International Journal of Advanced Technology in Engineering and Science
Vol. No. 14, Issue No. 10, October 2026
www.ijates.com
ijates
ISSN 2348 - 7550

Enhancing Energy Efficiency in Electrical Engineering Through Artificial Intelligence: A Sustainability-Oriented Review with India, Qatar and GCC Context

Mohamed Fahad Badurul Haq[1]

[1]*PhD Scholar, Asian International University, Imphal West, Ghari, Manipur, 795140, India*

Research Supervisor - Dr. Neeraj Tiwari[2]

[2]*Associate Professor, Asian International University,*
Imphal West, Ghari, Manipur, 795140, India

Abstract

Artificial intelligence (AI) is increasingly used to improve energy efficiency in electrical engineering applications, including building systems, smart appliances, predictive maintenance, and grid-interactive control. This review examines how machine learning, deep learning, reinforcement learning, and AI–IoT approaches support energy forecasting, anomaly detection, automated control, and power optimization. It considers their relevance to Qatar, the wider Gulf Cooperation Council (GCC), and India. In Qatar and the GCC, AI can help manage cooling-intensive buildings and support distributed solar energy. In India, it can support efficient cooling, industrial energy management, renewable-energy integration, and electricity distribution across varied climates and demand patterns. These opportunities must be weighed against model complexity, computational energy use, data quality, cybersecurity risks, and implementation costs. The paper concludes that effective adoption requires measurable energy baselines, explainable control decisions, resilient systems, and policies suited to each region's energy needs.

INTRODUCTION

Energy efficiency has moved from a desirable engineering objective to a strategic requirement in the context of climate pressures, rising electricity consumption, and the need to modernize infrastructure. Recent literature consistently frames AI as a useful instrument for energy optimization because it can process multi-source data, improve forecasting accuracy, automate control actions, and identify patterns that are difficult to detect using conventional rules-based systems In the electrical engineering domain, this has translated into AI-assisted applications for load prediction, HVAC optimization, demand response, smart metering, appliance management, non-intrusive load monitoring, and predictive maintenance of energy assets

The practical importance of these applications is even greater in hot-climate regions where cooling demand shapes annual and seasonal electricity use. For this reason, a regionally grounded discussion is useful for final submission quality. Qatar is an appropriate case because official sources position sustainability, environmental development, and knowledge-based modernization at the center of national policy through Qatar National Vision 2030, while energy-sector institutions have launched programs and strategies that explicitly target conservation, renewable energy deployment, and lower-carbon growth.

II. LITERATURE BASIS AND ANALYTICAL SCOPE

Recent review literature places AI for energy efficiency at the intersection of sensing, analytics, optimization, and control. Toderas presents AI for sustainability as a systems topic, emphasizing climate action, net-zero goals, ecological risk, and responsible deployment. Olagundoye et al. review AI applications in smart grids and smart homes, including forecasting, adaptive scheduling, and real-time energy optimization. Li et al. identify fault diagnosis, forecasting, scheduling, and operational control as important applications in building energy systems. Ogundiran et al. examine AI for thermal comfort, indoor air quality, energy prediction, anomaly detection, and HVAC management. Powroźnik and Szcześniak show how machine learning can help households respond to dynamic pricing and variable renewable generation.

These applications are also relevant to **India**, where energy-management systems must serve buildings, households, industries, and electricity networks across varied climates and demand patterns. AI could help manage cooling loads, identify energy waste, forecast demand, and coordinate electricity use with renewable generation. Taken together, the literature suggests that AI's contribution extends beyond predictive accuracy: it can turn energy data into timely decisions that reduce waste, shift load, improve asset use, and help buildings and users interact more effectively with electricity networks.

Literature stream	**Primary contribution to efficiency**	**Typical application domain**
AI for sustainability	Links digital optimization to climate and sustainability goals	Cross-sector energy and sustainability planning
Low-carbon smart homes and grids	Supports scheduling, demand-side management, and renewable integration	Smart homes, microgrids, distributed energy
Building energy systems	Improves diagnosis, prediction, scheduling, and control	HVAC, lighting, operations, asset management

Buildings and IEQ	Balances energy reduction with indoor environmental quality	Commercial/residential buildings
Household predictive analytics	Optimizes domestic consumption under price and demand variability	Smart homes and consumer energy management

III. HOW AI IMPROVES ENERGY EFFICIENCY IN ELECTRICAL ENGINEERING

A. Forecasting and predictive optimization

Forecasting remains one of the most visible energy-efficiency use cases for AI. Machine learning and deep learning allow systems to estimate future demand, identify consumption patterns, and anticipate operational deviations. In buildings, this enables pre-emptive adjustment of HVAC set points, lighting schedules, and equipment operation . In households and prosumer systems, predictive analytics can align appliance operation with tariff signals and renewable generation availability, thereby reducing cost and peak consumption Review evidence also indicates that reinforcement learning and hybrid approaches are increasingly used where energy management requires adaptive decisions under uncertainty

B. Predictive maintenance and anomaly detection

Energy efficiency is not created only at the planning stage; it is also preserved through condition-aware operation. AI-based anomaly detection and predictive maintenance help identify wasteful behavior, control drift, sensor inconsistencies, or asset degradation before they escalate into higher energy use or system failure. Li et al. identify fault diagnosis as a major machine-learning application area in building energy systems A Qatar-linked review hosted by Qatar University Digital Hub similarly frames AI-based anomaly detection as a way to reduce wasted energy and improve decision-making in residential buildings These ideas are particularly relevant for facilities with heavy cooling loads, where hidden performance degradation can substantially raise energy intensity.

C. Intelligent control of smart buildings and end-use systems

Smart buildings are increasingly treated as controllable energy nodes rather than passive consumers. Recent literature shows that AI and IoT integration can support occupancy-aware HVAC control, lighting automation, energy forecasting, renewable coordination, and demand-side management In this context, energy efficiency is produced through continuous optimization rather than one-time design compliance. This is important because retrofit-oriented control upgrades are often more feasible than full asset replacement, especially in mature building portfolios.

IV. QATAR AND GCC CONTEXT

A. Policy relevance and national strategy

Qatar National Vision 2030 identifies environmental development as one of the country's four development pillars and frames the national challenge as balancing growth with human and natural resources This high-level direction matters for engineering research because it explicitly links modernization, sustainability, and long-term living standards. At the sector level, official material from QatarEnergy states that the National Climate Change Action Plan targets a 25% reduction in Qatar's greenhouse-gas emissions by 2030 against a business-as-usual scenario with a 2019 baseline.These national sources justify the relevance of energy-efficiency research that can convert digital innovation into measurable operational savings.

B. KAHRAMAA programs and renewable-energy deployment

Qatar's energy-efficiency agenda is not only strategic but also programmatic. KAHRAMAA describes Tarsheed as the national campaign for the conservation and efficient use of water and electricity, aligned with Qatar National Vision 2030 In 2024, QNA reported that the Tarsheed program achieved approximately QAR 840 million in financial savings while reducing carbon emissions by 1.2 million tons; the same report also stated that the 2024 forum discussed smart systems, sustainability, IoT-based building management, and AI applications in smart buildings [9]. In parallel, the Qatar National Renewable Energy Strategy aims to expand renewable deployment and improve network readiness. Official KAHRAMAA material states a goal of deploying about 4 GW of utility-scale renewable capacity by 2030 and around 200 MW of distributed renewable generation, while recommending measures that maintain network reliability and enhance energy resilience.

C. Why the Qatari building sector matters

The regional case is especially compelling in buildings, where climate and building morphology significantly shape demand. A recent Qatar-focused study of residential compounds analyzed 172,796 residential buildings using KAHRAMAA data and reported a strong positive correlation ($R = 0.97$) between energy consumption and total built area Another Qatar-oriented study found that a modelled villa's annual electricity consumption could rise by 22% by 2100 and summer peaks by 26%, while rooftop PV remained financially viable with paybacks of 5–8 years These studies reinforce the value of AI-enabled forecasting, load management, rooftop solar coordination, and adaptive control in a cooling-dominant environment.

D. GCC-wide significance

The wider GCC context also strengthens the relevance of AI for energy efficiency. The GCC Interconnection Authority states that it has united the power grids of the UAE, Bahrain, Saudi Arabia, Oman, Qatar, and Kuwait into a single resilient network since 2009, with the aim of ensuring reliable and more sustainable electricity supply and optimizing generation resources. This means that AI-

enhanced efficiency at the building, distribution, and demand-response level can generate benefits that scale beyond individual assets and potentially support a more resilient regional electricity ecosystem.

V. CHALLENGES, LIMITATIONS, AND IMPLEMENTATION PRIORITIES

The literature does not suggest that AI adoption is automatic or risk free. Toderas emphasizes ecological footprint and governance concerns associated with AI Building-oriented reviews identify persistent issues related to interoperability, data quality, privacy, cyber risk, upfront investment, and limited real-world deployment. These constraints are especially important when energy systems are connected to wider digital infrastructure, because poor data governance or fragile integration can undermine both operational reliability and energy savings. In practical terms, final submission-ready arguments should therefore emphasize explainability, hardware-software interoperability, measurement and verification, and user-centered retrofitting rather than technology enthusiasm alone.

For Qatar and the GCC, these priorities translate into five implementation points. First, AI should be layered onto strong metering and data-quality foundations. Second, efficiency gains should be measured against clear baselines such as cooling load, occupancy, and seasonal demand. Third, model selection should favor operationally interpretable approaches when the use case involves safety-critical or comfort-critical controls. Fourth, digital energy management should be linked to regional policy instruments, including renewable integration and conservation programs. Fifth, AI design itself should remain efficient, consistent with the emerging Green AI perspective that warns against achieving sustainability goals using unnecessarily resource-intensive models.

VI. CONCLUSION

AI is now a credible engineering pathway for improving energy efficiency, particularly where energy systems generate continuous operational data and where demand profiles are shaped by climate variability, occupancy patterns, and distributed energy resources. The literature reviewed in this paper shows that AI can improve forecasting, automate efficient control, detect anomalies, and support predictive maintenance across buildings, households, and network-facing systems The Qatar and GCC context makes this discussion more than theoretical: official sources document a policy and infrastructure environment that is actively pursuing conservation, renewable integration, and sustainability through Qatar National Vision 2030, Tarsheed, QNRES, and the GCC grid interconnection . The key conclusion is therefore practical: AI should be implemented as part of a disciplined energy-management architecture that links data, control, resilience, and policy. When deployed this way, it can support both local asset performance and broader national and regional sustainability outcomes.

ijates
ISSN 2348 - 7550

REFERENCES

[1] M. Toderas, "Artificial Intelligence for Sustainability: A Systematic Review and Critical Analysis of AI Applications, Challenges, and Future Directions," Sustainability, vol. 17, no. 17, p. 8049, 2025, doi: 10.3390/su17178049.

[2] O. O. Olagundoye et al., "A Review of Artificial Intelligence Techniques for Low-Carbon Energy Integration and Optimization in Smart Grids and Smart Homes," Processes, vol. 14, no. 3, p. 464, 2026, doi: 10.3390/pr14030464.

[3] D. Li, Z. Qi, Y. Zhou, and M. Elchalakani, "Machine Learning Applications in Building Energy Systems: Review and Prospects," Buildings, vol. 15, no. 4, p. 648, 2025, doi: 10.3390/buildings15040648.

[4] J. Ogundiran, E. Asadi, and M. Gameiro da Silva, "A Systematic Review on the Use of AI for Energy Efficiency and Indoor Environmental Quality in Buildings," Sustainability, vol. 16, no. 9, p. 3627, 2024, doi: 10.3390/su16093627.

[5] P. Powroźnik and P. Szcześniak, "Predictive Analytics for Energy Efficiency: Leveraging Machine Learning to Optimize Household Energy Consumption," Energies, vol. 17, no. 23, p. 5866, 2024, doi: 10.3390/en17235866.

[6] National Planning Council, "Qatar National Vision 2030," State of Qatar. [Online]. Available: https://www.npc.qa/en/QNV/pages/default.aspx

[7] QatarEnergy, "National and International Alignment," Sustainability. [Online]. Available: https://www.qatarenergy.qa/en/Sustainability/Pages/NationalAndInternationalAlignment.aspx

[8] Qatar General Electricity & Water Corporation (KAHRAMAA), "Tarsheed Intro." [Online]. Available: https://www.km.qa/Tarsheed/Pages/TarsheedIntro.aspx

[9] Qatar News Agency, "KAHRAMAA's Tarsheed Program Saves QAR 840 Million in 2024, Cuts Carbon Emissions by 1.2 Million Tons," Nov. 4, 2024. [Online]. Available: https://qna.org.qa/en/news/news-details?id=0083-kahramaa%27s-tarsheed-program-saves-qar-840-million-in-2024,-cuts-carbon-emissions-by-12-million-tons&date=4/11/2024

[10] KAHRAMAA, "Qatar National Renewable Energy Strategy / BeSolar." [Online]. Available: https://www.km.qa/RenewableEnergy/Pages/BeSolar.aspx

[11] Y. Himeur, K. Ghanem, A. Alsalemi, F. Bensaali, and A. Amira, "Artificial intelligence based anomaly detection of energy consumption in buildings: A review, current trends and new perspectives," Applied Energy, 2021, doi: 10.1016/j.apenergy.2021.116601.

[12] R. Al-Mohammed and D. Ouahrani, "Evaluating Energy Consumption in Residential Buildings in Qatar: A Case Study on Compounds," Sustainability, vol. 16, no. 21, p. 9569, 2024, doi: 10.3390/su16219569.

[13] M. I. Khan, D. I. Al Huneidi, F. Asfand, and S. G. Al-Ghamdi, "Climate Change Implications for Optimal Sizing of Residential Rooftop Solar Photovoltaic Systems in Qatar," Sustainability, vol. 15, no. 24, p. 16815, 2023, doi: 10.3390/su152416815.

[14] Gulf Cooperation Council Interconnection Authority, "GCC Interconnection Authority," [Online]. Available: https://gccia.com.sa/