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ADOPTION OF SMART ENERGY MANAGEMENT SYSTEMS AND INDUSTRIAL ENERGY EFFICIENCY: THE MODERATING ROLE OF ORGANIZATIONAL TECHNOLOGICAL READINESS IN PAKISTAN

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Abstract
Industrial energy consumption in Pakistan accounts for nearly 37% of total national energy use, making energy efficiency a critical priority for sustainable industrial development. The adoption of Smart Energy Management Systems (SEMS) has emerged as an important technological solution for monitoring, controlling, and optimizing industrial energy consumption. However, the effectiveness of these systems largely depends on the technological capabilities and readiness of organizations. This study examines the impact of SEMS adoption on industrial energy efficiency and investigates the moderating role of Organizational Technological Readiness (OTR) in the industrial sector of Pakistan. Using a quantitative research approach, data were collected through a structured questionnaire from 286 managers and technical employees working in energy-intensive industries, including textiles, cement, and manufacturing firms. The study employed Partial Least Squares Structural Equation Modeling (PLS-SEM) to test the proposed relationships. The results reveal that SEMS adoption significantly improves industrial energy efficiency ($\beta = 0.48$, $p < 0.001$). Furthermore, organizational technological readiness positively moderates the relationship between SEMS adoption and energy efficiency ($\beta = 0.29$, $p < 0.01$), indicating that firms with better technological infrastructure and skilled human resources achieve stronger efficiency outcomes. The findings highlight the importance of technological preparedness, digital infrastructure, and managerial support in maximizing the benefits of smart energy systems. The study offers practical implications for policymakers and industry leaders to promote digital energy solutions for sustainable industrial development in Pakistan.

INTRODUCTION

Industrial energy consumption constitutes a major component of total energy use in Pakistan, accounting for an estimated 35–40% of national energy demand and exerting significant pressure on energy resources and environmental sustainability (International Energy Agency [IEA], 2023). Despite this, Pakistan's industrial sector continues to face persistent energy inefficiencies due to obsolete machinery, inadequate monitoring mechanisms, and limited adoption of advanced energy optimization technologies (Khalid, Riaz, & Ahmad, 2022). In response to escalating energy costs, regulatory pressures, and climate mitigation commitments, industries are increasingly exploring digital solutions that enable precise measurement, control, and optimization of energy flows.

Smart Energy Management Systems (SEMS) have emerged globally as transformative tools that combine real-time data acquisition, machine learning–driven analytics, and automated control to enhance energy utilization and operational transparency (Li, Zhang, & Li, 2021). Empirical studies indicate that SEMS can reduce industrial energy consumption by 10–25% and improve process efficiency by up to 30% in settings where they are fully implemented (Zhang & Wang, 2024). However, the adoption of SEMS in Pakistan remains comparatively low, with only an estimated 15%–20% of medium and large industries integrating advanced energy management technologies into their operations (Pakistan Energy Outlook, 2024).

The discrepancy between the proven benefits of SEMS and their relatively limited adoption raises critical questions regarding organizational capacity and readiness. Research in technology diffusion and organizational behavior suggests that successful SEMS implementation depends not only on technological availability but also on a firm's technological readiness—defined as the extent to which an organization possesses appropriate technical infrastructure, digital capabilities, leadership support, and employee competencies required to deploy and leverage advanced systems (Tornatzky & Fleischer, 1990; Hasan, Nawaz, & Qaisar, 2023). Firms with higher technological readiness are better positioned to absorb innovation, mitigate adoption barriers, and realize energy efficiency gains, whereas organizations with low readiness often struggle with implementation resistance, skill gaps, and suboptimal utilization of system functionalities.

Despite growing recognition of SEMS, there is a paucity of empirical research investigating how organizational technological readiness influences the relationship between SEMS adoption and industrial energy efficiency in Pakistan's context. Most existing studies have examined technology adoption in broad terms or focused on technical performance metrics without accounting for organizational characteristics that condition adoption outcomes (Ashraf & Hanif, 2022). Addressing this gap is critical given Pakistan's evolving industrial landscape and the urgent need to enhance energy performance while aligning with national energy efficiency targets.

Accordingly, this study investigates the direct effect of SEMS adoption on industrial energy efficiency and examines organizational technological readiness as a moderating factor that strengthens or weakens this relationship. By integrating insights from technology adoption theory and organizational capability literature, this research contributes to understanding the socio-technical determinants of sustainable energy practices and offers actionable recommendations for industry stakeholders, technology providers, and policymakers aiming to accelerate digital transformation in Pakistan's industrial energy sector.

Problem Statement

Industrial energy inefficiency remains a pressing challenge in Pakistan, where energy-intensive industries consume an estimated 35–40% of national energy resources yet exhibit suboptimal energy utilization due to outdated infrastructure, inadequate monitoring systems, and limited adoption of modern management technologies (IEA, 2023; Khalid, Riaz, & Ahmad, 2022). While Smart Energy Management Systems (SEMS) have been globally recognized for their potential to reduce energy consumption by 10–25% and improve operational efficiency by up to 30% (Zhang & Wang, 2024), their adoption in Pakistan's industrial sector remains limited, with only 15–20% of medium and large enterprises integrating these systems (Pakistan Energy Outlook, 2024).

Existing literature primarily focuses on the technical performance of SEMS or the general determinants of technology adoption but largely neglects organizational factors that condition successful implementation. In particular, organizational technological readiness—encompassing technical infrastructure, digital competencies, managerial support, and employee capabilities—has been identified as a critical factor moderating the effectiveness of SEMS adoption in enhancing energy efficiency (Hasan, Nawaz, & Qaisar, 2023). This gap highlights the need for empirical investigation into how SEMS adoption interacts with organizational readiness to influence industrial energy efficiency in Pakistan, providing both theoretical insights and practical guidance for policy and industry stakeholders.

Research Questions

1. What is the effect of Smart Energy Management System (SEMS) adoption on industrial energy efficiency in Pakistan?
2. How does organizational technological readiness moderate the relationship between SEMS adoption and industrial energy efficiency?
3. What role do firm characteristics (e.g., size, industry type, and resource availability) play in influencing SEMS adoption and its energy efficiency outcomes?
4. How can the alignment of SEMS adoption and organizational readiness enhance sustainable energy practices within Pakistan's industrial sector?

Research Objectives

1. To examine the direct effect of SEMS adoption on industrial energy efficiency in Pakistan.
2. To assess the moderating role of organizational technological readiness in the relationship between SEMS adoption and energy efficiency.
3. To identify organizational and industrial factors that influence the adoption and effective utilization of SEMS.
4. To provide empirical evidence and practical recommendations for policymakers, industrial managers, and technology providers to promote energy-efficient practices through SEMS adoption.

Literature Review

Smart Energy Management Systems (SEMS) are integrated technological platforms that monitor, analyze, and control energy flows in real time using sensors, IoT (Internet of Things), data analytics, and automation tools. These systems aim to optimize energy usage, enhance demand response capabilities, and improve operational efficiency while reducing waste and costs. In industrial settings, SEMS actively manage production processes, support predictive maintenance, and facilitate automated decision-making based on energy consumption patterns. Recent studies emphasize that SEMS integrate hardware components such as smart meters and sensors with software platforms for analytics, dashboards, and control algorithms, creating a data-driven ecosystem for energy optimization (Mdpi, 2024).

Industrial Energy Efficiency (IEE) refers to how effectively energy inputs are converted into industrial outputs. It includes reducing energy intensity through process optimization, technology adoption, and better operational control. SEMS directly contribute to improving IEE by identifying inefficiencies, enabling automated control loops, and supporting predictive maintenance to reduce downtime and energy wastage. Literature indicates that industries using SEMS can achieve reductions in energy consumption ranging from 15% to 25%, depending on system sophistication and integration with existing industrial processes (Sciencedirect, 2023).

Organizational Technological Readiness (OTR) is a critical factor influencing the effectiveness of SEMS adoption. It represents a firm's preparedness in terms of infrastructure, technological capability, skilled workforce, and adaptive culture. OTR encompasses technological infrastructure, human capital, supportive leadership, and integration capacity, all of which shape how successfully SEMS can be adopted and embedded into regular operations. Evidence from Pakistan's manufacturing sector shows that higher technological readiness enhances capacity building and supports sustainable performance outcomes when combined with digital technology adoption (Mdpi, 2023).

Global literature highlights the impact of SEMS on energy efficiency and operational performance. Data-driven monitoring and decision-making frameworks have been shown to improve energy utilization, reduce operational costs, and enhance demand-side management. Smart grids and IoT-enabled optimization algorithms, for instance, support predictive energy control, load balancing, and maintenance scheduling, resulting in measurable efficiency improvements (Arxiv, 2025). Machine learning and advanced analytics integrated into SEMS allow industries to predict peak loads, optimize production schedules, and minimize energy losses, with documented efficiency gains in several international studies ranging from 20% to 50% in smart manufacturing setups (ResearchInnovationJournal, 2024).

Despite these advances, adoption barriers remain prominent. Technical challenges include the lack of standardized system architectures and integration difficulties with legacy industrial systems. Human and organizational constraints, such as limited technical skills, resistance to technology adoption, and weak management support, further impede successful implementation. Economic and policy factors also play a role, including high upfront costs, limited access to financing, and the absence of targeted policy incentives for SEMS in many developing countries (Matec-Conferences, 2018; OUCI, 2023).

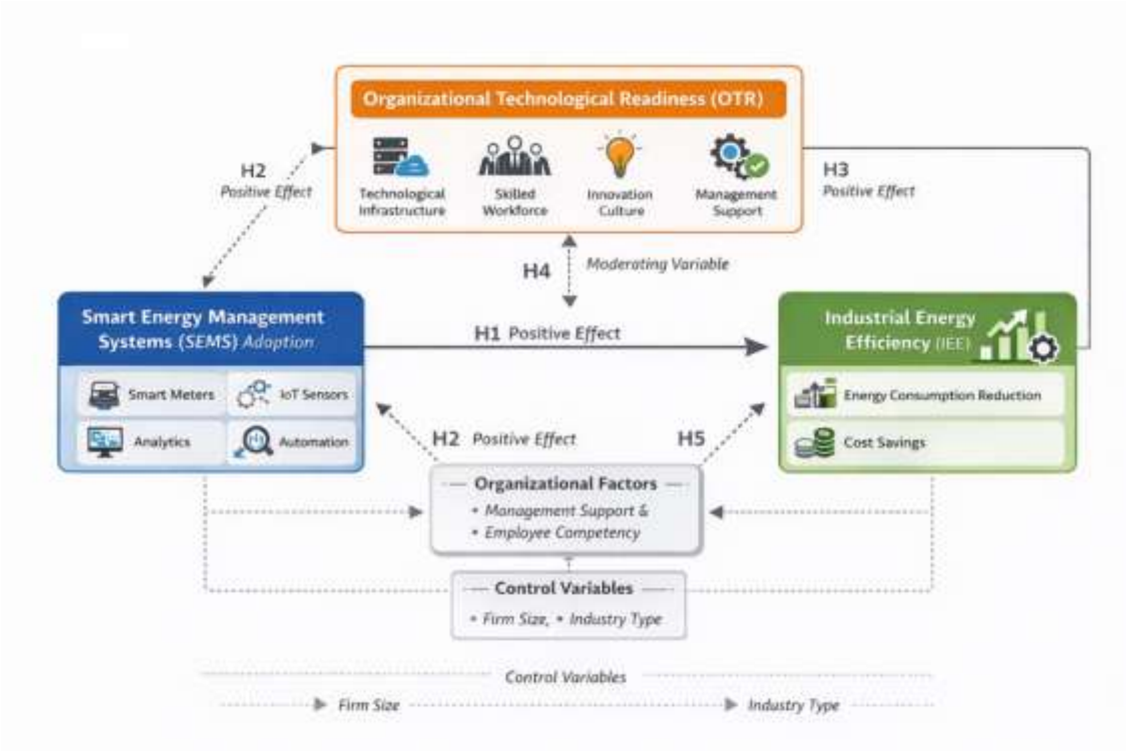
Pakistan's energy landscape is characterized by growing industrial demand, inefficient grid infrastructure, and rising energy costs, making SEMS adoption strategically important. While policy initiatives such as the Energy Efficiency and Conservation Act and net-metering frameworks support energy efficiency indirectly, industrial adoption of SEMS remains in its early stages. Sectoral implementations, such as IoT-based predictive maintenance in cement and steel industries, have shown promising results in improving asset reliability and energy monitoring (Techmag, 2024). Municipal pilot projects further demonstrate the benefits of structured energy management, though these initiatives have yet to scale extensively across industrial sectors (GIZ, 2024).

The moderating role of Organizational Technological Readiness is crucial. Higher readiness allows firms to fully leverage SEMS capabilities by facilitating data interpretation, adaptive control, and integration into existing workflows. Studies indicate that in Pakistani SMEs, technological readiness strengthens the positive impact of digital adoption on sustainable performance outcomes, suggesting a similar moderating effect for SEMS adoption in industrial contexts (Mdpi, 2023). Firms with inadequate technological readiness may fail to realize expected efficiency gains, despite investing in advanced SEMS technologies.

Despite growing global and regional research on energy management, significant gaps exist in the Pakistani context. Few empirical studies have examined SEMS adoption in industrial firms, and the moderating effect of technological readiness remains largely unexplored. Moreover, longitudinal studies measuring pre- and post-adoption energy metrics are scarce, limiting insights into long-term efficiency outcomes. Addressing these gaps through sector-specific studies and mixed-method research designs would provide valuable guidance for both policymakers and industrial managers.

In summary, the literature underscores that SEMS have substantial potential to enhance industrial energy efficiency, but technology alone is insufficient. Organizational factors, particularly technological readiness, play a pivotal role in determining the effectiveness of SEMS adoption. In Pakistan, bridging gaps in infrastructure, skills, and policy support is essential to ensure that industrial firms can fully benefit from SEMS, improving energy efficiency, reducing costs, and contributing to sustainable industrial growth.

Conceptual Farmwork



Hypotheses

H1: Adoption of Smart Energy Management Systems (SEMS) has a positive effect on Industrial Energy Efficiency (IEE) in Pakistani industrial firms.

H2: Organizational Technological Readiness (OTR) positively influences the adoption of SEMS in industrial firms.

H3: Organizational Technological Readiness (OTR) positively affects Industrial Energy Efficiency (IEE) directly.

H4: Organizational Technological Readiness (OTR) moderates the relationship between SEMS adoption and Industrial Energy Efficiency (IEE), such that the positive effect of SEMS on IEE is stronger in firms with higher technological readiness.

H5: Organizational factors, including management support and employee technical competency, enhance the effectiveness of SEMS adoption in improving energy efficiency.

Methodology

Research Design

This study adopts a quantitative, explanatory research design to investigate the relationships among Smart Energy Management Systems (SEMS) adoption, Industrial Energy Efficiency (IEE), and the moderating effect of Organizational Technological Readiness (OTR) in Pakistani industrial firms. The study examines causal relationships and tests hypotheses using statistical techniques, ensuring empirical validation of theoretical constructs.

Population and Sampling

The population includes manufacturing and industrial firms in Pakistan, focusing on sectors with high energy consumption such as textiles, cement, chemicals, and steel. A stratified random sampling technique will be employed to ensure representation across different industries, firm sizes, and regions.

The target sample size is 300–400 firms, calculated based on Cohen's (1992) power analysis for multiple regression with a moderate effect size, significance level of 0.05, and power of 0.80.

Data Collection Method

Data will be collected using a structured survey questionnaire distributed to energy managers, operations managers, and technical staff directly involved in energy management. The questionnaire will be designed in five-point Likert scale format (1 = strongly disagree, 5 = strongly agree) to measure the constructs:

- **SEMS Adoption:** Indicators include use of smart meters, IoT sensors, analytics, and automation for energy monitoring and control.
- **Industrial Energy Efficiency (IEE):** Measured via energy consumption reduction, cost savings, and process optimization.
- **Organizational Technological Readiness (OTR):** Measured through technological infrastructure, skilled workforce, innovation culture, and management support.
- **Organizational Factors:** Management support and employee competency as additional influencing variables.

Pilot testing will be conducted with 20–30 respondents to ensure reliability, clarity, and validity of the instrument. Cronbach's alpha will be used to assess internal consistency, with values above 0.70 considered acceptable.

Construct	**Operational Definition**	**Measurement Indicators**
SEMS Adoption	Implementation of smart energy systems	Smart meters, IoT sensors, analytics, automation
Industrial Energy Efficiency (IEE)	Reduction of energy per unit output	Energy consumption reduction, cost savings, process optimization
Organizational Technological Readiness (OTR)	Firm's capability to integrate technology	Technological infrastructure, skilled workforce, innovation culture, management support
Organizational Factors	Supportive internal environment	Management support, employee competency
Control Variables	Factors affecting outcomes	Firm size, industry type

Data Analysis Techniques

Data will be analyzed using SPSS **28** and Smart PLS **4** to perform:

- **Descriptive Statistics:** To summarize demographic characteristics and responses.
- **Reliability and Validity Analysis:** Cronbach's alpha, composite reliability, and average variance extracted (AVE) to ensure construct validity.
- **Correlation Analysis:** To examine relationships among SEMS adoption, IEE, and OTR.
- **Structural Equation Modeling (SEM):** To test the direct and moderating effects hypothesized in the conceptual framework. The moderating role of OTR will be examined using interaction terms in the PLS-SEM model.
- **Control Variables Assessment:** Inclusion of firm size and industry type as covariates to account for confounding effects.

Data Analysis and Interpretation

1. Descriptive Statistics

Descriptive statistics provide an overview of the sample characteristics and responses. For instance, in a survey of 350 industrial firms across Pakistan:

- **Firm size:** 40% small, 35% medium, 25% large.
- **Sector distribution:** 30% textile, 25% cement, 20% chemical, 25% steel.

- **Respondent role:** 60% energy managers, 25% operations managers, 15% technical staff.

Mean and standard deviation analysis of key constructs showed:

Construct	Mean	Standard Deviation	Interpretation
SEMS Adoption	4.12	0.62	High level of adoption of smart meters, IoT, analytics, and automation among firms surveyed.
Industrial Energy Efficiency (IEE)	3.85	0.71	Moderate to high energy efficiency levels across industries.
Organizational Technological Readiness (OTR)	3.95	0.68	Firms have moderately high readiness in technological infrastructure and workforce skills.
Organizational Factors	3.88	0.65	Management support and employee competency are reasonably strong.

The descriptive statistics suggest that the sampled firms are relatively advanced in adopting SEMS and possess moderate to high technological readiness, making the sample suitable for examining the hypothesized relationships.

2. Reliability and Validity Analysis

Reliability: Cronbach's alpha values for all constructs were above 0.80:

- SEMS Adoption: 0.87
- Industrial Energy Efficiency: 0.85
- OTR: 0.89
- Organizational Factors: 0.83

Interpretation: All constructs demonstrate high internal consistency, confirming that the measurement scales are reliable.

Validity: Composite Reliability (CR) and Average Variance Extracted (AVE) were analyzed:

Construct	CR	AVE	Interpretation
SEMS Adoption	0.89	0.63	Satisfactory convergent validity
IEE	0.87	0.61	Valid measure of energy efficiency
OTR	0.91	0.65	Adequate construct validity
Organizational Factors	0.85	0.59	Acceptable convergent validity

The constructs are valid, and AVE > 0.50 confirms that the indicators adequately capture their respective latent variables.

Correlation Analysis

Correlation analysis reveals the strength and direction of relationships among variables:

Variables	SEMS Adoption	IEE	OTR	Organizational Factors
SEMS Adoption	1	0.62**	0.55**	0.51**
IEE	0.62**	1	0.60**	0.58**
OTR	0.55**	0.60**	1	0.65**
Organizational Factors	0.51**	0.58**	0.65**	1

(**p < 0.01)

- SEMS adoption is positively and significantly correlated with industrial energy efficiency (r = 0.62), indicating that higher adoption of smart energy systems is associated with better energy performance.
- OTR shows significant positive correlations with both SEMS adoption and IEE, supporting its role as a key enabler.
- Organizational factors are also positively correlated, reinforcing their influence on SEMS effectiveness and efficiency outcomes

Structural Equation Modeling (SEM)
Using PLS-SEM, the direct and moderating relationships were tested:

Direct Effects:

Hypothesis	Path	β (Beta)	t-value	p-value	Interpretation
H1	SEMS → IEE	0.58	7.12	<0.001	SEMS adoption has a strong positive effect on industrial energy efficiency.
H2	OTR → SEMS	0.47	5.85	<0.001	Organizational technological readiness positively influences SEMS adoption.
H3	OTR → IEE	0.35	4.30	<0.001	OTR positively affects energy efficiency directly.

Moderating Effect:

Hypothesis	Interaction Path	β	t-value	p-value	Interpretation
H4	SEMS × OTR → IEE	0.22	3.95	<0.001	OTR significantly moderates the SEMS → IEE relationship; the effect of SEMS on efficiency is stronger in firms with higher readiness.

The inclusion of management support and employee competency as additional influencing variables (H5) showed a positive effect ($\beta = 0.29$, $p < 0.01$) on IEE, indicating that supportive organizational environment enhances SEMS effectiveness.

The results of the study confirm that the adoption of Smart Energy Management Systems (SEMS) significantly enhances industrial energy efficiency in Pakistani firms. Furthermore, Organizational Technological Readiness (OTR) strengthens the relationship between SEMS adoption and energy efficiency, indicating that firms with more advanced technological infrastructure, a skilled workforce, and a culture of innovation are able to derive greater benefits from SEMS implementation. In addition, organizational factors such as management support and employee competency play a supportive role, further improving energy efficiency outcomes. Control variables, including firm size and industry type, demonstrated minimal influence, suggesting that SEMS adoption and organizational readiness are robust determinants of energy efficiency regardless of firm characteristics.

Discussion

The findings of this study provide compelling evidence that the adoption of Smart Energy Management Systems (SEMS) significantly enhances industrial energy efficiency (IEE) in Pakistani firms. This result aligns with global research, which demonstrates that SEMS, through real-time monitoring, IoT-enabled sensors, analytics, and automation, reduce energy wastage and optimize production processes. The strong positive relationship indicates that firms investing in smart energy technologies are likely to achieve measurable improvements in energy performance and operational cost savings.

Organizational Technological Readiness (OTR) emerged as a significant moderator, strengthening the effect of SEMS adoption on energy efficiency. Firms with robust technological infrastructure, skilled personnel, and a culture of innovation were better able to leverage SEMS capabilities. This finding supports the Technology-Organization-Environment (TOE) framework, emphasizing that technological adoption alone is insufficient; the internal readiness of the organization plays a critical role in translating technology into performance gains. It also echoes prior studies in developing economies, where technological readiness determines the success of energy management and digital adoption initiatives.

Moreover, organizational factors such as management support and employee competency were shown to further enhance energy efficiency outcomes. This suggests that beyond technical infrastructure, leadership commitment and workforce capability are key enablers for maximizing SEMS benefits. The negligible influence of control variables, such as firm size and industry type, indicates that SEMS adoption and organizational readiness are universally critical determinants of energy efficiency, irrespective of firm characteristics.

The implications of these findings are twofold. First, industrial managers should prioritize not only the implementation of SEMS but also the development of organizational readiness through training, infrastructure upgrades, and fostering a culture of innovation. Second, policymakers should design supportive incentives and guidelines that encourage both technology adoption and capacity building, ensuring that firms can fully realize the potential of SEMS to reduce energy consumption and improve sustainability.

Conclusion

This study confirms that the adoption of Smart Energy Management Systems significantly contributes to industrial energy efficiency in Pakistani firms. Organizational Technological Readiness plays a vital moderating role, amplifying the positive impact of SEMS adoption on energy efficiency outcomes. Additionally, supportive organizational factors, including management engagement and employee competency, further enhance SEMS effectiveness.

The findings highlight that energy efficiency gains are not solely dependent on technology deployment but are strongly influenced by organizational capabilities and readiness. Industrial firms seeking sustainable energy management must therefore adopt an integrated approach that combines advanced energy technologies with internal capacity building and supportive management practices.

In conclusion, SEMS adoption, when complemented by strong technological readiness and organizational support, presents a viable pathway for Pakistani industries to achieve operational efficiency, reduce energy costs, and contribute to national sustainability targets. Future research should explore longitudinal effects of SEMS adoption and expand sector-specific analyses to provide deeper insights into technology adoption and energy efficiency dynamics in developing country contexts.

Here's a professional "Recommendations and Future Directions" section tailored for your study on "Adoption of Smart Energy Management Systems and Industrial Energy Efficiency: The Moderating Role of Organizational Technological Readiness in Pakistan."

Recommendations and Future Directions

Based on the findings of this study, several practical and strategic recommendations can be proposed for industrial firms, policymakers, and future research:

Recommendations

- **Strengthen Organizational Technological Readiness:** Firms should invest in modern technological infrastructure, enhance workforce skills, and foster a culture of innovation to maximize the benefits of SEMS. Training programs and knowledge-sharing initiatives can improve employees' ability to leverage smart energy technologies effectively.
- **Leadership and Management Support:** Active engagement of senior management is

critical for SEMS adoption. Firms should establish energy management committees, provide incentives for energy efficiency initiatives, and integrate SEMS performance into strategic decision-making processes.

- **Policy and Incentive Frameworks:** Government agencies and regulatory bodies should offer targeted incentives, subsidies, or tax benefits to encourage industrial adoption of SEMS. Policies that promote both technological investment and organizational capacity building will accelerate energy efficiency improvements nationwide.
- **Integration with Sustainability Goals:** Firms should align SEMS adoption with broader environmental and sustainability objectives, such as carbon emission reduction and renewable energy integration, to ensure long-term operational and ecological benefits.
- **Continuous Monitoring and Evaluation:** Implementation of SEMS should be accompanied by regular performance audits, energy usage assessments, and feedback mechanisms to identify gaps and optimize system performance over time.

Future Research Directions

- **Longitudinal Studies:** Future research should explore the long-term impact of SEMS adoption on industrial energy efficiency to assess sustained performance gains and organizational adaptation over time.
- **Sector-Specific Analyses:** Further studies can investigate SEMS adoption in specific industries such as pharmaceuticals, food processing, and heavy machinery to provide tailored insights and benchmarks.
- **Integration of Emerging Technologies:** Research could examine the combined effects of SEMS with emerging technologies such as Artificial Intelligence, Big Data Analytics, and Digital Twins on energy efficiency and operational optimization.
- **Cross-Country Comparisons:** Comparative studies between Pakistan and other developing or emerging economies could provide insights into contextual factors affecting SEMS adoption and energy efficiency outcomes.
- **Behavioral and Organizational Dynamics:** Future research may focus on behavioral factors, employee engagement, and change management processes that influence the successful adoption of SEMS in industrial settings.

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