits and low-cost operational improvements. For example, mandatory or programmatic audit requirements have been linked to reductions in building energy use, and public benchmarking platforms highlight the persistence of avoidable energy waste across building portfolios. [1], [2]

Energy recommendations are often prioritized using an energy management hierarchy. *Figure 1* illustrates a conceptual pyramid in which energy conservation and energy efficiency form the foundation, followed by new technology, and finally alternative energy adoption at the top. This framing aligns with SME constraints, motivating a remote assessment approach that emphasizes reliable identification of foundational, low-disruption measures before advancing to higher-capital solutions.

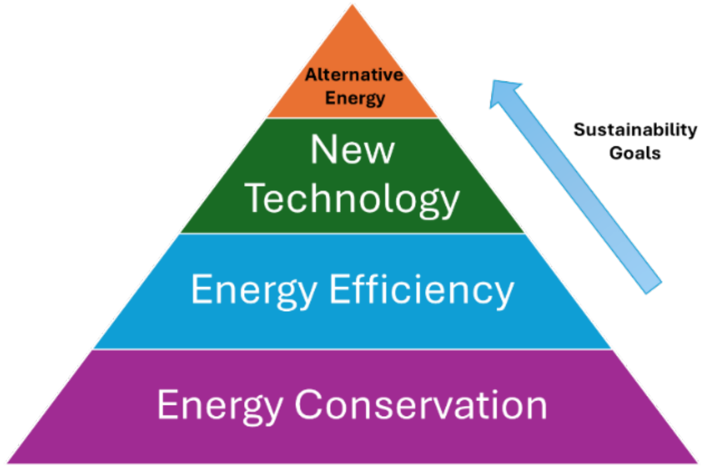

Figure 1. Energy management hierarchy pyramid (conceptual).

A key delivery challenge is that onsite audits require travel, plant coordination, safety onboarding, and time on the floor to collect and verify data. These steps increase cost and limit throughput, particularly when plants are geographically dispersed or require specialized access approvals. The constraint is more severe for SMEs and rural facilities, which often lack dedicated energy-management staff and have limited flexibility to host extended onsite visits. Furthermore, lowering audit cost does not automatically guarantee higher implementation; adoption decisions are often influenced by capital constraints, production priorities, operational risk tolerance, and recommendation credibility. [3]

Digitalization of industrial systems and the normalization of remote collaboration create a practical opportunity to deliver parts of the assessment process remotely. Remote assessments can reduce travel time, scheduling friction, and idle labor while increasing the number of facilities served, as demonstrated in remote residential/commercial programs and emerging industrial offerings. However, remote delivery introduces risks: incomplete documentation, inconsistent sensor calibration, limited ability to verify operating conditions, and greater reliance on assumptions. Audit quality comparability therefore requires a structured methodology that manages competency and uncertainty explicitly. [4], [5], [6]

This paper makes four contributions:

(1) A competency-based Skill Matrix mapping audit tasks and data-gathering methods to required skill levels for remote feasibility.
(2) A data-reliability Risk Matrix categorizing remote data sources and defining uncertainty-triggered mitigation actions.
(3) A repeatable end-to-end remote assessment workflow integrating feasibility screening, risk controls, and validation.
(4) An education-ready structure for course modules and workforce training aligned with staged learning outcomes.

Table 1 illustrates how high-throughput assessment programs can generate sustained savings opportunities and provide motivation for scalable workflows that increase coverage for resource-constrained facilities. [7]

Table 1. Illustrative assessment outcomes from a university-based assessment program (summary).

Name of ITAC Center	Total Implemented Savings ($)	Total Recommended Savings ($)	Total number of audits Conducted	Total Cost for Audit ($)
Texas A&M	13,599,991	25,478,518	221	3,536,000
Oklahoma State University	6,321,805	23,400,275	202	3,232,000
Louisiana State University	5,006,742	16,953,114	177	2,832,000
Lehigh University	10,004,493	33,190,690	177	2,832,000
University of Miami	18,007,888	33,990,223	164	2,624,000
University of Missouri-Columbia	8,645,214	20,703,108	162	2,592,000
Indiana University-Purdue University	4,097,391	14,489,201	161	2,576,000
West Virginia University	5,677,211	20,363,681	159	2,544,000
Arizona State University	14,183,784	34,042,594	159	2,544,000

2. Background and Related Work

2.1 Traditional Onsite Energy Audits

Onsite energy audits commonly follow progressive levels of rigor. A preliminary walkthrough identifies major systems, operating schedules, and obvious inefficiencies, while more detailed audits incorporate measurement campaigns, engineering calculations, and financial analysis. Standards and guidance emphasize facility observation, interviews, and measurement as key mechanisms to reduce uncertainty in savings estimates. In industrial settings, onsite work also supports identification of safety, reliability, and production constraints that affect feasibility. [8], [9], [10]

2.2 Why SMEs Are Harder to Serve

Traditional audit delivery burdens can outweigh benefits for smaller plants. Travel and scheduling may represent a dominant component of total cost, especially for facilities outside major metros. Short onsite windows often force assessors to prioritize easily observable opportunities, reducing depth for complex systems. SMEs may also have fewer historical data streams and limited internal staff time for data requests, which increases assessor effort and reduces confidence in estimates. Beyond audit delivery, implementation can be limited by capital constraints, downtime concerns, competing production priorities, and perceived operational risk. [3]

2.3 Remote and Hybrid Audits

Remote assessments shift portions of the audit process—data intake, preliminary analysis, and stakeholder engagement—into virtual formats. Residential and commercial programs have demonstrated that remote assessments can increase customer engagement and improve throughput, and industrial providers have promoted virtual audits as a strategy to scale services. Nevertheless, remote delivery can reduce the ability to capture opportunistic measurements and can magnify uncertainty for measures that depend on accurate process parameters. The field increasingly anticipates hybrid models where remote screening is used to narrow onsite scope to high-value verification activities. [4] – [6] *Figure 2* summarizes the conventional onsite audit workflow and highlights how qualitative and quantitative inputs are integrated, as well as where travel, access, and scheduling constraints increase audit cost and effort.

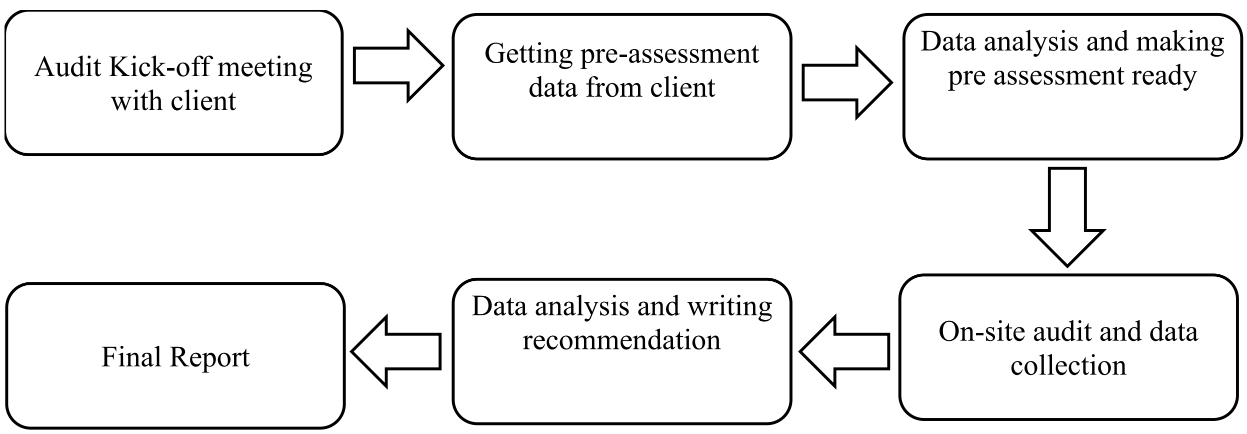

Figure 2. Conventional onsite audit process (schematic).

3. Research Design and Methods

A mixed-methods research design was used to ground the framework in practitioner needs and validate feasibility assumptions. The study combined: (i) a market-needs survey of audit professionals, (ii) a standardized energy-efficiency measure (EEM) catalog with associated data requirements, (iii) competency mapping using a Skill Matrix informed by staged learning models, and (iv) uncertainty mapping using a Risk Matrix that classifies data sources and defines mitigation actions. Practitioner feedback was used for refinement, and case-based validation compared remote reconstructions against prior onsite audits. [11]

3.1 Market Needs Survey and Analysis

Survey items focused on time burden, travel and scheduling constraints, availability of facility data, and perceived barriers to remote accuracy. Responses were summarized using descriptive statistics (mean and standard deviation), and hypothesis testing was used to confirm whether key challenges were consistently perceived across respondents. The purpose of this analysis was not to generalize to all industries, but to inform framework priorities and feasibility assumptions. [12] *Table 2* summarizes the hypothesis-test results confirming that key pain points in traditional audits are consistently perceived by respondents, and *Table 3* reports descriptive statistics for selected survey items used to prioritize framework design requirements.

Table 2. Hypothesis test results on perceived challenges in traditional audits (summary).

Hypothesis	**p-value**	**Findings**
High cost is not a challenge for Traditional audits	2.15498E-12	Not supported; p < .05
Traditional audits don't take more time and is exhausting	1.17048E-13	Not supported; p < .05
Accessibility to remote or hazardous locations is not a challenge in Traditional audits	1.41408E-10	Not supported; p < .05
Dependence on subjective experts is not a challenge in traditional audits	4.41156E-10	Not supported; p < .05
Lack of data or real time data integration is not a challenge in Traditional audits	3.25572E-10	Not supported; p < .05

Table 3. Market-needs survey findings (selected items; mean and standard deviation).

Key Survey Points	**Mean**	**SD**
Typical Time spent for On-site Visit (1 -5)	4.04	0.55
High cost as a challenge for Traditional audits	4.58	0.58
Time exhaustion as a challenge for Traditional audits	4.71	0.55
Accessibility to remote or hazardous locations as a challenge	4.46	0.65
Lack of data or real-time data integration as a challenge in Traditional audits	4.38	0.65
%Yes	Value	Value
Awareness of Digital tools for Energy audits	79%	79%
Remote audit a solution for challenges	83%	83%

3.2 EEM Catalog and Calculation Inputs

A catalog of commonly recommended EEMs was organized into major categories: lighting, HVAC and motors, process loads, compressed air, steam and thermal systems, insulation, control strategies, and operational scheduling. For each measure, required inputs were defined (e.g., nameplate data, runtime, load factor, temperature/pressure measurements, baseline energy rates, and production or occupancy schedules). This structure supports repeatable analysis and facilitates student training by enabling systematic screening of opportunities. Standard engineering methods were used for savings calculations, and input uncertainty was tracked through the risk matrix. [10], [6]

4. Smart Remote Energy Assessment Framework

The proposed framework operationalizes remote assessment through two primary control layers: (i) competency-based feasibility screening using a Skill Matrix, and (ii) uncertainty-based reliability screening using a Risk Matrix. The workflow begins with scoping and intake (utility bills, production logs, O&M documentation), followed by stakeholder interviews to confirm operating schedules and constraints. Remote walkthroughs (video, photographs, and guided virtual tours) validate system inventories and identify candidate measures. For each measure, the assessor evaluates (a) the minimum required skill level to collect and interpret inputs, and (b) the risk category of remote data sources. Measures exceeding remote thresholds are deferred, bounded conservatively, or flagged for targeted onsite verification. [7], [13]

4.1 Skill Matrix: Competency-Based Feasibility

The Skill Matrix maps audit tasks and data-gathering methods to competency levels. Lower-skill tasks include extracting utility data, capturing nameplate information, and computing schedule-based savings. Intermediate tasks include interpreting trend data and benchmarking, estimating load factors, and validating operating constraints through interviews. Higher-skill tasks include instrumentation planning, advanced process modeling, and complex thermal integration analysis. This matrix supports staffing decisions, defines student learning progression, and serves as a quality gate that prevents remote execution of tasks requiring specialized expertise or equipment. [14], [15] *Table 4* summarizes the criteria used to assign skill levels and screen which tasks are feasible to execute remotely.

Table 4. Skill level classification criteria used to screen remote feasibility.

Skill Level / Criteria's	Level 1–2	Level 3–5	Level 6–7	Level 8–10
Basic Data Collection - No skill or minimal training needed - Simple tasks (e.g., nameplate data, visual inspections)	✓			
Intermediate Operations with Equipment - Can operate basic to moderately advanced equipment (e.g., gauges) - May not require data analysis (Lvl 4–5) or minimal analysis (Lvl 6)		✓		
Advanced Engineering & Analysis - Requires deeper domain knowledge or specialized training - Involves additional data analysis and interpretation			✓	
Holistic/Whole Building Evaluation - Expert-level tasks integrating all previous skills - Comprehensive analysis, possibly requiring professional certification				✓

4.2 Risk Matrix: Data Reliability and Mitigation

The Risk Matrix classifies remote data sources by reliability and defines mitigation actions. Low-risk inputs include calibrated meter trends, vendor nameplate specifications, and well-documented operating schedules. Medium-risk inputs include unverified runtime estimates, incomplete maintenance records, and limited-resolution trend data. High-risk input includes subjective estimates of load factors, unclear process constraints, or measures requiring precision measurement. For medium- and high-risk conditions, the framework prescribes conservative assumptions, sensitivity bounds, targeted verification (short onsite measurement, temporary logging), or follow-up data requests. [6] *Table 5* provides representative data tasks, initial skill assumptions, and expert-informed adjustments that improve practical remote feasibility.

Table 5. Risk matrix for data reliability and alternative remote data-collection methods.

Before Condition				**After Condition with Improvement**		
Data Task	**Who need to perform it**	**Original Skill Level**	**Expert Feedback**	**Data Task**	**Who need to perform it**	**Adjusted Skill**
Utility billing and tariff analysis	Administrative staff, Analyst	3	Utility analysis could not be done by maintenance staff or Plant personnel. Suggested to break this into two.	Collection of Utility bills	Administrative staff	3
				Billing and Tariff analysis	Energy Auditor	6
Motor Load Measurements	Maintenance staff, Energy auditor	5	Maintenance staff could find it difficult to do it on their own.	Motor Load Measurements	Maintenance staff in guidance of energy auditor	5
Data Logging Setup & Retrieval	Maintenance staff, Energy auditor	5	Maintenance staff could find it difficult to do it on their own.	Data Logging Setup & Retrieval	Maintenance staff in guidance of energy auditor	5

4.3 Workflow and Deliverables

Figure 3 summarizes the end-to-end workflow. The process includes (1) scoping and client onboarding, (2) remote data collection and validation, (3) opportunity identification and screening, (4) savings and cost estimation, (5) uncertainty review and risk mitigation selection, and (6) recommendation reporting and follow-up planning. The deliverable in the report is structured to separate high-confidence measures from higher-uncertainty measures, explicitly documenting assumptions and recommended verification steps. This structure improves transparency and supports implementation decision-making.

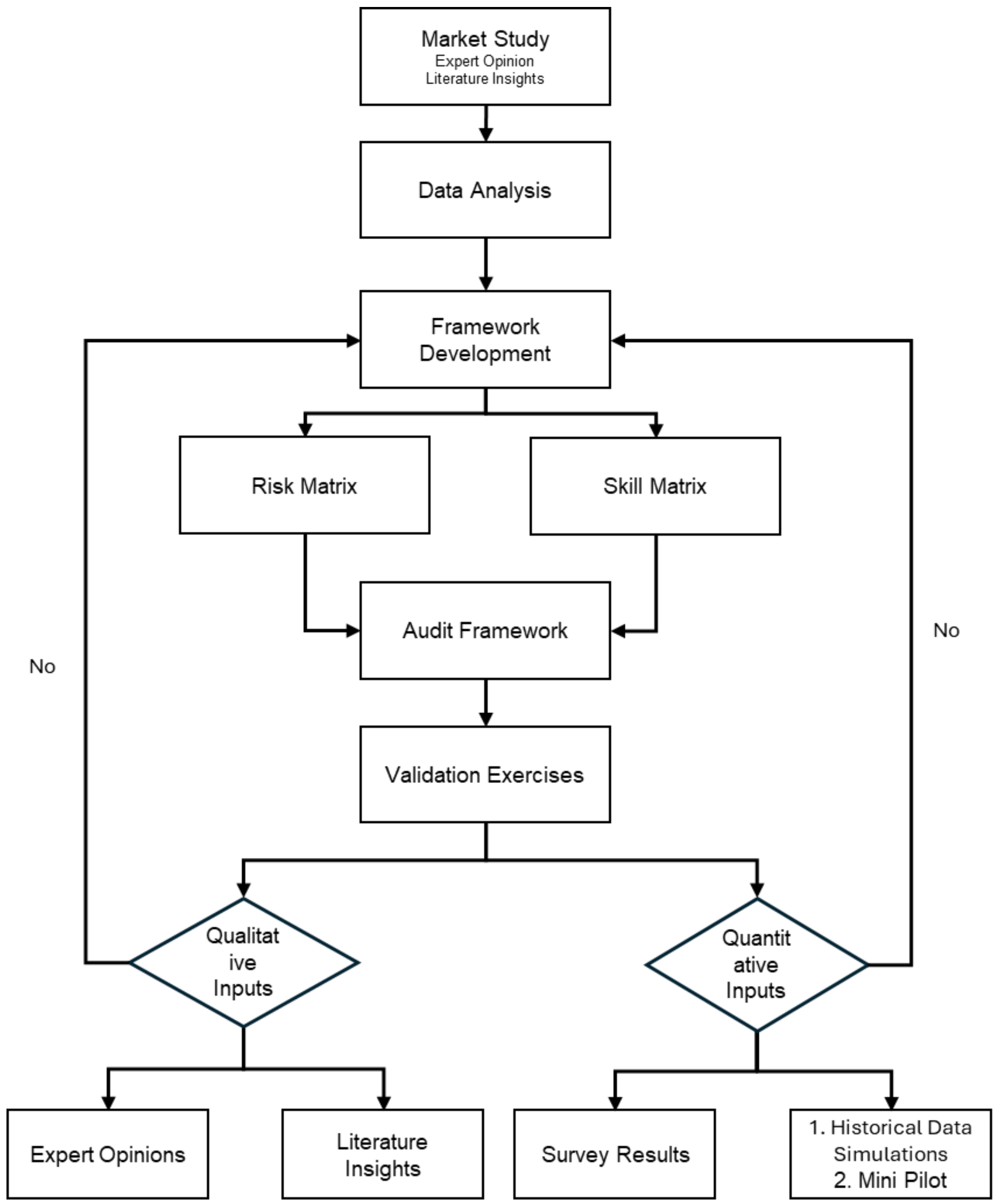

Figure 3. Framework development and deployment workflow (schematic).

Figure 4 presents the final Smart Remote Energy Assessment Framework at a high level, illustrating how the Skill Matrix and Risk Matrix act as gating controls for task feasibility and data reliability. The hybrid pathway is directional: the assessment begins with remote scoping and analysis, then transitions to targeted onsite verification only for high-risk or high-uncertainty inputs, before finalizing recommendations and reporting.

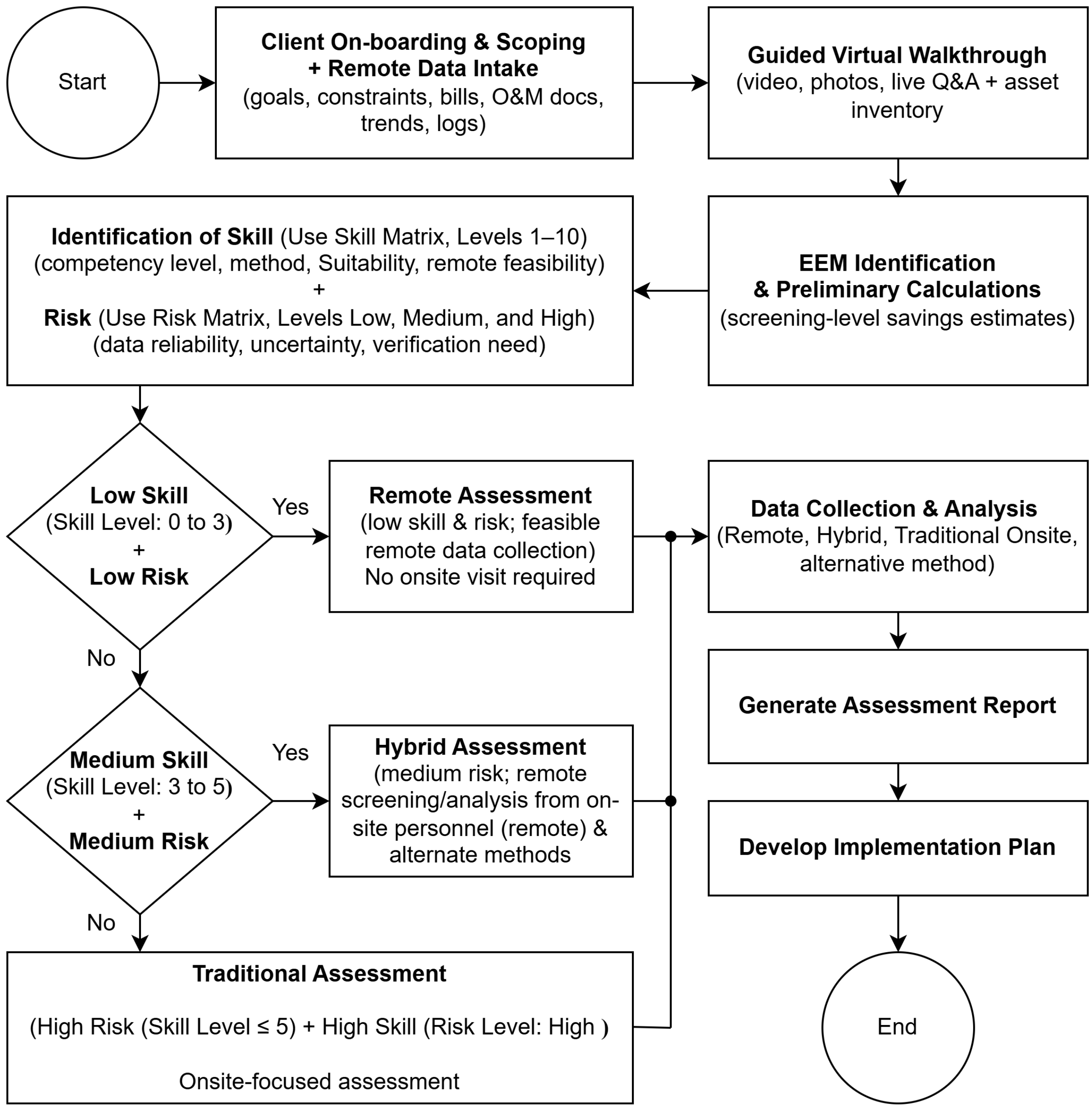

Figure 4. Final Smart Remote Energy Assessment Framework (high-level).

5. Validation and Results

Validation was conducted using retrospective comparisons between previously completed onsite audits and reconstructed remote workflows for multiple industrial facilities. For each case, the remote assessment used available bills, operational data, equipment documentation, and guided walkthrough records to generate an EEM portfolio and savings estimates. Remote outputs were compared against onsite baselines to evaluate portfolio similarity, magnitude of savings, and identification of high-risk items requiring verification. [7], [6]

5.1 Case-Based Findings

Across cases, remote workflows consistently reproduced scheduling and operational recommendations where data was available (e.g., reducing idle runtime, night/weekend setbacks, sequencing compressors). Motor and drive opportunities were feasible when nameplate and runtime information could be verified, while thermal-system opportunities showed higher uncertainty when temperature and flow data were unavailable. Lighting recommendations were highly transferable to remote delivery because fixture inventories and operating hours can be documented visually and cross-checked with billing trends.

The most significant divergence between remote and onsite outcomes occurred for measures requiring precision measurement or detailed process characterization (e.g., complex heat recovery, furnace tuning, or multi-utility integration). In these situations, the risk matrix classified inputs as high uncertainty and prompted conservative bounding or onsite verification. This behavior is consistent with the intended role of remote audits: maximize remote coverage of feasible opportunities and reserve limited onsite effort for high-value verification. *Table 6* compares workhours across key activities and illustrates how remote delivery reduces effort primarily through travel elimination and streamlined data intake while preserving reporting and reviewing requirements.

Table 6. Illustrative comparison of work hours between onsite and remote assessment workflows.

Task	Work Hour	
	Traditional Audit	Remote Audit
Per EEM/ Hour	2	1
Report compilation	5	5
Report review	5	5
Buffer	2	2

6. Educational Integration and Workforce Development

The framework is instruction-ready for engineering and engineering-technology curricula, enabling integration into lab, design, and energy-assessment courses. Students can be scaffolded through progressive competencies aligned with the Skill Matrix, ranging from basic data intake and documentation to advanced savings calculations and uncertainty-aware justification. Suggested learning outcomes include: (i) interpret facility energy data and operating schedules, (ii) compute savings using appropriate engineering methods, (iii) classify remote data quality and uncertainty and select mitigation actions, and (iv) communicate recommendations with feasibility and risk rationale. [14], [15] Assessment can be performed using analytic rubrics evaluating (a) technical correctness of inputs and calculations, (b) credibility and transparency of assumptions, (c) appropriate risk classification and mitigation, and (d) professional communication quality. The workflow also supports team-based learning by distributing roles such as data manager, walkthrough coordinator, calculations lead, and report editor, thereby mirroring real audit team structures and emphasizing collaborative problem-solving.

6.1 Professional Development and Human-in-the-Loop Learning in Remote/Hybrid Assessments

Remote and hybrid assessment workflows build transferable skills essential for energy-assessment careers, including structured interviewing, remote coordination with plant personnel, QA/QC of client-supplied data, and professional report writing and presentation of findings under real-world constraints (safety, access, production schedules, and implementation risk).

AI and automation can be used as productivity enablers (e.g., for data cleaning, baseline modeling, and drafting checklists), but the framework is intentionally designed to keep critical responsibilities human-in-the-loop. Students are required to justify recommendations, document assumptions and boundary conditions, and communicate credibility tiers to stakeholders. These activities demand engineering judgement, ethical responsibility, and client-facing professionalism.

Beyond routine calculations, the workflow develops higher-order competencies through repeated practice in: (i) scoping and opportunity prioritization; (ii) selecting appropriate calculation methods and bounding assumptions; (iii) uncertainty-aware decision making using the risk matrix; and (iv) measurement planning and verification design (i.e., defining what must be verified onsite, with what instrumentation, and why). The hybrid pathway is particularly valuable for teaching decision making when remote evidence is sufficient and when targeted on-site verification is necessary.

6.2 Alignment with Existing Training Pathways for Remote Assessment Practice

Multiple established workforce-development pathways already cultivate energy-audit and energy-management competencies, including U.S Department of Energy (DOE)-funded Industrial Assessment Center / Industrial Training and Assessment Center (IAC/ITAC) training [7], DOE Better Buildings & Better Plants [16] and energy management system programs including ISO 50001 [17] and 50001 Ready–aligned practices [18], and professional short courses and certifications offered by organizations such as the Association of Energy Engineers (AEE) [19] and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [20]. These pathways provide strong foundations in assessment methods, energy accounting, and implementation planning. In addition, widely used tools such as the U.S. Department of Energy (DOE) MEASUR software suite (e.g., AirMaster+, Pumping System

Assessment Tool, Steam System Tool Suite, and related modules) provide standardized calculation workflows that support training, consistent savings estimation, and transparent documentation of assumptions [21-22].

While many programs were historically centered on onsite practice, the accelerated adoption of virtual collaboration has expanded the use of remote data collection (e.g., utility and interval data review), virtual walkthroughs, and hybrid verification strategies. The proposed framework complements existing training by providing a repeatable, competency- and risk-gated structure that formalizes remote/hybrid audit execution. Instructors and workforce programs can use the framework to standardize data quality expectations, define when escalation to on-site verification is required, and ensure consistent documentation and QA/QC across cohorts, sites, and audit teams.

7. Discussion: SME Implementation, Equity, and Audit Quality

From an equity standpoint, reducing audit cost improves access for SMEs; however, implementation outcomes depend on organizational capacity and perceived risk. Prior work in U.S. manufacturing shows that implementation rate is shaped by management commitment, capital availability, production priorities, operational risk tolerance, and the specificity and credibility of recommended actions, in addition to payback period. Therefore, the framework prioritizes high-confidence, low-disruption measures that SMEs can adopt with limited capital (often operational or control-focused), while clearly labeling higher-uncertainty measures and providing verification options. [3]

Audit quality comparability is maintained through the framework's two-stage gating approach. The Skill Matrix prevents remote execution of tasks requiring specialized instrumentation or advanced judgment, while the Risk Matrix triggers conservative assumptions, sensitivity analysis, or targeted onsite verification when data uncertainty exceeds acceptable thresholds. This design reduces the likelihood of over-confident recommendations derived from weak data and provides a practical hybrid strategy: maximize remote coverage where feasible while reserving onsite effort for high-value verification. [6]

In practice, remote delivery also enables faster iteration. Facilities can receive preliminary findings earlier, request clarifications on assumptions, and prioritize a subset of measures for verification. This iterative loop supports implementation planning, especially when SMEs benefit from staged upgrades rather than one-time capital projects.

8. Limitations and Future Work

The primary limitation of remote assessments is dependence on client-provided data and availability of digital monitoring. Facilities with limited instrumentation, inconsistent recordkeeping, or constrained connectivity may require greater onsite effort. Future work will (i) expand validation across additional facility types and climates, (ii) track implementation outcomes at 6–12 months post-audit to quantify whether improved access translates to higher adoption, and (iii) refine education modules and rubrics to quantify student learning gains and assessment reliability.

9. Conclusions

This paper presented a Smart Remote Energy Assessment Framework that improves audit scalability while preserving recommendation credibility. By integrating competency-based feasibility screening with uncertainty-based data reliability controls, the framework expands access to energy assessments for SMEs and other resource-constrained facilities. Case-based validation supports the idea that most routine opportunities can be identified remotely with comparable magnitude, while higher-risk measures should be deferred, bound, or verified onsite. The framework provides a structured pathway for workforce development and engineering education through project-based learning and rubric-driven assessment.

References

[1] C. E. Kontokosta, D. Spiegel-Feld, and S. Papadopoulos, “The impact of mandatory energy audits on building energy use,” Nature Energy, vol. 5, no. 4, pp. 309–316, 2020, doi: 10.1038/s41560-020-0589-6.

[2] “Building Energy Use - GSA Sustainable Facilities Tool.” Accessed: March 1, 2026. [Online]. Available: https://sftool.gov/learn/about/44

[3] A. Sah, D. Tharwala, P. Niraula, K. Soni, M. McCombs, and H. D. Vora, “Prominent factors affecting implementation rate of energy efficiency recommendations in manufacturing industries in the USA,” International Journal of Energy Engineering, vol. 2, no. 3, 2020.

[4] E. Cooper, R. Sussman, and B. Rosenberg, “Remote Home Energy Assessments,” American Council for an Energy-Efficient Economy (ACEEE), Research Report B2102, 2021. Accessed: March 1, 2026. [Online]. Available: https://www.aceee.org/research-report/b2102

[5] “Virtual energy audits key to engaging customers and scaling clean energy,” DNV. Accessed: March 1, 2026. [Online]. Available: https://www.dnv.com

[6] “Modeled vs. Measured Energy Efficiency Audits – What You Need to Know,” AM Conservation. Accessed: March 1, 2026. [Online]. Available: https://amconservation.com

[7] “Industrial Training and Assessment Centers,” [Online]. Available: https://itac.university/

[8] “A Brief History of the ASHRAE Handbook.” Accessed: March 1, 2026. [Online]. Available: https://www.ashrae.org/about

[9] “Energy and Water Audits for Federal Buildings,” Energy.gov (FEMP). Accessed: March 1, 2026. [Online]. Available: https://www.energy.gov/femp

[10] B. L. Capehart, W. C. Turner, and W. J. Kennedy, Guide to Energy Management, 8th ed. River Publishers, 2020.

[11] P. Saraswati and A. Devi, “Mixed Methods-Research Methodology Review,” Mathews Journal of Nursing and Health Care, vol. 5, no. 4, 2023.
[12] D. C. Montgomery and G. C. Runger, Applied Statistics and Probability for Engineers, 7th ed. Wiley, 2018.
[13] “IAC Technical Documents,” Accessed: March 1, 2026. [Online]. Available: https://iac.university/technical-documents
[14] S. E. Dreyfus and H. L. Dreyfus, “A Five-Stage Model of the Mental Activities Involved in Directed Skill Acquisition,” Defense Technical Information Center.
[15] L. W. Anderson (Ed.), A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom’s Taxonomy of Educational Objectives. Pearson, 2001.
[16] “Better Building Better Plants Initiative, Accessed: March 1, 2026. [Online]. Available: https://betterbuildingssolutioncenter.energy.gov/
[17] “ISO 50001 Energy Management Systems,” Accessed: March 1, 2026. [Online]. Available: https://betterbuildingssolutioncenter.energy.gov/iso-50001
[18] “50001 Ready Program,” Accessed: March 1, 2026. [Online]. Available: https://www.energy.gov/eere/ito/50001-ready-program
[19] “Association of Energy Engineers – Training Programs,” Accessed: March 1, 2026. [Online]. Available: https://www.aeecenter.org/aee-training/training-programs/
[20] “American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) – Professional Development,” Accessed: March 1, 2026. [Online]. Available: https://www.ashrae.org/professional-development
[21] “DOE MEASUR,” [Online]. Available: https://www.energy.gov/eere/ito/measur
[22] “DOE MEASUR – Online Calculator and Assessment,” Accessed: March 1, 2026. [Online]. Available: https://measur.ornl.gov/landing-screen