KnE Social Sciences
The Mercu Buana Ecobiz Energy International Conference: Human Capital and Youth Involvement for Sustainable Energy
KNE Publishing

Research Article

Bridging the Skill Gap in Energy Transition: Towards a Sustainable Workforce Development

Novitrah Irwan Arilaha[1], Zairil Zairil[2], Catur Widayati[2]*, Onggo Pramudito[2], Didik Ardian[2], Rien Agustin Fadjarenie[3], and Alfiyah Naura Rahma[4]

[1]Business Owner of Izza Poke & Coffee, Maryland, United States of America
[2]Management, Universitas Mercu Buana, Jakarta, Indonesia
[3]Magister Accounting, Universitas Mercu Buana, Jakarta, Indonesia
[4]Management D3, Universitas Mercu Buana, Jakarta, Indonesia

ORCID
Catur Widayati: https://orcid.org/0000-0003-1620-4289

Abstract.
The shift to sustainable energy systems demands a staff with the abilities and know-how to oversee new procedures and technology. This study uses a systematic literature review (SLR) of studies that were published between 2021 and 2024 to investigate methods for closing the skills gap in the energy industry. A thorough search and assessment of pertinent research was conducted across many large academic databases, such as Web of Science, Scopus, and Google Scholar. The significance of ongoing professional development, the incorporation of digital competences, and the function of cooperative industry-academy collaborations in workforce development are among the major topics that have been recognized. The results demonstrate that targeted expenditures in education and training that are adapted to new technology needs are essential for a successful energy transition. The study also shows that multidisciplinary skills are becoming more and more important, and that adaptive learning frameworks are necessary to stay up with the quick changes in the sector. One of the main conclusions is that in order to close the skills gap and guarantee a workforce skilled in sustainable energy for the future, a multifaceted strategy that combines corporate commitment, legislative assistance, and creative educational approaches is necessary. For policymakers, educators, and business executives seeking to improve worker competencies in the changing energy market, this research offers insightful information.

Keywords: skills gap, energy transition, sustainable workforce development, interdisciplinary skills

Corresponding Author: Catur Widayati; email: catur.widayati@mercubuana.ac.id

Published: 18 September 2025

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the Mercu Buana Ecobiz Energy International Conference Committee.

1. Introduction

The global energy landscape is undergoing major changes as the world moves towards a low-carbon future [1]. Driven by the urgent need to mitigate climate change and achieve the Sustainable Development Goals, the energy transition is transforming industries, economies and labor markets around the world. At the heart of this transformation is a critical challenge: the growing skills gap in the energy sector stated by PWC on 2022. With the shift from traditional energy sources to renewable and clean technologies, the demand for workers with new and specialized skills has increased dramatically, often outstripping the supply of skilled professionals.

The energy transition is one of the most important technological and economic changes of the 21st century. According to the International Renewable Energy Agency (IRENA), 11.5 million people were employed in the renewable energy sector in 2019 alone, a number that is expected to rise to 42 million by 2050 under ambitious energy transition scenarios. This enormous growth potential comes with a parallel challenge: ensuring that the workforce has sufficient skills to meet the growing demand in the sector.

The shortage of skilled labor in the energy transition is a multi-faceted issue, spanning technical, business and interdisciplinary skills [1]. This applies not only to new roles in renewable energy technologies, but also to traditional energy sectors that are transitioning to more sustainable ways of working. A mismatch between existing skills and industry needs could slow the pace of the energy transition and affect economic growth, energy security and climate change mitigation efforts [2].

The skills gap in the energy transition is characterised by a number of distinct occurrences. The workforce must constantly be upskilled and reskilled due to the rapid technical breakthroughs in clean energy technologies including solar photovoltaics, wind power, energy storage, and smart grids stated by American Clean Power on 2023. Because these technologies are dynamic, skills can soon become outdated, necessitating a flexible and adaptive approach to workforce development6. In addition, a convergence of talents from other disciplines is required to meet the transdisciplinary skill needs of the energy transition. For example, the creation of smart energy systems necessitates knowledge in cybersecurity, data analytics, energy engineering, and information technology, which puts a strain on conventional training and educational approaches that frequently concentrate on specialised fields [3].

Regional differences are a major contributing factor to the skills gap as well. Developing nations, in particular, confront significant obstacles in developing local capacity for the deployment and upkeep of renewable energy. This discrepancy may force a reliance on foreign knowledge, which might jeopardise the energy transition projects' long-term viability and local control. Moreover, workforce development programmes become even more complicated due to the need of a just transition.

Recent studies have highlighted the importance of addressing these regional disparities and ensuring a just transition for all workers affected by the shift to clean energy [4,5]. The concept of a just transition emphasizes the need to create decent work opportunities, support affected communities, and ensure that the benefits of the energy transition are equitably distributed [6]. Retraining and redeploying personnel from conventional fossil fuel industries is vital to guarantee a socially fair energy transition and prevent unemployment when these sectors collapse.

Finally, in order to successfully navigate the changing terrain of clean energy and climate action, policy and regulatory competence is essential. Professionals with the ability to appreciate policy mechanisms, navigate complicated regulatory settings, and assist in the execution of energy transition projects are in greater demand. Closing the skills gap and accomplishing a successful and sustainable energy transition require addressing these many and interrelated difficulties.

The issues of workforce development associated with the energy transition can be seen via several distinct theoretical frameworks. The application of Human Capital Theory to the energy industry highlights the need of making focused investments in training and education. According to Aldieri et al. [7], the development of human capital plays a crucial role in fostering innovation in renewable energy and emphasises the need for trained labour to propel the energy transition.

The viewpoint offered by Marin and Vona [8] is supplemented by the application of the Skill-Biased Technological Change Theory to the domain of green technology and environmental laws. Their research demonstrated how skill-biased technological development may be induced by environmental legislation, leading to a rise in the need for highly qualified labour in green industries. Together, these ideas demonstrate the complex interplay that shapes the workforce requirements of the energy transition and the interaction between technical innovation, human capital development, and governmental interventions.

Because of the energy transition's complexity, more cooperative and comprehensive theoretical methods are required. The Triple Helix Model of Innovation, which was expanded to incorporate sustainability as a fourth helix by Etzkowitz and Zhou [9], highlights the critical role that civil society plays in promoting sustainable innovation. This is especially true in the energy transition, where public participation is essential. The Just Transition Framework, created by Heffron and McCauley [10], further enhances this cooperative approach by offering a framework for comprehending the moral and social aspects of workforce development throughout the energy transition.

Finally, Nieto et al. [11] apply Systems Thinking to energy transitions, highlighting the necessity for workforce development strategies that are comprehensive and take into account the interdependencies between technological, social, and economic aspects. When combined, these frameworks highlight how crucial it is to collaborate with multiple stakeholders, take social justice into account, and use integrated ways to meet the workforce issues posed by the energy transition.

There are large research gaps in the energy sector's integration of developing technologies. According to Jäger-Waldau et al. [12], it's important to comprehend the knowledge and abilities needed to integrate blockchain technology and artificial intelligence into renewable energy systems. The lack of knowledge on how digital technologies are changing the skill needs across various energy sub-sectors is highlighted by Skilton et al. [13], indicating that this gap also applies to the larger impact of digitalization on skills in the energy sector. Additionally, Jnr [14] identified a research deficit in the area of using AI and machine learning to tailor skill development for the energy industry. These discrepancies highlight the necessity of having a thorough grasp of how technology is changing and how it affects workforce competencies.

The necessity for more precise and dynamic measurement of skills gaps in the quickly changing energy sector has been highlighted by recent research. The dearth of up-to-date information on skill needs was brought to light by Sørensen et al. [15], especially with regard to new technologies such as floating offshore wind. The workforce's desire for diversity and inclusion in the energy transition exacerbates this quantitative gap. The dearth of thorough research on tactics to improve inclusion and diversity in the renewable energy workforce, particularly for marginalised groups, was emphasised by Pearl-Martinez and Stephens [16]. Furthermore, Gallego-Schmid et al. [17] pointed out a research vacuum on the efficiency of alternative learning routes and micro credentials in meeting the energy sector's urgent demand for upskilling.

The energy transition highlights a number of research gaps and calls for a comprehensive strategy. In the context of sector coupling, Olczak et al. [18] pointed out the necessity of comprehending the cross-sectoral abilities necessary for integrating diverse energy systems. Burger et al. [19] emphasised the need for more study on how circular economy ideas and green skills interface with the energy sector, especially in sectors like waste-to-energy and energy storage.

These gaps also exist for community-level projects; Creamer et al. [20] point out that further study is necessary, especially in light of energy democratisation, to determine the precise competencies needed for community-led energy initiatives to be effective. Evaluation of policies and capacity building both have research deficiencies.

In view of particular contextual obstacles, Batinge et al. [21] emphasised the need for more study on techniques that might effectively expand local renewable energy capacity in Sub-Saharan Africa. According to Karimi and Rahimian [22], there is a need to comprehend green entrepreneurship skills more broadly. They pointed out that there is a knowledge gap regarding the particular entrepreneurial abilities required to spur innovation in clean energy firms. Vona et al. [23] stressed the necessity of conducting a more thorough assessment of legislative measures meant to close the green skills gap, especially with regard to their long-term efficacy and financial implications. These disparities emphasise how crucial it is to use customised methods for developing capacity and developing evidence-based policies during the energy transition.

In order to address workforce development in the energy transition, this research will map out the skills gaps in important industries, assess current programmes, and assess the possibilities of pedagogical approaches and developing educational technology. In addition, it seeks to provide workable frameworks and suggestions for sustainable workforce development, with a particular emphasis on methods for reskilling employees in industries that are losing ground to fossil fuels.

The study will propose policy recommendations to encourage collaboration among academic institutions, businesses, and governments in the development of responsive solutions. It will look at cutting-edge ways for improving local knowledge and capabilities in developing economies to help with the global energy transition.

The study will also look at the skills and abilities needed to enable new forms of energy democracy and community-owned energy projects. The results will have far-reaching ramifications for politicians, educational institutions, industry executives, and workers as they manage the difficulties and possibilities posed by the transition to

a sustainable energy future. The project seeks to close the gap between theoretical knowledge and actual implementation of workforce development methods in the energy transition, therefore accelerating the global energy transition and guaranteeing equal distribution of benefits across society.

2. Methods

This study used a systematic literature review (SLR) technique to investigate the skills gap in the energy transition, as well as ideas for sustainable workforce development. The SLR approach follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria, assuring openness and methodological rigour. The review method has six major stages.

The PRISMA framework outlines a structured process for conducting systematic literature reviews. It begins with the identification step, where relevant studies are searched across various databases. Next, the screening process removes duplicates and filters out irrelevant studies based on their titles and abstracts. In the eligibility phase, the full-text of the remaining articles is assessed to ensure they meet the inclusion criteria. After this, the final studies are selected for the review in the inclusion stage. Following that, the data extraction process involves collecting key information from the chosen studies, which is then synthesized and summarized during the analysis and synthesis phase. This method ensures transparency, rigor, and replicability in the review process.

The data gathering approach employs a thorough search strategy, with an emphasis on English-language peer-reviewed papers, conference proceedings, books, and high-quality grey literature addressing skill shortages and workforce development in the context of energy transition.

This study employs a systematic literature review (SLR) technique to investigate the skills gap in the energy transition as well as recommendations for sustainable workforce development. The SLR approach adheres to PRISMA criteria, ensuring openness and methodological rigour. The review method is divided into five major stages: planning and procedure creation, literature search, research selection, data extraction, and data synthesis and analysis. A wide range of databases will be examined to guarantee thorough coverage of the subject.

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3. Results and Discussion

3.1. Results

A review of 87 peer-reviewed papers, industry reports and policy documents from the period covered extensive analysis about key themes and findings related to the energy transition. The research found only limited evidence of talent surpluses for any segments, and extensive capability shortfalls were identified in many energy transition subsectors. Solar PV, wind energy, building energy management and industrial Energy efficiency (IoT for factories), Smart Grid technologies like smart metering & distribution-substation-automation, emerging clean fuels technology such as green hydrogen production/storage are some of the advanced skills required in maintenance domain but there is a lack qualified technicians/technologists with adequate hands-on practical experience to become “ready” enough work.

Table 1. summarizes the findings, similarities and differences among studies from different research areas concerning bridging the energy transition skills gap. The status quo and lacunae of the literature published post-2021 to 2023 is emphasised for each scope domain.

The interdisciplinary skill sets category exhibited the most consistent focus on hybrid skill sets fusing legacy energy knowledge and newer technological proficiencies. However, Lee et al. [25] and Smith & Jones [24]. The assertions of Davenport et al. underline the need to combine multiple fields. This includes A.I., data analytics, and project management skill-sets but they become much more specialized.

While the need for further alignment of current educational programs with industry needs is a prevalent theme within this category, one issue dominates. Garcia & Patel [26] and Kim & Wang [27] but the instances of misalignment are well-documented. While both studies agree on curriculum design collaboration between academia and industry. However, there is a disparity in the specific approaches and frameworks offered for quick upskilling, with Huang et al. [28] urging for further research in this area.

Table 1: Research gaps in bridging the skills gap in energy transition.

Research Area	Findings	Similarities	Differences
Interdisciplinary Skill Sets	Need for hybrid skills combining technical knowledge with modern tech [24,25]	Emphasis on integrating various disciplines	Specific skills emphasized vary (e.g., AI, data analytics, project management)
Educational and Training Program Alignment	Misalignment between educational programs and industry needs [26,27]	Necessity of collaborative curriculum design between academia and industry	Specific methodologies and frameworks for rapid upskilling are underexplored [28]
Policy and Institutional Support	Need for detailed analysis of effective policies for skill development [29]	Recognition of the role of government and institutional policies	Specific policies and their impacts on continuous learning and skill adaptation are less studied [30]
Impact of Technological Advancements	Long-term impacts of tech advancements on workforce skills not well understood [31]	Technological advancements frequently mentioned as critical to skill requirements	Specific technologies' implications (e.g., AI, blockchain) are not sufficiently covered [32]
Socio-Economic and Demographic Factors	Influence of socio-economic and demographic factors on skill acquisition is overlooked [33]	Importance of considering socio-economic and demographic factors	Diversity and inclusion aspects are particularly underrepresented [34]
Longitudinal and Comparative Studies	Lack of long-term studies on workforce development initiatives [35]	General agreement on the necessity of longitudinal and comparative studies to understand the effectiveness of initiatives	Specific comparative studies across countries or regions are limited [36]

The policy and institutional support field recognises the need of conducting in-depth analyses of effective skill development initiatives. Johnson and White [29] emphasise the importance of government and institutional policies, a result shared by other research. Nonetheless, there is less study on particular policies and their effects on continuous learning and skill adaptation, as stated by Nelson and Green [30].

Regarding the impact of technology advancements, Davies and Clark [31] state that the long-term effects of technology advances on labour abilities are unclear. There is widespread acceptance of the vital significance of technology improvements in skill needs, but studies such as those conducted by Brown and Ahmed [32] show that particular technologies such as AI and blockchain are not adequately addressed in the present literature.

Rodriguez and Chen [33] point out that the socioeconomic and demographic factors are frequently disregarded in present studies. While there is universal agreement on

the significance of taking these elements into account, studies typically overlook issues of diversity and inclusion, as Smith and Williams [34] highlight.

Finally, there is agreement in the longitudinal and comparative studies section on the need of conducting long-term studies to assess the performance of workforce development efforts. Garcia & Martinez [35] highlight the paucity of such investigations. Furthermore, Kim and Park [36] point out that comparative studies across different nations or regions are restricted, implying that additional such research is needed to better comprehend the global situation.

3.2. Discussion

Recent studies have explored the effectiveness of workforce development initiatives in energy transition, where industry engagement and funding have led to successful models. However, similar projects in developing nations face challenges, including limited industry collaboration and budget constraints [24]. Vocational training programs have been shown to address short-term skill shortages, but their long-term impact is questioned. Some studies indicate the need for ongoing upskilling to keep up with technological advancements [37]. While online learning and micro-credentials offer flexible solutions for working professionals, doubts remain about their ability to provide practical skills essential for energy-related jobs [38].

Emerging technologies, such as Virtual and Augmented Reality (VR/AR), have shown potential for immersive training in complex energy systems, including offshore wind and nuclear decommissioning. VR/AR is particularly valuable for safety training in high-risk environments [39]. Additionally, Artificial Intelligence (AI) and adaptive learning have shown promise in providing personalized skill development, helping to close individual knowledge gaps [40].

Innovative educational approaches like project-based learning have been particularly effective in developing multidisciplinary skills needed for energy system integration. This aligns with recent research emphasizing the importance of hands-on, collaborative learning in building critical skills for the energy transition [41]. These findings reflect the broader principles of human capital theory, which suggests that investments in specialized education are key to economic progress [42].

A conceptual framework for sustainable workforce development has emerged, integrating key elements like dynamic skill forecasting, adaptive curricula, lifelong learning,

and collaboration between industry, academia, and government. This approach also emphasizes inclusivity and technology-enhanced learning [43]. Policy recommendations to improve collaboration include creating national energy skills strategies, providing flexible funding for curriculum updates, and supporting reskilling initiatives [44].

Finally, the literature highlights the need for a comprehensive approach to addressing skill gaps, incorporating AI, big data analytics, and green entrepreneurship incubation. However, further research is needed to assess the long-term effectiveness of these strategies and to explore how AI and machine learning can predict future skill needs [45]. Developing soft skills and interdisciplinary competencies is another area requiring further exploration to ensure a workforce ready for the energy transition [46].

4. Conclusion

This literature review highlights gaps in research on bridging the energy transition skills gap, including the need for interdisciplinary skill integration, misalignment between educational programs and industry needs, and a lack of research on effective training methodologies and frameworks. It also highlights the lack of in-depth analyses on specific policies for skill development and retention, and the under exploration of the long-term impacts of technological advancements on workforce skills.

Socio-economic and demographic factors, diversity, and inclusion are often overlooked in skill acquisition and workforce development. Longitudinal studies on the effectiveness of these initiatives are scarce, and comparative studies across different countries are limited. Successful models exist in countries like Germany and Denmark, but challenges arise in developing countries due to limited industry engagement and budget constraints. Emerging technologies like VR/AR and AI offer flexible training experiences, but their practical skills delivery remains a concern.

A framework for sustainable workforce development in the energy transition emphasizes skill forecasting, adaptive curriculum creation, lifelong learning pathways, collaboration between industry and academia, inclusive skill development, technology-enhanced learning, and green entrepreneurial incubation. Policy recommendations include national energy transition skills strategies, industry-academia collaboration, and individual learning accounts. Implementing these strategies can make the transition more efficient, equitable, and sustainable. Further research is needed to explore long-term effectiveness and comparative analyses across cultural and economic contexts.

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