Indonesian Journal Renewable Energy Issues Vol: 2, No 1, 2025, Page: 1-15

Design Thinking Expands Sterilisation of Solar-Powered Medical Devices in Indonesian Private Primary Healthcare

Haudh Al Maa'uun[1]*, Esa Iasyabillah Rosyada[2], Adinda Zahra Raisya Kamil[3] Arif Rohmansyah Huluq[4], Amira Khoirunnisa[5], Siti Zahra Khoirunnisa[6], Faiz Jihad Al Baihaqi[7]

[1] Power Plant Technologies Engineering, State Universty of Malang, Indonesia
[2] Architecture, Muhammadiyah University of Surakarta, Indonesia
[3] Business Administration, Diponegoro University, Indonesia
[4] Machine Engineering, Sultan Ageng Tirtayasa University, Indonesia
[5] Psychology Science, International Open University, Gambia
[6] Health Administration, Siber Muhammadiyah University, Indonesia
[7] Informatics Engineering, State Polytechnic of Indramayu, Indonesia

DOI: https://doi.org/10.47134/rei.v2i1.10
*Correspondence: Haudh Al Maa'uun
Email: haudh.al.2509347@students.um.ac.id

Received: 14-05-2025
Accepted: 22-06-2025
Published: 07-07-2025

Abstract: Indonesia faces a challenge of conventional energy scarcity in the future. The primary issue with the first-level healthcare industry is its limited use of solar energy, particularly for sterilising medical devices, which is crucial in remote areas to ensure their safety and effectiveness. The research aims to analyse the expansion of solar energy utilisation in the sterilisation of medical devices. The research employs a qualitative method with a grounded theory approach, collecting data through interviews and literature reviews. The research location is at the Rizki Sehat Clinic, Serang Regency, Indonesia. The design thinking approach enables the expansion of solar-powered medical sterilisers in private first-level health facilities, overcoming the limitations of electric and manual sterilisers, which have often been suboptimal due to electricity supply constraints and conventional energy operating costs. This innovation has proven to be efficient and environmentally friendly. It can be implemented gradually through a process that involves identifying needs, designing prototypes, conducting demonstrations, providing training, and expanding to additional facilities. The theoretical implications enrich the literature on the adoption of renewable energy technologies in healthcare. Practically, this study provides systematic implementation guidelines for health facility managers in improving the quality and sustainability of solar-powered medical device sterilisation services. The limitations of research on the scope of a single object, as well as conceptual studies, have not thoroughly evaluated economic aspects across various regions. The subsequent research was conducted in various regions with distinct characteristics, utilising a cost-benefit analysis that incorporated solar power and a digital monitoring system.

Keywords: Medical Device Sterilisation, Solar Energy, Design Thinking, Primary Healthcare, Indonesia.

Introduction

The scarcity of conventional energy sources, such as oil, gas, and coal, is projected to pose a significant challenge in the future, alongside increasing energy demand and limited available reserves (Arvidsson et al., 2021). Data indicate that the world's conventional energy is expected to experience a crisis and decline over the next fifty years (IEA, 2025). Conventional energy scarcity is driving the need for alternative energy innovations, such as solar energy, to ensure the sustainability of the energy supply amid increasing demand and limited reserves.

Especially in Indonesia, dependence on fossil energy is still very high and poses economic risks due to global price fluctuations and significant environmental impacts, thus threatening the stability and sustainability of the national energy system (IESR, 2024). Indonesia's conventional energy data, especially oil and gas, is only enough for the next one to two decades, while coal has a much longer reserve life (BPS, 2023). This condition highlights the importance of transitioning to renewable energy to ensure national energy security and long-term sustainability.

In response to the crisis, the presence of renewable energy sources is an urgent need to ensure sustainability and preservation of nature. Renewable energy, such as solar power, is not only environmentally friendly because it reduces carbon emissions, but also supports sustainable development principles that are aligned with the Sustainable Development Goals (SDGs)(Alisjahbana & Murniningtyas, 2018; Yuniar Yasmin et al., 2024). The use of renewable energy allows the creation of a more independent, clean, and sustainable energy system for future generations.

One of the important investments in the health service sector is the procurement of medical devices and the provision of cheap and affordable energy sources (Corio et al., 2023; Said et al., 2020). This investment is crucial to ensure optimal health services, especially in first-tier health facilities or *Fasilitas Kesehatan Tingkat Pertama* (FKTP) such as health centres, clinics and independent practices, which often face budget constraints and access to conventional energy infrastructure (HBS, 2018). The provision of efficient medical devices and affordable energy sources will improve service quality while reducing operational costs (Sanders & Ananda, 2021). Therefore, investment in efficient medical devices and affordable energy is a key strategy to strengthen access, quality, and sustainability of health services in FKTP, especially in resource-limited areas.

Indonesia has geographical advantages, including a tropical climate and its position on the equator, which provides it with exposure to sunlight throughout the year and stable, high radiation intensity. This condition strongly supports the application of solar-powered technology in various sectors, including the sterilisation of medical devices in FKTP, because of the abundant and reliable potential of solar energy throughout the year (Hendrayansyah, 2024; UI, 2022). However, unfortunately, the initial investment constraints for solar panel installations and energy storage systems are still quite expensive, especially for small scales such as FKTPs in remote areas and the mastery of domestic solar panel technology is still low, the demand for small markets, as well as public education and awareness of FKTP owners or managers about the benefits and maintenance of solar technology is still minimal (Bayu & Windarta, 2021; Kharisma et al., 2024).

However, one of the main challenges in expanding the sterilisation of solar-powered medical devices in first-tier healthcare facilities in Indonesia is budget constraints and limited access to innovative technologies. Many FKTPs still face challenges in procuring modern tools and resources for initial investment, as well as limited technical capacity in the operation and maintenance of renewable energy systems.

An interview with a private first health care manager who "*often face problems such as limited electricity, causing electric sterilisers to be often not used, manual sterilisation processes by boiling water, but not always reaching adequate temperature and pressure and limited operational funds to buy fuel or generators*" (Saputra, 2025).

Sterilisation of medical devices is a mandatory procedure in health services to prevent the transmission of infections. However, many health services in developing countries, including Indonesia, face limited electricity, so the sterilisation process is often not optimal (Soto et al., 2022). Solar energy offers sustainable solutions that can address these issues, but the adoption of this technology is still limited (Kishore et al., 2025). An innovative approach centred on user needs is needed to ensure these solutions are practical, easy to adopt, and sustainable.

The primary challenge in utilising solar energy for sterilising medical devices at the first level of healthcare services lies in the gap between Indonesia's vast geographical potential and the actual implementation of this technology in the field (Izuka et al., 2023). Although Indonesia has abundant and stable sunlight exposure throughout the year, the implementation of solar technology is still constrained by high initial cost factors, a lack of supporting infrastructure, limited expertise, and inadequate comprehensive regulatory and policy support (Pertamina, 2021; Ukoba et al., 2024).

Indonesia's advantage lies in its vast potential for solar energy, thanks to its geographical position on the equator and a tropical climate that allows for exposure to sunlight throughout the year using renewable energy, especially solar power, is still far from optimal (PLN, 2021). The primary gap lies in the disparity between increasing energy demand and the energy supply produced, particularly in remote areas that still face limited access to electricity. In addition, high initial investment costs, a lack of supporting infrastructure, limited skilled human resources, and inadequate education and public awareness, including among FKTP managers, are the main obstacles to the adoption of this technology. This has led to many first-tier health facilities (FKTP) in remote areas still relying on conventional energy that is not environmentally friendly and not always reliable.

Previous research Rahmawati et al., (2023) Researching the prototype design of a solar power plant for alternative energy sources in a portable medical device sterilisation machine with quantitative methods, experimental approaches, and explanatory analysis

Then, Castiblanco Jimenez et al. (2021) examine design thinking as a framework for designing sustainable waste sterilisation systems, specifically in the case of the Piedmont region, Italy, using quantitative methods, experimental approaches, and descriptive analysis. Meanwhile, Said et al. (2020) analysed the engineering of solar ovens for sterilisation of medical devices at the Pemouthan Ulu Induk District Health Centre, Ogan Ilir Regency, with a mixed research method, participatory action research (PAR) approach and descriptive analysis.

Sigalingging and Ananda (2021) analyse the design and construction of sterilisation room energy supply devices using solar power systems with quantitative methods, experimental approaches, and descriptive analysis. Meanwhile, the study aims to expand the sterilisation of solar-powered medical devices, especially in first-level health services, such as health centres, clinics, and medical independent practices, which, incidentally, still have many limitations.

Methodology

The qualitative research method employing the Grounded Theory approach enables researchers to achieve a profound and comprehensive understanding of phenomena that are not amenable to quantification or explanation through purely descriptive means (Haig, 2007). Grounded Theory is distinguished by its capacity to generate or refine theoretical frameworks directly from empirical data encountered in the field (Strauss & Corbin, 1998). In alignment with this perspective, Creswell and Clark (2011) argue that this approach facilitates the development of theories at the conceptual level, thereby making a significant contribution to the advancement of knowledge within a given discipline.

The rationale for employing this method lies in its distinctive strength: it enables the formulation of theories that are intrinsically grounded in empirical data collected directly from the field, thereby minimising the influence of prior theoretical constructs. The application of Grounded Theory is particularly apt for investigating and elucidating the expansion of solar-powered medical sterilisation technologies within Indonesia's primary healthcare sector, as it allows for a nuanced understanding of contextual factors and emergent patterns relevant to the local context.

Data Collection and Validation

Data were gathered through in-depth interviews with managers and medical equipment sterilisation service officers at Rizki Sehat Privata Clinic in Serang Regency of Indonesia, utilising purposive sampling techniques. The inclusion criteria prioritised individuals possessing substantial knowledge and expertise regarding medical equipment and facility management, ensuring the relevance and credibility of the information obtained.

Data validation employs source triangulation techniques to verify the information obtained by combining the perspectives of various sources, thereby exploring a phenomenon more holistically and reducing the potential for bias that may occur when relying on only one data source, from collection to presentation and conclusion.

Data Analysis

The data analysis process employed the design thinking methodology, integrated with the six models of social evolution. Design thinking is widely recognised for its effectiveness in addressing complex challenges through a creative, user-centred, and iterative approach. In the context of data analysis, this methodology facilitates the identification of solutions closely aligned with user needs, enabling the extraction of more profound and meaningful insights. The principal strengths of design thinking in data analysis include its emphasis on user orientation, collaborative engagement with diverse stakeholders, iterative refinement, and innovative problem-solving. Consequently, this approach yields solutions that are not only more creative and relevant but also demonstrably effective in addressing the multifaceted nature of problems, maintaining a consistent focus on user needs.

The analytical approach uses the *Design Thinking Model Social Evolution 6* (SE6) as the evolution process of social innovation by combining the evolution model 6 with the six-stage spiral model of social innovation (Murray et al., 2010). The goal can be to create a model by modifying the social innovation process to make it more accessible, intuitive and applicable to multidisciplinary sciences (Moreira et al., 2021).

The analytical strategy adopted in this study integrates the Social Evolution 6 (SE6) design thinking model as a progressive framework for social innovation, achieved by synthesising the Evolution 6 model with the six-stage Social Innovation Spiral proposed by Murray et al., (2010). This fusion enables a dynamic and iterative process that traces the six social innovations through distinct stages: empathy, exploration, elaboration, exposure, execution and expansion, thus facilitating a holistic and user-centred approach to complex problem-solving. The principal objective of employing this combined model is to develop a more accessible, intuitive, and multidisciplinary framework for social innovation, as articulated by Moreira et al., (2021) thereby enhancing its applicability across diverse scientific and professional domains.

The preparation of the six social evolution models and the social innovation spiral model involved defining innovation and evolution as a logical form, serving as the basis for creating an ideal model tailored to the needs of its users. The following illustrations answer the objectives of this research:

Figure 1. 6 Social Evolution Model
(Source: Moreira et al., 2021)

Each phase within the model requires clear delineation to ensure that each component is comprehensively articulated, as outlined below:

a) Empathy: This stage involves identifying emerging challenges and understanding underlying social needs, serving as the foundation for subsequent innovation.
b) Exploration: At this juncture, the focus shifts to generating and refining ideas that address the identified needs and challenges.
c) Elaboration: This phase encompasses the development of prototypes, iterative testing, and further refinement, facilitating the transformation of concepts into viable solutions.
d) Exposure: Here, the project is formally presented to relevant stakeholders, enabling feedback and broader engagement.
e) Execution: This stage involves the practical implementation of the solution, accompanied by rigorous evaluation to assess its impact and effectiveness.
f) Expansion: The final phase seeks to achieve systemic change by scaling successful innovations and integrating them into broader social structures.

The design thinking process model serves as a foundational framework, typically commencing with an interview phase to gather insights, followed by the formulation of the core problem, the ideation and development of potential solutions, the creation of prototypes, and finally, the rigorous testing of these prototypes to determine their effectiveness in addressing the identified issues (Syed et al., 2021).

This methodological approach was instrumental in formulating recommendations for expanding medical device sterilisation services in primary healthcare facilities. The process aligns with strategies for developing healthcare industries that transition incrementally from conventional to renewable energy sources, particularly solar power, thereby supporting sustainable innovation in healthcare delivery. Furthermore, the model's suitability is reinforced by its adaptability to the specific characteristics of innovation and evolution, including the scale, composition, dynamics, and temporal constraints inherent in the local context (Pressman, 2019).

Result and Discussion

Research Results

Improving the quality of innovation and implementation of sterilisation for solar-powered medical devices in private first-tier health facilities requires a thorough understanding of each stage of the innovation process, from empathy to expansion. Each stage—empathy, exploration, elaboration, exposure, execution, and expansion—has a strategic role in ensuring that the solutions developed are truly relevant, effective, and sustainable.

This process requires the active involvement of all stakeholders, from identifying user needs and challenges (empathy), finding and developing ideas (exploration), designing and testing solutions (elaboration), dissemination and demonstration of innovations (exposure), implementation in the field (execution), to expanding impact and systemic adoption (expansion). With a structured and collaborative approach, each of these stages can reinforce each other and contribute to creating health service innovations that are adaptive, responsive, and oriented to the real needs of the community, as can be summarised in the following figure:

Table 1. 6 Social Innovation Models Expanding Solar-Powered Medical Device Sterilisers

Empathy	Exploration	Elaboration	Exposure	Execution	Expansion
Electric sterilisers are often unusable, and manual sterilisation processes, such as boiling water, do not always reach adequate temperatures and pressures, and are limited by operational funds to purchase fuel or generators.	Identify the need for efficient, affordable, and environmentally friendly sterilisation solutions, such as the utilisation of solar energy for the sterilisation of medical devices.	Designing and prototyping solar-powered sterilisers, conducting trials to ensure temperatures and pressures that meet medical standards	Introduce and demonstrate solar sterilisers to health facility managers and staff.	Implement solar sterilisers in healthcare facilities, train officers, and monitor the effectiveness and efficiency of using the tools.	Expanding the use of solar sterilisers to more private first-tier healthcare facilities and conducting sustainability impact evaluations

The informant responded to the readiness of health facility management in adopting solar-powered medical device sterilisation technology by explaining that "*The readiness of our facilities is quite good, especially in terms of basic infrastructure and commitment to innovation. However, we still need technical training for staff and funding support to ensure optimal implementation and maintenance of tools can be carried out on an ongoing basis"* (Saputra, 2025). Meanwhile, the sterilisation officer responded, "*My experience has been quite positive; the solar-powered steriliser is easy to operate and environmentally friendly. However, I still need to adapt to the new features and understand routine maintenance procedures to keep the tool working optimally"* (Muhayat, 2025).

Regarding the main limitations, the manager mentioned, "*The main challenges are budget constraints for initial investment, as well as a lack of technical knowledge related to the operation and maintenance of solar-based equipment. In addition, we also need to ensure that the quality of sterilisation still meets applicable health standards"* (Saputra, 2025). Meanwhile, related to the benefits, the sterilisation officer argued, "*The main benefit is operational cost efficiency because it does not depend on PLN's electricity, and the equipment can still be used even if there is a power outage. In addition, the use of solar energy also supports environmental sustainability programs at our facilities"* (Muhayat, 2025).

Discussion

Health facility managers report a commitment to good infrastructure and innovation for adopting solar-powered sterilisation, but highlight the need for technical training and funding support, consistent with international findings on the importance of human resource readiness and financial backing for renewable energy adoption in healthcare

(Pakravan & Johnson, 2021; Ani, 2021). Ongoing technical training and access to initial investment funds are crucial for optimal operation and maintenance of solar systems in primary healthcare settings (Ani, 2021). Key challenges include limited initial investment budgets and a lack of technical knowledge, common barriers in developing countries (Kishore et al., 2025). The sustainability of solar systems depends on innovative financing and staff training, while maintaining sterilisation quality aligns with WHO recommendations for quality control and periodic evaluation of new medical technologies (Sharma et al., 2024; WHO et al., 2023).

Sterilisation staff report positive experiences with solar-powered sterilisers, noting ease of use and environmental benefits, but still require adaptation to new features and regular maintenance. Simple user interfaces and proper training increase adoption and reduce operational barriers, emphasising the need for ongoing technical support (Garvey, 2024). Primary benefits include operational cost savings, resilience to power outages, and environmental sustainability. Solar systems lower energy costs, improve service reliability in areas with unstable electricity, and support sustainability and carbon reduction goals in healthcare (Khogali et al., 2022; Soto et al., 2022).

Efforts to Increase Empathy in Expanding the Sterilisation of Solar-Powered Medical Devices in Private First-Tier Health Facilities

Empathy here means health workers and managers understand the challenges faced by patients and sterilisation staff, such as limited electricity, high costs, and infection risks from poor sterilisation. Strong empathy improves service quality, patient satisfaction, and outcomes, as solutions better match user needs (Rohlèn & Skilbred, 2016). Empathy should also guide technological innovation, like solar sterilisers, by involving end-users in every stage, from identifying problems to evaluating impact. This leads to more relevant and user-friendly solutions, as well as greater trust among staff and patients. Innovations rooted in empathy are more widely adopted, while those lacking empathy often fail and increase dissatisfaction (HBS, 2018).

In the digital era, digital empathy—authentic, responsive, patient-focused communication—is vital. Technology like monitoring apps should consider digital literacy, culture, and user preferences, especially in private first-tier facilities (Kishore et al., 2025). Digital empathy fosters stronger relationships and facilitates effective technology adoption. Empathy can be improved through training, simulation, and fostering an organisational culture that values empathy. Role-play, reflection, and leadership training enhance empathy skills (Izuka et al., 2023). Involving patients and sterilisation staff in development teams ensures solutions meet real needs. Thus, empathy underpins the sustainable expansion of solar-powered sterilisation in private first-tier healthcare facilities.

Efforts To Increase Exploration in Expanding The Sterilisation Of Solar-Powered Medical Devices in Private First-Tier Health Facilities

The exploration began by identifying key challenges, including limited access to electricity, high operational costs, and the risk of infection due to suboptimal sterilisation. A study by WHO et al. (2023) demonstrates that a solar-powered autoclave system can produce sterile steam with high efficiency using a simple solar collector, even in less-than-ideal weather conditions, making it suitable for small clinics in areas with limited electricity availability. These findings confirm that technology exploration must consider real conditions in the field for the solutions developed to be truly applicable.

Furthermore, the exploration of solutions also includes an analysis of the economic and environmental benefits of solar energy applications. Research by Raman et al., (2024) It shows that the installation of solar power systems in primary healthcare centres can lower energy costs by up to 75% over the operational life and significantly reduce carbon emissions. By reducing reliance on diesel generators and fossil fuels, private healthcare facilities can allocate larger budgets to patient care and services. This exploration must also consider the need for energy storage, ensuring the steriliser continues to function optimally in the absence of sunlight.

Further exploration is needed to integrate health facility design with renewable energy sources as a whole. The integration of solar panels and energy storage systems into the design of healthcare facilities not only improves operational efficiency but also enhances the facility's resilience to power supply disruptions. Article Faisal (2021) highlights that the application of renewable energy, especially solar, can increase resilience, cost efficiency, and support the achievement of net-zero emission targets in the health sector. This exploratory approach also encourages cross-disciplinary collaboration between engineers, facility managers, and healthcare workers.

Finally, exploration in this context should be driven by global trends and evolving best practices. Many countries and medical device manufacturers are now actively developing and adopting solar-powered medical devices, such as vaccine refrigerators and sterilisers, which have been shown to improve access to healthcare in remote areas (Jati, 2024). Exploration efforts should include technology feasibility studies, involvement of local stakeholders, and design adaptation to suit the needs and conditions of private first-tier health facilities in Indonesia. Thus, comprehensive exploration will accelerate the adoption of environmentally friendly and sustainable solutions in the healthcare sector.

Efforts To Improve Elaboration on Expanding the Sterilisation of Solar-Powered Medical Devices in Private First-Tier Health Facilities

Expanding sterilisation for solar-powered medical devices in private first-tier healthcare facilities requires a systematic approach, from design to prototype testing tailored to local needs. Capellán-Pérez et al. (2020) highlighted the need for solar autoclave prototypes that achieve standard sterilisation temperatures and pressures. Tests showed that the device can maintain 121°C and 2.1 bar for over 20 minutes, meeting international standards. Arvidsson et al. (2021) further stressed the importance of material selection and efficient solar collector design for reliable sterile vapour production across diverse conditions, making thorough component testing essential. Integration with facility infrastructure is also key. Nigeria's ECM (2025) program demonstrated that solar solutions enhance device reliability, reduce electricity costs by 40–50%, and mitigate voltage fluctuation risks. Sigalingging and Ananda (2021) found that 90% of facilities using solar systems report cost savings and greater reliability. Therefore, solar designs should be adapted to meet facility energy needs and ensure adequate maintenance and monitoring mechanisms.

Environmental and sustainability factors must be taken into consideration. Yasmin et al., (2024) found that solar systems with battery storage can reduce carbon emissions by up to 9,371 kg CO_2 and decrease energy costs by up to 75% compared to diesel, while also enabling sterilisation in off-grid facilities, thereby expanding access in remote areas (Said et al., 2020). Continuous evaluation and adjustment are vital. Rohlèn and Skilbred (2016) showed that adoption success depends on user training, stakeholder engagement, and technical support, while regular evaluation and design adaptation based on user feedback ensure operational fit and healthcare impact (Kishore et al., 2025). Thus, comprehensive, participatory elaboration is key to the successful expansion of solar-powered sterilisation in private first-tier healthcare facilities.

Efforts To Increase Exposure in Expanding The Sterilisation Of Solar-Powered Medical Devices in Private First-Tier Health Facilities

Exposure involves sharing innovation results, technology demonstrations, and engaging stakeholders. Effective interventions—such as live demonstrations, training, and donor involvement, significantly accelerate the adoption of solar electrification in healthcare, boosting managers' confidence when they witness proven success (WHO et al., 2023). Demonstrating solar sterilisers to healthcare staff and management through field tests and on-site training is crucial, as it lets workers observe, test, and understand the technology's benefits, building confidence and reducing resistance to change (Castiblanco Jimenez et al., 2021).

Publishing results and best practices via media, conferences, and networks is also vital. Sharing test outcomes, success stories, and user testimonials encourages wider adoption, while partnerships with international organisations and donors expand exposure through training and technical support (Benedettini, 2022; PLN, 2021). Continuous monitoring, evaluation, and feedback—such as forums, reports, and follow-ups—help address challenges and refine innovations, ensuring successful and sustainable adoption of solar-powered sterilisers in private first-tier healthcare facilities (HBS, 2018; ECM, 2025).

Efforts to Improve The Execution of Expanding The Sterilisation of Solar-Powered Medical Devices In Private First-Tier Health Facilities

Expanding solar-powered medical device sterilisation in private first-tier health facilities requires careful planning and collaboration. Passively designed solar autoclaves can provide reliable sterilisation even in poor weather, making them suitable for areas with limited electricity access Pakravan and Johnson (2021). Success depends on adapting systems to local needs, involving users early, and providing technical training. Sustainability is a significant challenge, as many projects fail due to poor design, lack of training, inadequate financing or maintenance WHO et al., (2023). Effective execution requires quality equipment, accurate power planning, and funding for ongoing maintenance and part replacement.

Integration with existing facility infrastructure is also essential. Solar systems with batteries can cut energy costs by up to 75%, reduce emissions, and improve device reliability, but must be paired with continuous training and performance monitoring (Ani, 2021; Ukoba et al. 2024)). Ultimately, adequate policy support, agency collaboration, and community involvement are essential. Supportive regulations, transparent business models, and stakeholder engagement at every stage enable sustainable implementation and help improve service quality, access, and clean energy adoption in Indonesia’s health sector (Izuka et al., 2023; UI, 2022).

Efforts To Increase The Expansion of Sterilisation of Solar-Powered Medical Devices in Private First-Tier Health Facilities

Ensuring that solar power systems in health facilities meet requirements for capacity, device compatibility, and ease of use is crucial for successful expansion. Well-designed solar photovoltaic systems can reliably operate medical devices, including sterilisers, for over 25 years with proper maintenance (Soto et al., 2022). Falling costs of panels and batteries, along with better inverter technology, have enabled wider adoption in smaller healthcare facilities. Expansion should be supported by innovative financing, cross-sector collaboration, and maintenance guarantees. India's experience shows that government and donor support, along with partnerships, are key to success (Khogali et al., 2022). This approach enhances healthcare quality, reduces costs, and lowers emissions. Indonesia can adopt similar models, involving local governments, the private sector, and philanthropy for solar steriliser implementation (Corio et al., 2023).

Technological advances—such as integrating solar panels with energy storage and advanced sterilisation methods like solar autoclaves and electron beam sterilisation—boost efficiency, even in remote areas (IESR, 2024; IEA, 2025). Digital monitoring should be included to maintain safety and quality standards, enhancing both service quality and public trust. Finally, ongoing training, advocacy, and education are essential. The success of renewable energy in healthcare depends on human resource readiness and community acceptance (Ani, 2021). Training, best practice forums, and public education will support the adoption and sustainability of these initiatives. This comprehensive approach can improve healthcare quality, cost efficiency, and environmental sustainability in Indonesia’s private first-tier facilities (IESR, 2024; Yasmin et al., 2024).

Conclusion

The design thinking approach enables the expansion of solar-powered medical sterilisers in private first-level health facilities, overcoming the limitations of electric and manual sterilisers that have often been suboptimal due to electricity supply constraints and conventional energy operating costs. This innovation has proven to be efficient and environmentally friendly. It can be implemented gradually through a process that involves identifying needs, designing prototypes, conducting demonstrations, providing training, and expanding to additional facilities.

The theoretical implications of these findings enrich the literature on the adoption of renewable energy technologies in healthcare, particularly in the context of developing countries, such as Indonesia, which face infrastructure and resource challenges. Practically, this study provides systematic implementation guidelines for health facility managers to improve the quality and sustainability of solar-powered medical device sterilisation services. However, this study has limitations in its scope, as it is still limited to a single object and has not thoroughly evaluated economic aspects across various regions.

Further research was then conducted in various regions with different characteristics, involving a more comprehensive cost-benefit analysis and an exploration of integrating solar technology with digital monitoring systems to enhance the effectiveness and efficiency of health services.

References

Alisjahbana, A. S., & Murniningtyas, E. (2018). *Tujuan Pembangunan Berkelanjutan Di Indonesia: Konsep Target Dan Strategi Implementasi*. Universitas Padjadjaran. https://doi.org/10.18356/9789210010788

Ani, V. A. (2021). Powering primary healthcare centres with clean energy sources. *Renewable Energy and Environmental Sustainability*, *6*(7), 1–17. https://doi.org/10.1051/rees/2020009

Arvidsson, R., Svanström, M., Harvey, S., & Sandén, B. A. (2021). Life-cycle impact assessment methods for physical energy scarcity: considerations and suggestions. *International Journal of Life Cycle Assessment*, *26*(12), 2339–2354. https://doi.org/10.1007/s11367-021-02004-x

Bayu, H., & Windarta, J. (2021). Tinjauan Kebijakan dan Regulasi Pengembangan PLTS di Indonesia. *Jurnal Energi Baru Dan Terbarukan*, *2*(3), 123–132. https://doi.org/10.14710/jebt.2021.10043

Benedettini, O. (2022). Green Servitization in the Single-Use Medical Device Industry: How Device OEMs Create Supply Chain Circularity through Reprocessing. *Sustainability (Switzerland)*, *14*(12670), 1–21. https://doi.org/10.3390/su141912670

BPS (2023). *Neraca Energi Indonesia 2018 - 2022* (Vol. 25). www.bps.go.id

Capellán-Pérez, I., De Blas, I., Nieto, J., De Castro, C., Miguel, L. J., Carpintero, Ó., Mediavilla, M., Lobejón, L. F., Ferreras-Alonso, N., Rodrigo, P., Frechoso, F., & Álvarez-Antelo, D. (2020). MEDEAS: A new modeling framework integrating global biophysical and socioeconomic constraints. *Energy and Environmental Science*, *13*(3), 986–1017. https://doi.org/10.1039/c9ee02627d

Castiblanco Jimenez, I. A., Mauro, S., Napoli, D., Marcolin, F., Vezzetti, E., Rojas Torres, M. C., Specchia, S., & Moos, S. (2021). Design thinking as a framework for the design of a sustainable waste sterilization system: The case of piedmont region, italy. *Electronics (Switzerland)*, *10*(2665), 1–25. https://doi.org/10.3390/electronics10212665

Corio, D., Ritnawati, ’Atiq, M., Yanti, M. I. M., Sukardin, M. S., Dahri, A. T., Suleman, M. R. N., Ahmadi, H., Mursalim, & Rauf, R. (2023). *Energi Indonesia: Masalah dan Potensi Pembangkit Listrik dalam Mewujudkan Kemandirian Energi*. Yayasan Kita Menulis.

Creswell, J. W., & Clark, P. V. L. (2011). *Designing and Conducting Mixed Methods Research*. Sage Publications.

ECM (2025). *Climate Resilience And Powering Healthcare In The Global South.*

Faisal. (2021). Urgensi Pengaturan Pengembangan Energi Terbarukan Sebagai Wujud Mendukung Ketahanan Energi Nasional. *Ensiklopedia Social Review*, *3*(1), 18–24. https://doi.org/https://doi.org/10.33559/esr.v3i1.675

Garvey, M. (2024). Medical Device-Associated Healthcare Infections: Sterilization and the Potential of Novel Biological Approaches to Ensure Patient Safety. *International Journal of Molecular Sciences*, *25*(1). https://doi.org/10.3390/ijms25010201

Haig, B. (2007). Grounded theory. In *Encyclopedia of Measurement and Statistics* (pp. 419–421). SAGE Publications, Inc. https://doi.org/10.1080/17439760.2016.1262614

HBS. (2018). *Improving Access to Reliable Energy for Primary Healthcare Centres in Nigeria*. https://ng.boell.org/en/2019/01/08/improving-access-reliable-energy-primary-healthcare-centres-nigeria

Hendrayansyah. (2024). *Pengembangan Potensi Energi Hidro Guna Meningkatkan Perekonomian Nasional* (pp. 1–93). Lembaga Ketahanan Nasional RI.

IEA. (2025). *Global Energy Review 2020*. https://doi.org/10.1787/a60abbf2-en

IESR. (2024). *Indonesia Energy Transition Outlook 2015: Navigating Indonesia’s Energy Transition at the Crossroads: A Pivotal Moment for Redefining the Future*.

Izuka, U., Ojo, G. G., Ayodeji, S. A., Ndiwe, T. C., & Ehiaguina, V. E. (2023). Powering Rural Healthcare With Sustainable Energy: a Global Review of Solar Solutions. *Engineering*

Science & Technology Journal, *4*(4), 190–208. https://doi.org/10.51594/estj.v4i4.582

Jati, S. A. K. (2024). Dinamika Hukum Dalam Pengembangan Energi Baru Terbarukan Di Indonesia: Tinjauan Terhadap Aspek Regulasi Dan Implementasinya Dalam Pembangunan Infrastruktur Energi Berkelanjutan. *Jurnal Legal Reasoning*, *6*(2), 89–101. https://doi.org/https://doi.org/10.35814/jlr.v6i2.6023

Kharisma, A., Pinandita, S., & Jayanti, A. E. (2024). Literature Review: Kajian Potensi Energi Surya Alternatif Energi Listrik. *Jurnal Energi Baru Dan Terbarukan*, *5*(2), 145–154. https://doi.org/10.14710/jebt.2024.23956

Khogali, A., Ahmed, A., Ibrahim, M., Karrar, K., Elsheikh, M., Abdelraheem, E., Cluver, L., & Elmukashfi, E. (2022). Building power-ful health systems: the impacts of electrification on health outcomes in LMICs. *Psychology, Health and Medicine*, *27*(sup1), 124–137. https://doi.org/10.1080/13548506.2022.2109049

Kishore, T. S., Kumar, P. U., & Ippili, V. (2025). Review of global sustainable solar energy policies: Significance and impact. *Innovation and Green Development*, *4*(2), 100224. https://doi.org/10.1016/j.igd.2025.100224

Moreira, J., Santos, J., Palma, G., & Tschimmel, K. (2021). Design Thinking para a Inovação Social Desenvolvimento do modelo Social Evolution 6. In *Coleção Convergências Research Books* (Issue 2, pp. 169–176). Edições IPCB.

Muhayat. (2025). *Wawancara Petugas*. Klinik Rizki Sehat.

Murray, R., Grice, J. J., & Mulgan, G. (2010). *The Open Book of Social Innovation*. www.socialinnovator.info

Pakravan, M. H., & Johnson, A. C. (2021). Electrification planning for healthcare facilities in low-income countries, application of a portfolio-level, multi criteria decision-making approach. *ISPRS International Journal of Geo-Information*, *10*(11), 1–20. https://doi.org/10.3390/ijgi10110750

Pertamina. (2021). *Annual Report PT Pertamina Bina Medika 2022*.

PLN. (2021). *Optimalisasi Strategi Mewujudkan Transisi Energi Berkelanjutan*. https://web.pln.co.id/statics/uploads/2023/02/SR-PLN-2021-Low-revisi-0111.pdf

Pressman, A. (2019). *Design Thinking : A Guide to Creative Problem Solving for Everyone*. Routledge Taylor & Francis Group.

Rahmawati, Bayusari, I., Caroline, C., Hermawati, H., & Mawarni, L. (2023). Desain Prototipe Pembangkit Listrik Tenaga Surya Untuk Sumber Energi Alternatif Pada Mesin Sterilisasi Alat Medis Portable. *Jurnal Rekayasa Elektro Sriwijaya*, *4*(2), 73–82.

https://doi.org/10.36706/jres.v4i2.85

Raman, R., Lathabhai, H., Pattnaik, D., Kumar, C., & Nedungadi, P. (2024). Research contribution of bibliometric studies related to sustainable development goals and sustainability. *Discover Sustainability*, *5*(7), 1–39. https://doi.org/10.1007/s43621-024-00182-w

Rohlèn, S., & Skilbred, M. (2016). *Strategy for designing solar-powered UPS systems in hospitals in Eastern Africa [Chalmers University of* Technology]. http://publications.lib.chalmers.se/records/fulltext/243122/243122.pdf

Said, M., D.A, B., Faizal, M., & Enggal. N. (2020). Rekayasa Oven Surya Untuk Sterilisasi Alat Kesehatan Di Puskesmas Kecamatan Pemulutan Ulu Induk Kabupaten Ogan Ilir. *Seminar Nasional AVoER XII 2, November*, 919–924. https://ejournal.ft.unsri.ac.id/index.php/avoer/article/view/308

Saputra, A. (2025). *Wawancara Pemilik* (p. 1). Klinik Rizki Sehat.

Sharma, L., Singh, J., Dhiman, R., Vargas Nunez, D. R., Ba, A. E., Joshi, K. J., Modi, B., Padhi, A., Tandon, J. K., & Seidel, M. (2024). Advancing Solar Energy for Primary Healthcare in Developing Nations: Addressing Current Challenges and Enabling Progress Through UNICEF and Collaborative Partnerships. *Cureus*, *16*(1), 1–7. https://doi.org/10.7759/cureus.51571

Sigalingging, T. M., & Ananda, Y. (2021). Rancang Bangun Alat Suplai Energi Ruangan Sterilisasi Menggunakan Sistem Tenaga Surya. *Jurnal Simetri Rekayasa*, *3*(2), 178–186. https://jurnal.harapan.ac.id/index.php/JSR/article/view/520

Soto, E. A., Hernandez-Guzman, A., Vizcarrondo-Ortega, A., McNealey, A., & Bosman, L. B. (2022). Solar Energy Implementation for Health-Care Facilities in Developing and Underdeveloped Countries: Overview, Opportunities, and Challenges. *Energies*, *15*(22). https://doi.org/10.3390/en15228602

Strauss, A. L., & Corbin, J. (1998). *Basics of Qualitative Research: Grounded Theory Procedures and Techniques* (2nd ed.). Sage Publications.

Syed, F., Shah, S. H., Waseem, Z., & Tariq, A. (2021). Design Thinking for Social Innovation: A Systematic Literature Review & Future Research Directions. In *SSRN Electronic Journal* (Digitalisation, Disruption, and Innovation). https://doi.org/10.2139/ssrn.3916835

UI. (2022). *Pionir Kemajuan: Pendekatan Kolaboratif Universitas Indonesia untuk Meningkatkan Efisiensi Sumber Daya dan Kemitraan Global*.

Ukoba, K., Yoro, K. O., Eterigho-Ikelegbe, O., Ibegbulam, C., & Jen, T. C. (2024). Adaptation of solar energy in the Global South: Prospects, challenges and opportunities. *Heliyon*, *10*(7), e28009. https://doi.org/10.1016/j.heliyon.2024.e28009

WHO, The World Bank, IRENA, & Sustainable Energy for All. (2023). Energizing health: accelerating electricity access in health-care facilities. In the *WHO*. World Health Organization

Yasmin, S. Y., Febrian Syah, F., Azka, A. A., & Aribowo, D. (2024). Energi Surya Sebagai Solusi Dalam Peningkatan Efisiensi Energi Perspektif SDGs 7 (Sustainable Development Goals 7) 2030 (Studi Kasus Penerapan Panel Surya Mewujudkan Smart And Green Campus di UNTIRTA). *Venus: Jurnal Publikasi Rumpun Ilmu Teknik*, *2*(2), 108–118. https://doi.org/https://doi.org/10.61132/venus.v2i2.252