



Engineers' Experiences with Artificial Intelligence Integration in Renewable Energy Systems

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ABSTRACT

Artificial Intelligence (AI) is increasingly integrated into renewable energy systems, offering efficiency and reliability in meeting the growing demands of urban environments. Within this technological advancement, the experiences of engineers who design and implement AI-driven systems remain underexplored, particularly regarding the ethical, emotional, and professional dimensions of their engagement. However, prior studies have largely emphasized technical performance, leaving unanswered how engineers themselves make sense of the challenges and opportunities posed by AI integration. This study addresses this gap by adopting an interpretative phenomenological approach to explore the lived experiences of engineers implementing AI in renewable energy projects. Data were collected through semi-structured, in-depth interviews with twelve practicing engineers and analyzed using Interpretative Phenomenological Analysis (IPA) to capture subjective meaning-making processes. The findings reveal four interconnected themes: negotiating technical complexities, managing ethical responsibility, adapting within multidisciplinary teams, and developing trust that fosters professional growth. These findings provide new empirical insights into how engineers construct professional meaning and navigate ethical dilemmas in technologically dynamic contexts. They underscore the dual nature of AI integration—as both a catalyst for innovation and a source of professional tension—highlighting the importance of reflective practice and ethical awareness in engineering design. This study's primary contribution lies in advancing a human-centered understanding of AI integration, emphasizing that technological adoption in renewable energy systems must account for the experiential and moral dimensions of engineering work. Practically, the research offers implications for organizational leaders and policymakers to design training, support mechanisms, and governance frameworks that foster ethical resilience and interdisciplinary collaboration among engineers. By illuminating these dimensions, the research contributes to a more human-centered framework for AI integration in renewable energy systems and lays the groundwork for future investigations across broader contexts.



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INTRODUCTION

The increasing integration of Artificial Intelligence (AI) into renewable energy systems represents one of the most significant technological shifts in contemporary engineering and technology (Cao et al., 2025). Urban areas, in particular, face growing demands for efficient and sustainable energy solutions, positioning AI as a critical enabler for optimizing energy generation, distribution, and consumption (Mukhlis, 2025a). While the technological capabilities of AI in forecasting demand, managing grid stability, and improving efficiency have been well-documented, the human dimension of this transformation has received comparatively less attention.

Beyond technical performance, the adoption of AI in renewable energy systems intersects with broader social and cultural dynamics (Mukhlis, 2025b). Engineers, as central actors in this

transformation, do not merely apply algorithms but engage in a lived process of adaptation, negotiation, and meaning-making (Y. Wang et al., 2025). Their subjective experiences reflect not only professional expertise but also emotional, ethical, and social considerations embedded within the context of urban sustainability and technological innovation (Anani et al., 2025). These dimensions are especially salient in contexts where energy systems directly affect public well-being and societal resilience.

Exploring the subjective experiences of engineers is therefore essential to understanding the deeper implications of AI adoption in renewable energy. Phenomenology offers a lens through which the personal and collective meanings of such experiences can be articulated, beyond surface-level accounts of efficiency or productivity (Guo et al., 2025). This interpretive orientation is vital for illuminating how professionals navigate uncertainty, responsibility, and trust in relation to emerging technologies. By grounding analysis in the lived realities of those directly engaged in AI deployment, the study contributes to a richer and more human-centered understanding of technological transformation in the energy sector.

Research on the lived experiences of professionals in complex technological environments has emerged as a vital field of inquiry, particularly as advanced systems such as Artificial Intelligence (AI) increasingly intersect with human decision-making (Mohammed & Khalid, 2025). In the context of renewable energy, engineers' experiences represent more than technical expertise; they encompass personal, ethical, and social dimensions that shape how technology is understood, trusted, and applied in practice (Mukhlis, Suradi, et al., 2023). Recognizing these subjective dimensions is essential for capturing the holistic reality of technological integration in society.

Despite this importance, methodological challenges persist in exploring the depth of such experiences (Erdat & Çay Şenler, 2025). Much of the existing literature has relied heavily on quantitative frameworks, emphasizing system performance, algorithmic accuracy, or statistical modeling of efficiency (Mukhlis & Saidah, 2025). While valuable, these approaches tend to overlook the nuanced realities of how professionals experience and interpret the implementation of AI in energy systems (Liu et al., 2025). Surveys and statistical measures, for instance, often fail to grasp the emotional tensions, ethical reflections, and evolving professional identities that accompany engineers' engagement with AI.

These limitations suggest that prior research methods, while effective in technical assessments, are insufficient for understanding the full essence of human experience within this phenomenon (Erol et al., 2025). Capturing the lived meaning of engineers' interactions with AI requires an approach capable of accessing subjective interpretations and existential concerns that quantitative analyses alone cannot reveal (Mukhlis & Abdullah, 2025). Phenomenology, with its emphasis on exploring the essence of lived experiences, provides a pathway for addressing this gap, offering the means to illuminate dimensions of meaning that remain obscured in conventional research paradigms.

Current solutions in the field of AI-driven renewable energy systems have predominantly relied on practical, performance-oriented approaches (Florida-Benítez & Coca-Stefaniak, 2025). These approaches often emphasize algorithmic optimization, system efficiency, and predictive accuracy as key outcomes for addressing the increasing complexity of urban energy demands (Mukhlis, Janwari, et al., 2023). While such strategies have advanced the technical reliability of AI systems, they remain limited in capturing the lived realities of those directly engaged in their implementation.

A critical limitation of these approaches is their inability to account for the subjective dimensions of engineers' experiences (Chen & Hu, 2025). By focusing primarily on measurable indicators of success, prior studies have overlooked the deeper layers of meaning through which engineers interpret, negotiate, and adapt to technological change (Mukhlis et al., 2024). As a result, much of the existing knowledge reflects a partial understanding one that highlights technical advancements while neglecting the emotional tensions, ethical responsibilities, and professional transformations inherent in the process of AI integration.

This gap underscores the need for an alternative research orientation that prioritizes the exploration of experience and meaning (Rickli & Vllasi, 2025). Phenomenology, with its capacity to illuminate the essence of lived experiences, offers a more holistic approach to understanding how engineers engage with AI in renewable energy contexts (Mukhlis, Maryam, et al., 2023). By shifting the focus from external outcomes to internal perspectives, phenomenology enables the development of richer insights into the complex interplay between technology, professional identity, and social responsibility.

Previous studies have examined the role of Artificial Intelligence in renewable energy systems, focusing mainly on technical outcomes such as efficiency, optimization, and predictive reliability (Holtbrügge et al., 2025). While these contributions have advanced the field, they have often neglected the human side of technology integration. Research on subjective experiences in engineering contexts remains limited, especially in relation to ethical concerns, emotional tensions, and professional adaptation (Kocak et al., 2025). Theoretical perspectives on human–technology interaction suggest that understanding meaning requires more than technical metrics (Rad, 2025). This study builds on these insights by turning attention to the lived experiences of engineers as central to understanding AI integration in energy systems.

To address this gap, this study adopts an interpretative phenomenological approach. This method was chosen because it is well suited for exploring how individuals make sense of their professional and social realities (Ozbey & Yaşa, 2025). By focusing on the essence of lived experience, phenomenology provides deeper insights into how engineers negotiate uncertainty, responsibility, and trust when working with AI (Mukhlis, Arifin, Ridwan, & Zulbaidah, 2025). This orientation directly responds to the limitations of earlier approaches, which have failed to capture subjective meaning. In doing so, the study offers a human-centered perspective that complements and enriches the existing technical literature.

The structure of this article follows a clear and logical flow. The introduction outlines the significance of the research and positions it within the current body of knowledge (Anser et al., 2025). The next sections describe the context of AI in renewable energy systems and the methodological approach of phenomenology (Richarde et al., 2025). Data collection and analysis procedures are then explained, followed by the presentation of results organized around key themes (Mukhlis, Arifin, Ridwan, Zulbaidah, et al., 2025). Finally, the article discusses the implications of these findings and concludes with reflections on theoretical and practical contributions.

RESEARCH METHODS

Study Design

This study employed an interpretative phenomenological design to explore the lived experiences of engineers engaged in the implementation of Artificial Intelligence (AI) for renewable energy optimization in urban systems. The phenomenological approach was chosen because of its focus on uncovering the subjective meanings embedded within personal and professional experiences. By emphasizing individual perspectives, the design enabled the identification of nuanced insights into how engineers negotiated technical, ethical, and social complexities in their engagement with AI. Interpretative phenomenology, rooted in Heideggerian hermeneutics, was specifically applied to allow for a deeper understanding of the contextual and existential dimensions of participants' experiences, moving beyond surface descriptions toward interpretative meaning.

Participants

Participants consisted of practicing engineers with direct involvement in the design, deployment, or management of AI-driven renewable energy systems. Eligibility was based on professional experience in AI projects related to urban energy infrastructure within the past five years. Engineers who lacked direct implementation roles or whose experiences were exclusively managerial without technical engagement were excluded. Purposive sampling was applied to ensure the inclusion of individuals whose perspectives were most relevant to the research question. The sample comprised

12 engineers, with ages ranging between 29 and 47 years (mean age = 38), including both male and female participants. This diversity in demographic and professional backgrounds enriched the exploration of perspectives and ensured the representation of a range of experiential insights.

Data Collection

Data were collected through semi-structured, in-depth interviews guided by an interview protocol designed to elicit detailed accounts of personal and professional experiences. Each interview lasted between 60 and 90 minutes and was conducted either in a private meeting room at the participants' workplace or via secure online platforms to accommodate availability. The interview environment was arranged to foster comfort and confidentiality, ensuring participants could speak openly about their experiences. All interviews were audio-recorded with consent and later transcribed verbatim. In addition to interviews, observational notes and project-related documents provided supplementary contextual information.

Data Analysis

Data were analyzed using Interpretative Phenomenological Analysis (IPA), following a systematic, iterative process to uncover themes that represented the essence of participants' experiences. The process began with repeated readings of the transcripts to gain a holistic understanding, followed by the identification of meaning units and initial codes. Codes were then clustered into broader categories to capture emerging themes, which were further refined through thematic reduction. NVivo software supported the organization of data but did not replace the interpretative focus of the analysis. Through this stepwise procedure, essential themes were distilled that reflected the intersection of technical, ethical, and social aspects of AI implementation in renewable energy systems.

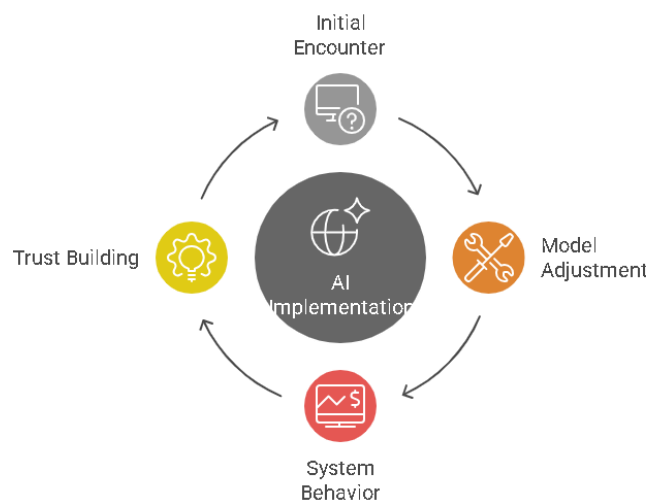
RESULTS

Negotiating Technical Complexities in AI Integration

Participants consistently described their initial encounters with AI implementation as a process marked by technical uncertainty and complex decision-making. Many reflected on the difficulties of adapting AI algorithms to the unpredictable dynamics of renewable energy systems, particularly within urban environments where demand fluctuations are significant. One participant stated:

“We had the models ready, but the system was not behaving as the simulations suggested. Every adjustment felt like walking in the dark until we slowly began to trust the AI's capacity to learn from the environment.” (P3)

AI Adaptation Cycle in Renewable Energy



This testimony illustrates the cognitive tension between reliance on established engineering practices and the need to embrace AI's adaptive logic. Beyond individual experiences, the synthesis of these accounts indicates that engineers collectively redefine their notion of technical mastery—shifting from deterministic problem-solving toward an iterative learning process co-shaped by AI performance. This reframing suggests that effective AI integration depends not only on technical calibration but also on the cultivation of adaptive expertise and tolerance for technological unpredictability.

Emotional Tension and Ethical Responsibility

A recurrent theme was the emotional burden tied to ethical considerations in deploying AI for energy optimization. Engineers expressed concerns about over-reliance on AI decisions, particularly when these could directly impact public energy security. As one participant emphasized:

“I constantly ask myself—what if the system fails during a peak demand? Who will be held accountable, me or the machine? This question never leaves my mind.” (P7)

This account underscores the ethical dilemmas engineers face, navigating between trust in technology and professional accountability. Analytically, these reflections reveal that ethical tension emerges not from technical inadequacy but from the ambiguous distribution of responsibility between human and machine agents. Engineers' self-questioning behaviors demonstrate a moral consciousness that frames AI not merely as an operational asset but as a partner requiring ongoing ethical negotiation. This synthesis highlights that emotional engagement and ethical reflection are integral components of responsible AI engineering, rather than peripheral concerns.

Social Adaptation and Team Dynamics

The participants also described their adaptation process within multidisciplinary teams where AI specialists, data scientists, and traditional energy engineers had to collaborate. Several engineers admitted initial feelings of professional displacement when confronted with data-driven approaches that seemed to overshadow conventional engineering expertise. A participant explained:

“At first, I felt like my engineering knowledge was being replaced by data models. But later, I realized the collaboration was not about replacement, but about finding a new balance between human experience and AI prediction.” (P2)

These reflections reveal the shifting identity of engineers as they integrate into AI-driven teams. The broader analytical synthesis shows that such adaptation involves a dual negotiation: redefining professional legitimacy while constructing a shared epistemic space with data scientists. This process generates new interdisciplinary norms, where engineers' tacit knowledge complements algorithmic reasoning, leading to a hybrid professional identity that values interpretive flexibility over rigid expertise.

Emergent Trust and Professional Growth

Despite initial struggles, most participants described a growing sense of trust in AI systems over time, alongside a recognition of their own professional development. This transformation was often articulated as a personal journey of learning, acceptance, and innovation. As one participant remarked:

“Working with AI has changed the way I think as an engineer. I no longer see it as a tool, but as a partner that forces me to expand my perspective and skills.” (P5)

This emergent trust not only reflects acceptance of technology but also indicates how engagement with AI fosters broader professional growth, enabling engineers to redefine their competencies in line with technological advancement. Synthesizing these narratives reveals that trust is not a static attitude but a developmental process built through iterative interaction and reflective learning. AI thus becomes both a catalyst for professional transformation and a mirror for engineers'

evolving sense of agency, underscoring the interdependence between technological innovation and human self-renewal.

DISCUSSION

This study revealed that engineers' experiences of implementing Artificial Intelligence (AI) in renewable energy systems are shaped by a complex interplay of technical negotiation, ethical responsibility, social adaptation, and professional growth (M. Wang et al., 2025). These findings directly address the guiding research question by uncovering how engineers interpret and respond to the uncertainties, challenges, and opportunities embedded in AI integration.

Contribution of Findings to the Research Question

The findings provide a nuanced answer to the central question of how engineers experience the integration of AI in renewable energy systems (Srivastava et al., 2025). Rather than being limited to technical problem-solving, the experiences highlight a dynamic process of adaptation in which engineers grapple with uncertainty, accountability, and shifting professional identities (Asghar et al., 2025). The discovery that trust in AI emerges gradually and is tied to personal and collective meaning-making represents a critical contribution to understanding human–technology relations (Cho et al., 2025). By framing the engineers' perspectives as central to the success of technological adoption, the study shifts attention from purely technical metrics toward a more holistic appreciation of how professional practices evolve in response to innovation (Alruwaili & Mgamal, 2025). This contribution not only enriches theoretical understanding of phenomenology in engineering contexts but also offers practical insights for fostering more human-centered approaches to technological development.

Relation to Previous Literature and Theory

The results both align with and extend earlier research. Studies such as (Kim et al., 2025) highlighted the importance of human factors in AI adoption, yet they primarily examined these issues through descriptive or system-level perspectives. The present findings deepen this conversation by illustrating the lived emotional tensions and ethical concerns that accompany AI deployment, resonating with (van den Berg, 2025) emphasis on the emotional dimensions of technological change. At the same time, the emergence of trust and professional growth identified in this study complements (Kirikkaleli et al., 2025) work on trust in AI, while extending it by situating trust within the broader transformation of engineers' professional identities. Taken together, the findings demonstrate that phenomenology is not only a valid methodological choice but also a necessary one for capturing dimensions of meaning overlooked by traditional approaches.

Implications of the Findings

The findings of this study carry both scientific and practical implications. By highlighting how engineers construct meaning around the integration of AI in renewable energy systems, the study provides a richer understanding of the social and professional dimensions of technological adoption (Heil et al., 2025). These insights suggest that organizational leaders and policymakers should consider not only technical training but also strategies that support ethical reflection, emotional resilience, and collaborative practices among engineers (Almheiri et al., 2025). At a broader level, the results emphasize that successful AI implementation in critical infrastructure depends on cultivating trust and professional growth, elements that transcend technical efficiency and enter the domain of cultural and institutional transformation (Gaanoun & Alsuhaibani, 2025). This perspective is highly relevant in urban contexts where energy reliability and sustainability directly affect community well-being.

Limitations of the Study

Despite its contributions, this study has several limitations that must be acknowledged. The reliance on a relatively small sample of engineers, while consistent with phenomenological inquiry, limits the extent to which findings can be generalized across diverse contexts. Furthermore, the focus on urban energy systems may not fully capture the experiences of engineers working in rural or less

technologically advanced environments (Suchikova, 2025). The interpretative nature of the analysis also means that the findings are shaped by the specific context in which the data were collected, rather than representing universal truths (Eyal, 2025). These limitations, however, are consistent with the phenomenological commitment to depth over breadth and point toward directions for further exploration.

Prospective Directions for Future Research

The study opens pathways for future investigations into human experiences with emerging technologies. Expanding the scope to include multidisciplinary perspectives, such as policymakers, community stakeholders, or data scientists, could provide a more holistic view of AI integration in renewable energy systems. Comparative studies across different cultural or institutional settings would also be valuable for identifying how contextual factors shape the lived experience of engineers. Additionally, future research could examine longitudinal changes in professional identity as AI continues to evolve, thereby extending the insights of this study into the dynamic relationship between technology and human practice. These prospective directions affirm the importance of phenomenological inquiry in capturing the evolving interplay between innovation and lived experience.

CONCLUSION

This study examined the lived experiences of engineers implementing Artificial Intelligence in renewable energy systems, focusing on the subjective meanings that arise in this technological transformation. The findings revealed four essential dimensions of experience: negotiating technical complexities, managing ethical responsibility, adapting within social and professional contexts, and developing trust that fosters professional growth. These insights extend beyond prior research by addressing the limitations of purely technical or quantitative approaches, offering a more holistic understanding of how engineers interpret and engage with AI. The study contributes to the literature by demonstrating that the success of AI adoption relies not only on computational performance but also on the human capacity to adapt, trust, and evolve professionally. While the findings are shaped by the specific context of urban energy systems, they open opportunities for broader investigations across different cultural and institutional environments.

In practical terms, the results suggest that engineering organizations should develop structured training programs that integrate ethical reasoning and reflective practice alongside technical skill development. This approach can strengthen engineers' readiness to manage the cognitive and moral complexity inherent in AI-based systems. From a policy perspective, regulatory bodies and professional associations are encouraged to establish guidelines that clarify accountability frameworks in AI deployment, ensuring transparent responsibility-sharing between human and algorithmic agents. Institutions overseeing renewable energy innovation should also foster interdisciplinary collaboration among engineers, data scientists, and policymakers to build human-centered AI ecosystems that promote ethical resilience, adaptive learning, and public trust. Future studies may build on these results by exploring longitudinal changes in professional identity or by expanding the scope to include perspectives from other stakeholders involved in AI-driven energy innovation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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