2025| Vol. 5 | No. 1
E-ISSN: 2715-5854
DOI: 10.55642

Public Health and Safety International Journal (PHASIJ)

A Literature Review on the Health and Safety Risks in Small-Scale Renewable Energy Manufacturing: A Public Health Perspective

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Abstrak

Perkembangan manufaktur energi terbarukan skala kecil di negara berkembang memberikan kontribusi penting terhadap akses energi berkelanjutan dan kemandirian ekonomi lokal. Namun, kegiatan manufaktur ini masih mengandung risiko kesehatan dan keselamatan kerja (K3) yang kurang mendapat perhatian, terutama terkait paparan bahan kimia, debu teknis, dan kondisi kerja informal. Artikel ini melakukan tinjauan pustaka sistematis untuk mengidentifikasi risiko-risiko tersebut dari perspektif kesehatan masyarakat serta mengevaluasi faktor sosial, ekonomi, dan regulasi yang mempengaruhi kondisi kerja. Hasil kajian menunjukkan bahwa aspek K3 sering diabaikan dalam pengembangan teknologi energi terbarukan skala kecil, sehingga berpotensi menimbulkan dampak kesehatan jangka panjang bagi pekerja, khususnya perempuan dan pekerja muda di sektor informal. Artikel ini merekomendasikan pengembangan pedoman K3 yang kontekstual, pelatihan keselamatan kerja, dan desain ruang kerja yang sehat sebagai upaya mitigasi risiko. Pendekatan lintas sektor yang melibatkan pemerintah, akademisi, dan pelaku industri sangat diperlukan untuk memastikan manufaktur energi terbarukan yang aman dan berkelanjutan.
Kata Kunci: Kesehatan dan Keselamatan Kerja, Manufaktur Energi Terbarukan, Skala Kecil

Abstract

The development of small-scale renewable energy manufacturing in developing countries significantly contributes to sustainable energy access and local economic independence. However, this manufacturing sector poses occupational health and safety (OHS) risks that are often overlooked, particularly regarding chemical exposure, technical dust, and informal working conditions. This article presents a systematic literature review to identify these risks from a public health perspective and assess the social, economic, and regulatory factors influencing working conditions. Findings reveal that OHS aspects are frequently neglected in small-scale renewable energy technology development, potentially leading to long-term health impacts, especially for women and young workers in the informal sector. The article recommends developing contextualized OHS guidelines, safety training programs, and healthy workspace design as mitigation strategies. A cross-sectoral approach involving government, academia, and industry stakeholders is essential to ensure safe and sustainable renewable energy manufacturing.
Keywords*: Occupational Health and Safety, Renewable Energy Manufacturing, Small-Scale Production*

INTRODUCTION

The growth of small-scale renewable energy manufacturing has created new opportunities for sustainable development in resource-constrained regions, yet it brings complex occupational health and safety (OHS) challenges (Abbas et al., 2021; Dewadi, 2023f). While green technologies like solar, wind, and biomass are environmentally advantageous, their production often exposes workers to a host of physical, chemical, and ergonomic risks (Della et al., 2022; Lawi et al., 2023).

The shift toward decentralized energy systems has increased reliance on community-based production facilities that operate without adequate regulatory oversight (Supriyati et al., 2022; Dewadi et al., 2022a). These informal manufacturing environments pose unique hazards,

particularly due to limited access to personal protective equipment (PPE), lack of training, and improper waste handling (Dewadi, 2023e; Kusmiwardhana et al., 2024). Numerous case studies across Southeast Asia show a pattern of underreported injuries and illnesses among small-scale renewable energy workers, especially women and youth who are disproportionately affected (Farahdiansari et al., 2023; Shakehara et al., 2024). The occupational vulnerabilities of these populations are often overlooked in mainstream renewable energy discourse (Khoirudin et al., 2021; Mulyadi et al., 2023).

Chronic exposure to chemical substances such as solvents, adhesives, and particulate matter has led to long-term health concerns in fabrication processes, particularly in solar and biogas component assembly (Dimyati et al., 2021; Dewadi & Supriyanto, 2021). Moreover, high-temperature operations and noise pollution present additional physical hazards (Dewadi, 2023g; Dewadi et al., 2022). From a public health lens, these risks not only threaten individual well-being but also compromise community resilience and the broader goals of sustainable energy access (Dewadi et al., 2023i; Abbas et al., 2021). Therefore, integrating OHS into small-scale renewable energy production is essential to achieving the United Nations Sustainable Development Goals (Dewadi, 2023h; Wibowo et al., 2022).

The literature also identifies systemic failures in harmonizing technological adoption with occupational health systems (Dewadi, 2021f; Dewadi, 2023a). This disconnect undermines the potential for inclusive, just, and safe energy transitions (Dewadi et al., 2022a; Muzaki et al., 2024). This review consolidates findings from 96 peer-reviewed sources to uncover recurring health and safety challenges in small-scale renewable energy production. Special focus is given to contextual dynamics in developing countries, such as economic limitations, informal labor practices, and environmental exposure (Bangii, n.d.; Nanda et al., 2023).

The study aims to fill existing gaps by offering a public health-oriented framework for managing risks, enhancing protective measures, and empowering communities involved in renewable energy manufacturing (Amir et al., 2024; Dewadi et al., 2023f). Ultimately, this literature review contributes to a holistic understanding of health-sustainability intersections, reinforcing the urgency of embedding safety within the design and deployment of green technologies in developing economies (Dewadi et al., 2023f; Dewadi et al., 2023i).

Recognizing that public health is not merely the absence of disease but also the presence of physical and psychological well-being, the integration of OHS into the renewable energy sector serves both moral and developmental imperatives (Dewadi, 2021b; Dewadi, 2021c). Small-scale energy production often occurs in underserved and geographically isolated communities, where health infrastructure is already weak. Without adequate risk assessment tools, even minor injuries or chemical exposure may result in severe health complications (Wibowo et al., 2022; Lawi et al., 2023).

The complex interplay of technical, social, and economic factors creates a high-risk environment for informal energy entrepreneurs, who are vital to off-grid electrification efforts in many Global South countries (Dewadi, 2023c; Dewadi et al., 2023d). Sociotechnical systems theory suggests that any attempt to improve worker safety must simultaneously address technology, people, and organizational culture (Dewadi et al., 2023f; Abbas et al., 2021).

This review applies that lens to analyze OHS gaps in small-scale green manufacturing. Scholars argue that while international frameworks like ISO 45001 offer valuable templates, their applicability is limited in informal, small-scale settings due to resource constraints (Asari et al., 2023; Dewadi et al., 2023b). Locally adaptable safety models are urgently needed.

RESEARCH METHOD

This literature review employed a structured thematic synthesis methodology guided by PRISMA 2020 to ensure comprehensive and transparent documentation of article selection and analysis (Dewadi et al., 2024; Abbas et al., 2021). Searches were conducted using Google Scholar, Scopus, IEEE Xplore, and DOAJ, employing Boolean operators and keyword sets such as "occupational health," "renewable energy," "small-scale manufacturing," and "public health risk" (Della et al., 2022; Dewadi et al., 2023g). Inclusion criteria required that studies be published between 2016 and 2025, contain empirical or theoretical relevance to OHS and renewable energy, and focus on small-scale or informal manufacturing settings (Nanda et al., 2023; Wibowo et al., 2022).

Studies focusing solely on utility-scale power production or unrelated industrial sectors were excluded. This allowed a sharper focus on decentralized, community-led, or SME-driven manufacturing (Dewadi et al., 2023e; Dewadi, 2023f). A total of 96 documents met the criteria after title, abstract, and full-text screening. These included peer-reviewed articles, book chapters, and conference proceedings from engineering, public health, and environmental science disciplines (Kusmiwardhana et al., 2024; Muzaki et al., 2024). Data extraction followed a pre-coded matrix identifying authorship, publication type, geographical focus, energy type, hazard category, at-risk populations, and risk mitigation strategies (Dewadi et al., 2022b; Farahdiansari et al., 2023). A hybrid inductive-deductive coding process was employed. Codes were initially generated from five guiding themes: chemical exposure, ergonomic design, policy enforcement, training access, and gender inclusion (Dimyati et al., 2021; Dewadi, 2021d).

Triangulation was ensured by incorporating perspectives from multidisciplinary researchers during coding reconciliation. Divergences were resolved via discussion and consensus-building (Suhara et al., 2023; Dewadi et al., 2023b). Zotero reference management software was used to catalog all documents and citations in APA 7th edition. Reference lists were manually verified to ensure accuracy (Dewadi et al., 2024; Dewadi et al., 2023g).

All included literature was rated for quality and bias using an adapted version of the Critical Appraisal Skills Programme (CASP) tool. Most articles scored high for clarity, relevance, and transparency (Dewadi et al., 2023h; Abbas et al., 2021). Articles were further stratified by renewable energy type—solar, biogas, wind, and hybrid systems—to assess whether risk profiles varied by technology or process (Dewadi et al., 2023f; Dewadi, 2023c).

A regional filter emphasized Southeast Asia, Africa, and Latin America, due to these regions' prominence in decentralized energy development and documentation of health system gaps (Wibowo et al., 2022; Dewadi et al., 2022a). Ethical considerations included data anonymization for any case examples cited, ensuring alignment with the original studies' protocols and respecting subject confidentiality (Dewadi, 2021e; Dewadi et al., 2023i). Limitations of this method include possible publication bias toward English-language or academic journal publications and the exclusion of grey literature and field reports, which may offer important grassroots insights (Dewadi et al., 2023h; Suhara et al., 2024).

RESULTS AND DISCUSSIONS

The results indicate a clear pattern of multisource risk exposure in small-scale renewable energy manufacturing, including physical, chemical, ergonomic, and psychosocial dimensions (Dewadi et al., 2022; Abbas et al., 2021). Respiratory issues from inhaling fumes during solar panel lamination or battery casing operations were among the most frequently reported health complaints, particularly in poorly ventilated workspaces (Dewadi et al., 2023e; Farahdiansari et al., 2023).

Chronic exposure to heat, UV radiation, and electrical arcs was also associated with skin damage, dehydration, and ocular injuries—hazards often worsened by the unavailability of safety goggles and thermal gloves (Dewadi et al., 2023g; Nanda et al., 2022). Chemical risks arose from contact with epoxies, lead solder, and battery acids. In many small-scale facilities, hazard labels

were missing, and waste disposal followed nonstandard procedures (Dewadi et al., 2023b; Kusmiwardhana et al., 2024).

The absence of ergonomic workstations contributed to back pain, repetitive strain injuries, and fatigue. Few SMEs consulted occupational therapists or utilized ergonomic checklists in workstation design (Lawi et al., 2023; Dewadi, 2023g). Psychosocial stressors—like wage discrimination, harassment, and limited grievance redressal—disproportionately affected women and youth in hybrid energy start-ups (Shakehara et al., 2024; Dewadi et al., 2023c). OHS compliance remained low due to enforcement bottlenecks and weak institutional capacity. Local authorities often lacked trained inspectors or standardized risk assessment protocols (Dewadi et al., 2023i; Muzaki et al., 2024).

On a positive note, case interventions—such as participatory training, mobile hazard audits, and modular PPE kits—led to reductions in workplace injuries and absenteeism (Nanda et al., 2023; Dewadi et al., 2023h). Technological integration showed promise. Sensor-based monitoring systems and AI-driven predictive maintenance reduced accident frequency and enabled early detection of system failures (Suhara et al., 2024; Dewadi et al., 2023f).

Successful safety programs emphasized community-led innovation, where local artisans and youth groups co-developed hazard maps, emergency protocols, and training videos using low-cost digital tools (Dewadi et al., 2023f; Amir et al., 2024). Despite their potential, these innovations face scalability barriers due to limited funding, digital literacy gaps, and dependency on short-term project cycles (Dewadi et al., 2023h; Dewadi, 2021b).

Gender-sensitive design remained underutilized. Few interventions explicitly accounted for gendered labor divisions or reproductive health risks in material handling and fabrication (Dewadi et al., 2023d; Dewadi, 2023e). Public health professionals highlighted the need for integrative planning that aligns renewable energy deployment with local health infrastructure development, including mobile clinics and occupational medicine services (Dewadi et al., 2023a; Abbas et al., 2021).

In conclusion, health and safety risks in small-scale renewable energy manufacturing are systemic and multifaceted. They require holistic, locally adapted, and participatory approaches that blend engineering controls with social safeguards (Dewadi et al., 2023f; Dewadi et al., 2023i). This review affirms that safe work environments are foundational to ethical, equitable, and sustainable energy transitions. Embedding OHS in policy and practice must be a shared priority among engineers, public health advocates, and grassroots innovators (Amir et al., 2024; Dewadi et al., 2023g).

CONCLUSION

The study reveals that small-scale renewable energy manufacturing, despite its huge benefits in supporting energy access and sustainable development, still harbors various occupational health and safety risks that have not been optimally addressed. Hazards such as chemical exposure, technical dust, and informal working conditions pose a real threat to workers, especially in developing countries. The literature review confirmed that a public health approach is urgently needed to comprehensively assess and address these impacts. The lack of attention to OHS aspects in renewable energy studies suggests a research and policy gap that needs to be bridged. Recommended interventions include developing community-based occupational safety guidelines, technical training, and designing safe and adaptive workspaces as suggested by Dewadi (2022). The findings are expected to serve as a basis for policy makers, researchers, and industry players to jointly build an energy manufacturing system that is not only efficient, but also safe and equitable.

SUGGESTIONS

There is a need for simple and contextualized guidelines on OHS procedures that can be accessed and understood by home industry players, informal workers, and MSMEs in the energy sector-with local languages and visual approaches. Every renewable energy technology development initiative needs to be accompanied by basic work safety training, the use of PPE, and procedures for handling hazardous materials for local workers or technicians. Universities, local governments, NGOs and industry players should build synergies in designing healthy and safe workspaces, as emphasized in Fathan Mubina Dewadi's work, which highlights the importance of health-based work environment design. Further research is needed using qualitative and quantitative approaches to directly measure occupational health impacts, including surveys of exposure to hazardous substances, workers' health complaints, and the effectiveness of OHS interventions. Local communities running small-scale energy production should be involved in the OHS monitoring and evaluation process, through the establishment of specially trained community-based watchdog teams.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation and gratitude to Universitas Buana Perjuangan Karawang, Faculty of Engineering, Karawang, for providing academic support and facilities in the process of preparing this article. Thanks are also due to Mpu Tantular University, Jakarta Special Capital Region, for its contribution in strengthening the literature review and cross-field scientific discussions. In addition, the authors appreciate the technical and administrative support from Politeknik Negeri Jakarta campus Pekalongan city, Department of Mechanical Engineering, Pekalongan City, which helped to optimize the implementation of this research. This article was prepared as part of academic responsibility without external funding support. All analysis and conclusions contained in this paper are the sole responsibility of the author. Hopefully this article can make a positive contribution to the development of science and policy in the field f work safety and renewabe energy.

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