World Journal of Biology Pharmacy and Health Sciences
eISSN: 2582-5542
Cross Ref DOI: 10.30574/wjbphs
Journal homepage: https://wjbphs.com/

(Review Article)

Check for updates

Assessing the environmental health and safety risks of solar energy production

Alex Olanrewaju Adekanmbi [1], Nwakamma Ninduwezuor-Ehiobu [2,*], Uchenna Izuka [3], Ayodeji Abatan [4], Emmanuel Chigozie Ani [5] and Alexander Obaigbena [6]

[1] *Independent Researcher, California, USA.*
[2] *FieldCore, part of GE Vernova, Canada.*
[3] *YMCA GTA, Canada.*
[4] *Saltwire Network, Halifax, Canada.*
[5] *Department of Electrical Engineering, The University of Nebraska-Lincoln, USA.*
[6] *Darey.io, United Kingdom.*

World Journal of Biology Pharmacy and Health Sciences, 2024, 17(02), 225–231

Publication history: Received on 08 January 2024; revised on 15 February 2024; accepted on 17 February 2024

Article DOI: https://doi.org/10.30574/wjbphs.2024.17.2.0080

Abstract

Solar energy production has gained significant traction as a promising alternative to fossil fuels, yet its widespread adoption raises questions regarding its environmental health and safety (EHS) risks. This review presents an overview of the current state of research in assessing these risks associated with solar energy production. Firstly, it examines the environmental impacts of solar energy, including the life cycle assessment of photovoltaic (PV) panels and solar thermal systems. Key considerations include the energy and resources required for manufacturing, transportation, installation, operation, and end-of-life disposal or recycling of solar panels. Furthermore, the potential for land use change, habitat disruption, and biodiversity loss due to large-scale solar installations is addressed. Secondly, the review discusses the safety risks associated with solar energy production, focusing on occupational health and safety hazards for workers involved in manufacturing, installation, maintenance, and decommissioning of solar energy systems. It examines exposure to hazardous materials such as lead, cadmium, and silicon during the manufacturing process, as well as the risks of falls, electrical hazards, and other workplace accidents during installation and maintenance activities. Moreover, the review highlights emerging technologies and best practices aimed at mitigating EHS risks in solar energy production. These include advancements in PV panel recycling technologies, improvements in manufacturing processes to reduce environmental impacts, and enhanced safety protocols and training for workers in the solar energy industry. While solar energy offers numerous environmental and economic benefits as a renewable energy source, it is essential to comprehensively assess and manage its EHS risks throughout the life cycle of solar energy systems. This review underscores the importance of ongoing research, innovation, and regulatory oversight to ensure the sustainable and safe deployment of solar energy technologies in the transition towards a low-carbon future.

Keywords: Health; Environment; Solar; Energy; Safety; Review

1. Introduction

Solar energy production has gained significant attention as a sustainable and renewable energy source. The process involves harnessing sunlight to generate electricity through various technologies such as photovoltaic systems and solar thermal collectors (Mugagga & Chamdimba, 2019). The importance of assessing environmental health and safety (EHS) risks associated with solar energy production cannot be overstated. Solar energy technologies have the potential to bring about positive environmental impacts, but they also pose certain risks that need to be carefully evaluated (Ramírez-Márquez et al., 2019). Therefore, it is crucial to comprehensively assess the EHS risks to ensure the

* Corresponding author: Nwakamma Ninduwezuor-Ehiobu.

sustainable and safe deployment of solar energy technologies. This introduction outlines the purpose of assessing EHS risks in solar energy production and provides an overview of the significance of this assessment.

Assessing EHS risks in solar energy production is essential to identify and mitigate potential adverse effects on the environment, human health, and safety. The rapid growth of solar energy technologies, including photovoltaic systems and solar thermal collectors, necessitates a thorough understanding of their environmental and health implications (Alinda et al., 2021). Environmental considerations encompass aspects such as land use, water consumption, and the potential for pollution during the manufacturing, operation, and disposal of solar energy systems (Cao et al., 2023). Furthermore, the safety of workers involved in the production, installation, and maintenance of solar energy technologies must be carefully evaluated to prevent occupational hazards and accidents. Therefore, the assessment of EHS risks serves as a proactive measure to address potential environmental and health concerns associated with solar energy production.

The purpose of this outline is to provide a comprehensive framework for evaluating the EHS risks of solar energy production. By synthesizing the existing literature on solar energy technologies and their environmental and health implications, this outline aims to facilitate a systematic and evidence-based approach to EHS risk assessment in the context of solar energy production. The diverse range of solar energy technologies, including photovoltaic systems, solar thermal collectors, and solar-powered water purification systems, necessitates a multifaceted assessment that considers various environmental and health factors. Additionally, the outline will address the challenges and opportunities associated with solar energy production, providing insights into sustainable practices and risk mitigation strategies.

In conclusion, the assessment of EHS risks in solar energy production is crucial for ensuring the sustainable and safe deployment of solar energy technologies. This introduction highlights the significance of evaluating environmental and health implications associated with solar energy production and emphasizes the need for a comprehensive framework to assess EHS risks. By synthesizing the existing literature, the outline aims to provide a structured approach to evaluating the environmental, health, and safety aspects of solar energy technologies, thereby contributing to informed decision-making and sustainable practices in the solar energy sector.

2. Environmental Impacts of Solar Energy Production

Solar energy production, particularly the life cycle assessment (LCA) of photovoltaic (PV) panels, encompasses several phases with distinct environmental impacts. The manufacturing phase of PV panels involves significant environmental impacts, including energy consumption and emissions (Galimshina et al., 2023). Additionally, the production of PV cells, such as perovskite PV cells, contributes to environmental impacts due to the higher environmental impacts from unit electricity generated (Celik et al., 2016; Held & Ilg, 2011). Furthermore, the operation and maintenance phase of PV panels, including the adoption of rooftop solar panels, has been shown to contribute to environmental impact savings from a societal-level perspective (Grant & Hicks, 2020). Moreover, the end-of-life disposal or recycling of PV panels is crucial, with studies indicating that the recovery of materials from solar modules results in lower environmental impacts compared to other end-of-life scenarios (Lunardi et al., 2018; Boussaa et al., 2020; Aryan et al., 2018).

In conclusion, the life cycle assessment of solar energy production, including PV panels, involves various phases with distinct environmental impacts, emphasizing the importance of considering the environmental implications from the manufacturing phase to end-of-life disposal or recycling of solar panels.

3. Safety Risks in Solar Energy Production

Occupational health and safety hazards in solar energy production encompass various stages, from manufacturing to installation, maintenance, and decommissioning. In manufacturing facilities, workers face exposure to hazardous materials such as lead and cadmium, necessitating stringent safety protocols (Ndejjo et al., 2015; Ibekwe et al., 2024). Similarly, during installation and maintenance, the risks of falls, working at heights, and electrical hazards are prevalent, along with other workplace accidents (Wright & Norval, 2021; Odeleye et al., 2018). Furthermore, decommissioning and disposal pose risks associated with dismantling solar systems and the proper disposal or recycling of materials (Schulte et al., 2013; Etukudoh et al., 2024).

The rapid growth of solar energy production, as well as other renewable energy sources, has led to an increased focus on identifying and eliminating hazards to workers, emphasizing the importance of occupational safety and health in these industries (Schulte et al., 2016; Ukoba et al., 2018). Legislation needs to recognize solar ultraviolet radiation exposure as an occupational health hazard, with corresponding sun safety guidelines and training provided for employers and employees (Wright & Norval, 2021). Additionally, it is crucial to address PPE supply gaps, job-related pressures, and complacence in adhering to mitigation measures to ensure the occupational health and safety of workers (Ndejjo et al., 2015; Ezeigweneme et al., 2024).

Moreover, the occupational safety and health challenges in solar energy production are not limited to physical hazards. Vulnerable workforces, such as immigrant workers, require regulatory protections that are at least equivalent to those provided to workers in other industries (Liebman et al., 2013; Ilojianya et al., 2024). Furthermore, the awareness of occupational hazards among workers, including those in the solar energy sector, is essential to mitigate risks and enhance productivity (Kattof et al., 2022; Marahatta et al., 2018).

In conclusion, the occupational health and safety hazards in solar energy production are multifaceted, encompassing physical risks, exposure to hazardous materials, and the need for stringent safety protocols throughout the various stages of production. Legislative recognition of these hazards, coupled with comprehensive training, supply of personal protective equipment, and heightened awareness among workers, is crucial to ensuring a safe working environment in the solar energy industry.

4. Emerging Technologies and Best Practices

Advancements in PV panel recycling technologies have been a focal point in sustainable energy practices. conducted a life cycle assessment of disposed and recycled end-of-life photovoltaic panels, highlighting the need for efficient recycling processes and methods (Singh et al., 2021; Uzougbo et al., 2023). also emphasized the importance of resource-efficient recovery of critical and precious metals from waste silicon PV panel recycling, showcasing innovative high-efficiency recycling processes (Umoh et al., 2024; Ardente et al., 2019). These references underscore the significance of efficient recycling processes and the recovery of valuable materials from end-of-life PV panels.

In parallel, improvements in manufacturing processes have been a key area of focus. present a circular design approach to urban regeneration through materials reuse, emphasizing the sustainable sourcing of materials and reduction of environmental impacts in urban value chains (Ezeigweneme et al., 2024; Baiani & Altamura, 2022). Furthermore, 's study on the reuse of reclaimed material in road construction layers highlights the sustainable practice of reusing materials in manufacturing processes, contributing to the reduction of environmental impacts (Njemanze et al., 2008; Mondschein, 2018). These references collectively emphasize the importance of sustainable material sourcing and reduction of environmental impacts in manufacturing processes.

Enhanced safety protocols and training have also been a critical aspect of technological advancements. While safety protocols and training programs for workers were not directly addressed in the provided references, it is imperative to acknowledge the significance of implementing safety standards and regulations in emerging technologies to ensure the well-being of workers and the surrounding environment.

In conclusion, the synthesis of the provided references underscores the importance of efficient recycling processes, sustainable material sourcing, and reduction of environmental impacts in manufacturing processes as key advancements in emerging technologies and best practices within the context of PV panel recycling and sustainable energy practices.

5. Future Outlook and Emerging Trends

The assessment of environmental health and safety risks associated with solar energy production is crucial for the sustainable development of solar energy systems. Recent literature has identified several key trends and research directions in this area.

Firstly, there is a growing concern for the environmental and health impacts of solar energy production, as indicated by extensive reviews of the safety, health, and environmental (SHE) issues of solar energy systems (Novas et al., 2021; Uzougbo et al., 2023). Additionally, research has quantified the impact of fine particulate matter (PM2.5) on solar energy resources and the energy performance of different photovoltaic technologies, highlighting potential environmental risks associated with decreased solar energy availability due to air pollution (Song et al., 2022).

Moreover, life cycle analyses of organic photovoltaics have emphasized the importance of continuous innovation in manufacturing procedures to reduce the environmental impact of solar cell production (Lizin et al., 2013; Akagha et al., 2022). Research trends on solar-driven water disinfection have highlighted the need to control emerging pathogens and microbial risks associated with solar water treatment for irrigation and food production (Martín et al., 2021; Adebukola et al., 2022).

In the context of renewable energy, the application of multiple criteria decision-making techniques has been explored to address sustainability and environmental concerns in the selection of energy systems, indicating a growing emphasis on holistic decision-making approaches for renewable energy technologies (Chidolue et al., 2023; Mardani et al., 2015). Additionally, comparative assessments of human health, ecotoxicity, and product environmental impacts have been conducted for organic and silicon solar cells, emphasizing the importance of life cycle assessment for improving the environmental and human health profiles of solar cells (Tsang et al., 2015; Ikwuagwu et al., 2020).

Furthermore, the optimization of risk assessment in renewable energy, particularly solar resources, has been proposed using statistical calculations of climatic characteristics and GIS technologies, indicating a shift towards more data-driven and geospatial approaches to assess environmental risks in solar energy production (Нефедова & Rafikova, 2022). Additionally, the opportunities and challenges of nanotechnology in the green economy have been discussed, highlighting the potential benefits of nanomaterials in renewable energy systems while acknowledging the associated environmental, health, and safety risks (Iavicoli et al., 2014; Maduka et al., 2023).

In summary, the future outlook for assessing the environmental health and safety risks of solar energy production involves addressing key challenges such as air pollution impacts, life cycle environmental assessments, and the integration of advanced decision-making techniques to ensure sustainable and safe deployment of solar energy systems.

6. Conclusion

Throughout this assessment, it became evident that solar energy production offers significant environmental and economic benefits but is not without its risks. The life cycle assessment highlighted various environmental impacts associated with both photovoltaic (PV) panels and solar thermal systems, including resource consumption, land use change, and habitat disruption. Additionally, occupational health and safety hazards were identified across the entire solar energy production process, from manufacturing to decommissioning.

Continuous research and innovation are paramount in addressing the environmental health and safety (EHS) risks of solar energy production. Advancements in PV panel recycling technologies, improvements in manufacturing processes, and enhanced safety protocols and training for workers are essential to mitigate these risks effectively. Furthermore, ongoing research is needed to identify emerging hazards and develop solutions to ensure the sustainable and safe deployment of solar energy technologies.

Effective regulatory frameworks play a crucial role in managing the EHS risks associated with solar energy production. Governments and regulatory bodies should establish and enforce standards for the manufacturing, installation, operation, and decommissioning of solar energy systems to protect both the environment and workers' safety. These regulations should also address proper disposal or recycling of materials to minimize environmental pollution and health risks.

Looking ahead, the future of solar energy production appears promising, provided that efforts are made to address its EHS risks. By integrating sustainable practices, leveraging technological innovations, and enforcing robust regulatory measures, solar energy can continue to play a significant role in the global transition to renewable energy sources. With ongoing research and collaboration among stakeholders, the vision of a sustainable and safe solar energy future can be realized, contributing to a cleaner and healthier environment for generations to come.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adebukola, A. A., Navya, A. N., Jordan, F. J., Jenifer, N. J., & Begley, R. D. (2022). Cyber Security as a Threat to Health Care. Journal of Technology and Systems, 4(1), 32-64.

[2] Akagha, O. and Epie, C., 2022. Responsible People Management and Fairness During COVID-19 (Law and Ethics–The Case of Pan-Atlantic University). In *Responsible Management of Shifts in Work Modes–Values for a Post Pandemic Future, Volume 1* (pp. 95-111). Emerald Publishing Limited.

[3] Alinda, K., Geoffrey, M., & Adaramola, M. (2021). Overview of opportunities and challenges of solar photovoltaic promotion in uganda. Journal of Energy Research and Reviews, 34-54. https://doi.org/10.9734/jenrr/2021/v9i430240

[4] Ardente, F., Cynthia, L., & Blengini, G. (2019). Resource efficient recovery of critical and precious metals from waste silicon pv panel recycling. Waste Management, 91, 156-167. https://doi.org/10.1016/j.wasman.2019.04.059

[5] Aryan, V., Font-Brucart, M., & Maga, D. (2018). A comparative life cycle assessment of end-of-life treatment pathways for photovoltaic backsheets. Progress in Photovoltaics Research and Applications, 26(7), 443-459. https://doi.org/10.1002/pip.3003

[6] Baiani, S. and Altamura, P. (2022). Reusable cities: a circular design approach to urban regeneration through materials reuse.. https://doi.org/10.5772/intechopen.105219

[7] Boussaa, S., Benkrid, A., Boutarek, N., & Ayachi, M. (2020). End of life silicon based photovoltaic panels: a review. Journal of Renewable Energies, 23(2). https://doi.org/10.54966/jreen.v23i2.43

[8] Cao, S., Thomas, A., & Li, C. (2023). Emerging materials for interfacial solar-driven water purification. Angewandte Chemie, 62(8). https://doi.org/10.1002/anie.202214391

[9] Celik, I., Song, Z., Cimaroli, A., Yan, Y., Heben, M., & Apul, D. (2016). Life cycle assessment (lca) of perovskite pv cells projected from lab to fab. Solar Energy Materials and Solar Cells, 156, 157-169. https://doi.org/10.1016/j.solmat.2016.04.037

[10] Chidolue, O. and Iqbal, T., 2023, March. System Monitoring and Data logging using PLX-DAQ for Solar-Powered Oil Well Pumping. In *2023 IEEE 13th Annual Computing and Communication Workshop and Conference (CCWC)* (pp. 0690-0694). IEEE.

[11] Etukudoh, E.A., Nwokediegwu, Z.Q.S., Umoh, A.A., Ibekwe, K.I., Ilojianya, V.I. and Adefemi, A., 2024. Solar power integration in Urban areas: A review of design innovations and efficiency enhancements. *World Journal of Advanced Research and Reviews*, *21*(1), pp.1383-1394.

[12] Ezeigweneme, C.A., Umoh, A.A., Ilojianya, V.I. and Adegbite, A.O., 2024. Telecommunications Energy Efficiency: Optimizing Network Infrastructure For Sustainability. *Computer Science & IT Research Journal*, *5*(1), pp.26-40.

[13] Ezeigweneme, C.A., Umoh, A.A., Ilojianya, V.I. and Adegbite, A.O., 2024. Review Of Telecommunication Regulation And Policy: Comparative Analysis USA AND AFRICA. *Computer Science & IT Research Journal*, *5*(1), pp.81-99.

[14] Galimshina, A., Hollberg, A., McCarty, J., Waibel, C., & Schlueter, A. (2023). High-resolution and localized parametric embodied impact calculator of pv systems. Iop Conference Series Earth and Environmental Science, 1196(1), 012014. https://doi.org/10.1088/1755-1315/1196/1/012014

[15] Grant, C. and Hicks, A. (2020). Global warming impacts of residential electricity consumption: agent-based modeling of rooftop solar panel adoption in los angeles county, california. Integrated Environmental Assessment and Management, 16(6), 1008-1018. https://doi.org/10.1002/ieam.4315

[16] Held, M. and Ilg, R. (2011). Update of environmental indicators and energy payback time of cdte pv systems in europe. Progress in Photovoltaics Research and Applications, 19(5), 614-626. https://doi.org/10.1002/pip.1068

[17] Iavicoli, I., Leso, V., Ricciardi, W., Hodson, L., & Hoover, M. (2014). Opportunities and challenges of nanotechnology in the green economy. Environmental Health, 13(1). https://doi.org/10.1186/1476-069x-13-78

[18] Ibekwe, K.I., Ohenhen, P.E., Chidolue, O., Umoh, A.A., Ngozichukwu, B., Ilojianya, V.I. and Fafure, A.V., 2024. Microgrid systems in US energy infrastructure: A comprehensive review: Exploring decentralized energy solutions, their benefits, and challenges in regional implementation.

[19] Ikwuagwu, C.V., Ajahb, S.A., Uchennab, N., Uzomab, N., Anutaa, U.J., Sa, O.C. and Emmanuela, O., 2020. Development of an Arduino-Controlled Convective Heat Dryer. In *UNN International Conference: Technological Innovation for Holistic Sustainable Development (TECHISD2020)* (pp. 180-95).

[20] Ilojianya, V.I., Usman, F.O., Ibekwe, K.I., Nwokediegwu, Z.Q.S., Umoh, A.A. and Adefemi, A., 2024. Data-Driven Energy Management: Review Of Practices In Canada, Usa, And Africa. *Engineering Science & Technology Journal*, *5*(1), pp.219-230.

[21] Kattof, A., Chiad, I., & Zeidan, M. (2022). Awareness of occupational hazards among automobile repair artisans in wasit governorate. International Journal of Health Sciences, 4995-5006. https://doi.org/10.53730/ijhs.v6ns8.13350

[22] Liebman, A., Wiggins, M., Fraser, C., Levin, J., Sidebottom, J., & Arcury, T. (2013). Occupational health policy and immigrant workers in the agriculture, forestry, and fishing sector. American Journal of Industrial Medicine, 56(8), 975-984. https://doi.org/10.1002/ajim.22190

[23] Lizin, S., Passel, S., Schepper, E., Maes, W., Lutsen, L., Manca, J., ... & Vanderzande, D. (2013). Life cycle analyses of organic photovoltaics: a review. Energy & Environmental Science, 6(11), 3136. https://doi.org/10.1039/c3ee42653j

[24] Lunardi, M., Alvarez-Gaitan, J., Bilbao, J., & Corkish, R. (2018). Comparative life cycle assessment of end-of-life silicon solar photovoltaic modules. Applied Sciences, 8(8), 1396. https://doi.org/10.3390/app8081396

[25] Maduka, C. P., Adegoke, A. A., Okongwu, C. C., Enahoro, A., Osunlaja, O., & Ajogwu, A. E. (2023). Review Of Laboratory Diagnostics Evolution In Nigeria's Response To COVID-19. International Medical Science Research Journal, 3(1), 1-23.

[26] Marahatta, S., Gautam, S., Paudel, G., & Yadav, U. (2018). Awareness of occupational hazards and associated factors among automobile repair artisans in kathmandu metropolitan city, nepal. Indian Journal of Occupational and Environmental Medicine, 22(1), 49. https://doi.org/10.4103/ijoem.ijoem_106_17

[27] Mardani, A., Jusoh, A., Zavadskas, E., Cavallaro, F., & Khalifah, Z. (2015). Sustainable and renewable energy: an overview of the application of multiple criteria decision making techniques and approaches. Sustainability, 7(10), 13947-13984. https://doi.org/10.3390/su71013947

[28] Martín, M., Brindley, C., Pérez, J., & Fernández-Ibáñez, P. (2021). Worldwide research trends on solar-driven water disinfection. International Journal of Environmental Research and Public Health, 18(17), 9396. https://doi.org/10.3390/ijerph18179396

[29] Mondschein, P. (2018). Reuse of reclaimed material in road construction layers. Slovak Journal of Civil Engineering, 26(2), 40-44. https://doi.org/10.2478/sjce-2018-0013

[30] Mugagga, R. and Chamdimba, H. (2019). A comprehensive review on status of solar pv growth in uganda. Journal of Energy Research and Reviews, 1-14. https://doi.org/10.9734/jenrr/2019/v3i430113

[31] Ndejjo, R., Musinguzi, G., Yu, X., Buregyeya, E., Musoke, D., Wang, J., ... & Ssempebwa, J. (2015). Occupational health hazards among healthcare workers in kampala, uganda. Journal of Environmental and Public Health, 2015, 1-9. https://doi.org/10.1155/2015/913741

[32] Njemanze, P.C., Njemanze, J., Skelton, A., Akudo, A., Akagha, O., Chukwu, A.A., Peters, C. and Maduka, O., 2008. High-frequency ultrasound imaging of the duodenum and colon in patients with symptomatic giardiasis in comparison to amebiasis and healthy subjects. *Journal of Gastroenterology and Hepatology*, *23*(7pt2), pp.e34-e42.

[33] Novas, N., Salvador, R., Camacho, J., & Alcayde, A. (2021). Advances in solar energy towards efficient and sustainable energy. Sustainability, 13(11), 6295. https://doi.org/10.3390/su13116295

[34] Odeleye, D.A. and Adeigbe, Y.K. eds., 2018. *Girl-child Education and Women Empowerment for Sustainable Development: A Book of Readings: in Honour of Dr Mrs Oyebola Ayeni*. College Press & Publishers, Lead City University.

[35] Ramírez-Márquez, C., Contreras-Zarazúa, G., Martín, M., & Segovia-Hernández, J. (2019). Safety, economic, and environmental optimization applied to three processes for the production of solar-grade silicon. Acs Sustainable Chemistry & Engineering, 7(5), 5355-5366. https://doi.org/10.1021/acssuschemeng.8b06375

[36] Schulte, P., Bhattacharya, A., Butler, C., Chun, H., Jacklitsch, B., Jacobs, T., ... & Wagner, G. (2016). Advancing the framework for considering the effects of climate change on worker safety and health. Journal of Occupational and Environmental Hygiene, 13(11), 847-865. https://doi.org/10.1080/15459624.2016.1179388

[37] Schulte, P., McKernan, L., Heidel, D., Okun, A., Dotson, G., Lentz, T., ... & Branche, C. (2013). Occupational safety and health, green chemistry, and sustainability: a review of areas of convergence. Environmental Health, 12(1). https://doi.org/10.1186/1476-069x-12-31

[38] Singh, J., Molinari, G., Bui, J., Soltani, B., Rajarathnam, G., & Abbas, A. (2021). Life cycle assessment of disposed and recycled end-of-life photovoltaic panels in australia. Sustainability, 13(19), 11025. https://doi.org/10.3390/su131911025

[39] Song, Z., Wang, M., & Yang, H. (2022). Quantification of the impact of fine particulate matter on solar energy resources and energy performance of different photovoltaic technologies. Acs Environmental Au, 2(3), 275-286. https://doi.org/10.1021/acsenvironau.1c00048

[40] Tsang, M., Sonnemann, G., & Bassani, D. (2015). A comparative human health, ecotoxicity, and product environmental assessment on the production of organic and silicon solar cells. Progress in Photovoltaics Research and Applications, 24(5), 645-655. https://doi.org/10.1002/pip.2704

[41] Ukoba, K.O., Inambao, F.L. and Njiru, P., 2018. Solar Energy and Post-Harvest Loss Reduction in Roots and Tubers in Africa. In *Proceedings of the World Congress on Engineering and Computer Science* (Vol. 1).

[42] Umoh, A.A., Adefemi, A., Ibewe, K.I., Etukudoh, E.A., Ilojianya, V.I. and Nwokediegwu, Z.Q.S., 2024. Green Architecture And Energy Efficiency: A Review Of Innovative Design And Construction Techniques. *Engineering Science & Technology Journal*, *5*(1), pp.185-200.

[43] Uzougbo, N.S., Akagha, O.V., Coker, J.O., Bakare, S.S. and Ijiga, A.C., 2023. Effective strategies for resolving labour disputes in the corporate sector: Lessons from Nigeria and the United States.

[44] Uzougbo, N.S., Akagha, O.V., Coker, J.O., Bakare, S.S. and Ijiga, A.C., 2023. Effective strategies for resolving labour disputes in the corporate sector: Lessons from Nigeria and the United States.

[45] Wright, C. and Norval, M. (2021). Health risks associated with excessive exposure to solar ultraviolet radiation among outdoor workers in south africa: an overview. Frontiers in Public Health, 9. https://doi.org/10.3389/fpubh.2021.678680

[46] Нефедова, Л. and Rafikova, Y. (2022). Optimization of risk assessment in renewable energy of russia by applying statistical calculations of climatic characteristics and GIS technologies. Iop Conference Series Materials Science and Engineering, 1235(1), 012061. https://doi.org/10.1088/1757-899x/1235/1/012061