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Techno-Economics And Environmental Aspects Of Institutional Solar Cooking In India

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Abstract: *Solar cooking systems, which are gaining popularity as a result of growing awareness of energy, environmental, and health issues, offer an environmentally friendly alternative to traditional cooking methods, solar cooking technologies are becoming increasingly important, particularly in areas with limited or costly fuel sources. Research highlights phase change materials (PCMs), heat retention systems, and reflector designs like the Scheffler reflector, which allow efficient cooking even during the night, but widespread adoption is hindered by things like cultural preferences, low awareness, and cloudy weather. This is particularly true in developing areas. Multi-criteria decision-making tools can help solve these issues supported by improved energy storage, hybrid systems, and policy frameworks, efforts are underway to incorporate solar cooking into sustainable development strategies. Solar cookers have a significant potential to combat energy poverty and contribute to global climate change mitigation by reducing deforestation, lowering greenhouse gas emissions, and saving costs for low-income families.*
Keywords: *Solar cookers, Scheffler reflector, phase change materials, hybrid systems*

1 INTRODUCTION

Solar cooking has emerged as an alternative to conventional energy sources such as charcoal, wood, and liquefied petroleum gas (LPG). This is a sustainable and environmentally friendly method of food preparation. This introduction combines findings from a number of research papers and discusses the present state of solar cooking systems, their technological advancements, and their social, economic, and environmental effect.

Solar cooking systems use the sun's abundant energy to produce heat, which can be used for cooking. These systems are particularly valuable in areas where traditional fuel sources are scarce or environmentally harmful. As a growing global population faces challenges related to climate change, depleting natural resources, and energy insecurity, solar cooking is a viable solution. These papers provide a comprehensive understanding of the growth, efficiency, and implementation of solar cooking technologies, particularly in underdeveloped and developing nations where clean energy solutions are essential.

Solar cooking systems have seen significant improvements in design and functionality over the past few decades. Nowadays, solar cookers are designed to improve reliability and efficiency even in areas where sunlight may be limited. Scheffler reflectors, parabolic dish collectors, flat plate collectors, and evacuated tube collectors have become popular solar energy collectors among a variety of design [Ceviz et al. 2024]. These designs allow for more precise solar energy focusing, which allows for faster and more efficient cooking processes.

Researchers have tried various materials and configurations to improve solar cookers' performance. For instance, systems that use phase change materials (PCMs) like paraffin wax and heat storage materials (HSMs) like sand and iron fragments have been developed to store solar heat during the evening [Gawandeand Ingole 2021, Patel and Patel 2024].These systems make solar cooking more convenient for daily use because they ensure that cooking can continue even when sunlight is no longer available.

Indirect solar cooking systems, in which heat is transferred to cooking vessels through a fluid, are another step forward in solar cooking technologies [Dhiman and Sachdeva 2022]. These systems allow indoor cooking, making them more suitable for cities or weather conditions that make outdoor cooking impractical.

Solar cooking systems improve environmental sustainability by reducing our reliance on biomass and fossil fuels. Conventional cooking techniques that use wood, charcoal, or kerosene cause a significant amount of carbon dioxide and other pollutants to be released into the atmosphere. Solar cooking provides communities with a cleaner, healthier option by removing these emission [Thakur et al. 2023].

Solar cooking can help reduce the loss of forests used for firewood in developing countries, particularly in areas where deforestation is a major issue. Solar cooking can reduce the demand for biomass, reducing the pressure on natural resources and resulting in better environmental conservation efforts.

Solar cooking also has significant economic benefits, Cooking fuel takes a big part of the income of many families in rural areas. These households can save money by using solar cooking. This money can then be used for other important things like education and healthcare.

Furthermore, reducing the need for fuel collection could save time and labor, especially for women, and allow them to participate in other productive activities [Sarangi et al. 2024].

Solar cooking has many benefits, but its adoption is limited due to a number of issues. Solar cooking systems' initial cost is a major obstacle. Although solar cookers are cost-effective over time, many low-income families can't afford the upfront investment. To make these systems more accessible, financial support and subsidies may be required.

Cultural and behavioral resistance to new cooking techniques is another obstacle. Many communities have deep-rooted cooking customs that depend on particular fuels and methods. Without adequate education and demonstration of the technology's benefits, a shift in these practices can be difficult to achieve for solar cooking.

Adoption has also been hampered by technological limitations, like the inability to cook at night or in cloudy weather, While innovations like PCMs and HSMs address some of these issues, more research and development is needed to make solar cooking systems more reliable and convenient [Khatri et al. 2022].

Continued research and development will help solar cooking systems become more practical, more efficient, and less expensive. Innovations like using Sterling engines to produce electricity from overheat are promising areas of research [Alkhalaf et al. 2023]. This could provide households with both a clean cooking method and power for other important things.

Furthermore, the expansion of solar cooking technologies for use in institutions (e.g., community kitchens or schools) has the potential to significantly reduce fuel usage and emissions on a larger scale. According to studies, solar cooking systems can be effectively used to cook meals for hundreds of people in institutions. These systems provide a cost-effective and sustainable solution for mass cooking. [Indora and Kandpal 2018 a,b].

Finally, widespread adoption of solar cooking will depend on policy support. By providing incentives, raising awareness, and providing infrastructure, governments can play a key role in supporting the use of solar energy for cooking. When solar cooking is integrated into larger renewable energy and sustainable development initiatives, it will become a mainstream solution to energy and environmental issues [Mishra et al. 2023].

Solar cooking systems are a promising solution to many energy, environmental, and health issues that communities around the world face. Solar cooking can improve public health, contribute to environmental sustainability, and drastically reduce reliance on non-renewable fuels through technological advancements and greater public awareness. Solar cooking is difficult to adopt, but continued research, innovation, and policy support can help overcome these obstacles, making it a widespread and viable practice.This collection of research papers helps you understand current and future solar cooking technologies and how they can help achieve global sustainability goals.

2 LITERATURE REVIEW

Solar cooking has emerged as a promising solution for the transition towards clean and renewable energy sources. It is addressing the global need to reduce environmental pollution and improve public health, particularly in developing and low-income countries.Solar cooking technologies, as stated in the study, offer a cost-effective and sustainable alternative to traditional fuel-based cooking methods, which rely heavily on nonrenewable resources like kerosene, liquefied petroleum gas (LPG), and firewood. Solar cooking systems are designed to utilize solar energy for cooking purposes, which offers significant social, economic, and environmental benefits.

Solar cooking systems come in a variety of designs, each of which is optimized for various types of cooking and local conditions. These systems include box cookers, parabolic cookers, evacuated tube cookers, and hybrid systems that include thermal energy storage units. A comprehensive overview of solar cooking designs and their functions is provided [Ceviz et al. 2024]. The reference emphasizes their environmental and social benefits.

According to this article, solar cooking systems can be very helpful in areas with limited access to traditional energy resources by reducing energy consumption and addressing health issues associated with

cooking.The article talks about different solar cooking methods and recent developments in the field, highlighting how important it is for government to support this sustainable option.
Solar cooking systems' design and materials used have a big impact on how effective and efficient they are despite its numerous benefits, the adoption of solar cooking technology is hindered [Thakur et al. 2023]. It draws attention to the fact that, although solar cooking is a feasible green energy solution, society does not yet endorse it.
This study prioritizes issues that slow down technology adoption, which hinders progress toward sustainable development goals (SDGs). This is done by using multiple attribute decision-making (MADM) techniques. These barriers are identified and ranked by the Decision-making Trial and Evaluation Laboratory (DEMATEL) method. DEMATEL provides insightful information to policymakers and energy sector stakeholders.
Over the past decades, solar cookers have improved in terms of efficiency and price. Updated technological advancements in solar cooking are discussed [Sarangi et al. 2024], with a focus on enhancing performance by incorporating mirrors and insulating materials. However, due to issues like cost and materials availability, solar cooking is still not widely used worldwide. The study emphasizes the need for additional regulation and assistance in order to make solar cooking systems more feasible.
Thermal energy storage materials are another significant development in solar cooking technology. Phase change materials (PCMs) and solid heat storage materials (SHSMs) are integrated into solar cookers [Gawand and Ingole 2021, Patel and Patel 2024].These materials make it possible for solar cookers to store heat during the day, which allows you to cook in the evening even after the sunsets. Experimental studies in these papers show that certain combinations of storage materials, like sand and iron chunks, are good at retaining heat for long cooking times. These studies show that solar cookers with energy storage devices are more useful and reliable for daily use.
Solar cooking's environmental benefits have been well documented. Solar cookers reduce carbon emissions, deforestation, and indoor air pollution by replacing traditional biomass and fossil fuel-based cooking methods. in India, where cooking constitutes a significant portion of energy consumption, has a lot of potential for solar cooking [Khatri et al. 2022].
The study describes the environmental, health, and economic benefits of implementing solar cooking systems, noting that these systems have the potential to drastically reduce households' dependence on nonrenewable energy sources. However, issues such as cooking during cloudy conditions persist, and the paper requires additional research to resolve these limitations.
Solar cooking systems, especially those with energy storage capabilities, are analyzed economically [Alkhalaf et al. 2023]. It has been shown that the use of latent energy storage systems like paraffin wax and high-density polyethylene (HDPE) has the potential to reduce cooking time and improve the overall performance of solar cookers. The research emphasizes how important it is to incorporate energy storage into solar cooking systems, as this will make them more versatile and able to work even when sunlight is less. Cooking times for various conditions were predicted using regression models, which provides a valuable tool for optimizing cookerperformance.
Solar cooking's financial feasibility is further investigated [Kumar et al. 2024], which offers a thorough review of the Scheffler dish solar cooker. This study investigates the cost-effectiveness of solar cooking systems in places like schools and community kitchen. According to the study, solar cooking not only drastically lowers costs associated with conventional fuel sources like LPG but also reduces CO_2 emissions. These systems have a payback period of 5.3–7.9 years, showing their long-term economic benefits [Gakhar et al. 2013, Gothwal et al. 2018, Gothwal et al. 2019, Ranjan et al. 2016, Ranjan et al. 2019, Sharma et al. 2018, Sharma and Doda 2017]. Solar cooking has clear benefits, but its adoption rate is low around the world. Because of technological, cultural, and social barriers, technology acceptance is limited. Technical limitations of existing designs are among the numerous barriers that prevent the widespread adoption of solar cooking systems [Dhiman and Sachdeva 2023]. The study finds that insulated receivers offer the best heat retention and cooking efficiency in parabolic dish system. However, the study also notes that more research is needed to improve the reliability of solar cookers in different weather conditions.
Cultural factors also contribute to the slow adoption of solar cooking technologies. The introduction of new technologies requires careful consideration of local customs and practices in many regions, where traditional cooking methods are deeply ingrained in daily life. A case study of self-made solar cooking

experiments in the United States is presented [Kuznetsov et al. 2022]. Case study shows how solar cooking can be integrated into community practices. The study emphasizes iterative design processes and user engagement to make solar cooking more accessible and appealing to the general public.

Solar cooking is not only for individual homes; It also has great potential for community and institutional use. Financial analyses of large-scale solar cooking systems, especially in institutions like schools and community kitchens, are provided. These research studies look at solar steam cooking systems using Scheffler dishes and other concentrating solar technologies. The research shows that larger solar cooking systems benefit from economies of scale, making them more financially viable for institutions that serve large numbers of people.

Large-scale solar cooking systems offer significant environmental and health benefits in addition to making money. These systems help lower carbon emissions and improve indoor air quality by reducing the need for conventional fuels. Solar-heated water could be used for institutional cooking purposes, such as school lunch programmes at midday. Solar water heating systems could save significant amounts of LPG every year, according to the study [Doda 2024, Sharma et al. 2023]. This further supports the idea of using solar cooking in institutions.Solar cooking's future depends on continued technological developments and supportive policies. A summary of current initiatives and policies aimed at encouraging solar cooking, particularly in developing nations. The review emphasizes that government assistance, public awareness campaigns, and subsidies are necessary in order to make solar cooking more affordable and accessible [Dhakar and Doda 2023, Doda et al. 2021, Shekhawat et al. 2019, Shrivastava et. 2020]. Further research is required to address current issues and improve the performance of solar cookers in order to maximize the potential of solar cookin. Making energy storage systems more efficient, making cookers more durable and efficient, and creating designs that are practical and culturally acceptable should be the main areas of future work in Environmental, economic, and health benefits of solar cooking will also depend on policies that promote its widespread adoption, particularly in areas with high solar radiation [Indora and Kandpal 2018, Indora and Kandpal 2019, Venkateshwaran, et al. 2025, Saxena, et al.2025].

3. CONCLUSIONS

Although solar cooking provides an environmentally friendly and cost-effective solution for energy demands, its success depends on overcoming technological and social barriers. Solar cooking devices demand will increase day by day as it completely depends upon the solar radiation which is present in abundant but its effective utilization completely depends upon the continuous research to increase the efficiency and design which can benefit the Society Future research should concentrate on enhancing thermal storage capabilities, increasing cooking efficiency, and establishing policies that encourage large-scale adoption. With continued innovation and supportive regulatory frameworks, solar cooking may play a critical role in achieving this goal.

4. Limitations and Recommendations

Solar cooking offers many benefits, but it also has some drawbacks: slow cooking times, dependence on sunlight, and high initial investment costs. Weather conditions and the need for thermal storage solutions for cooking during the night can affect solar cookers' efficiency. Further research should concentrate on improving heat retention materials, lowering production costs, and integrating hybrid renewable energy systems in order to address these issues. Additionally, public awareness programs, government policies, and subsidies can play a significant role in encouraging the widespread adoption of solar cooking technology. Solar cooking can become a more economical and accessible solution for sustainable energy use around the world by overcoming these restrictions.

REFERENCES

1. Alkhalaf Q, et al. (2023) Performance investigation of a Scheffler solar cooking system combined with Stirling engine. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.01.399
2. Ceviz MA, et al. (2024) A comprehensive review of solar cooking systems.WIREs Energy Environ13:1-19. https://doi.org/10.1002/wene.516
3. Chauhan K, et al. (2022) Design and Experimental Studies of a Funnel Solar Cooker with Phase Change Material. Energies15. https://doi.org/10.3390/en15239182
4. Dhakar C and Doda DK (2023) A parametric Approach for Decision Making of Low-Carbon Building Envelope Design, Journal of Polymer & Composites, ISSN: 2321-2810 (online)/ 2321-8525 (print),11: S35-S43.

https://journals.stmjournals.com/jopc/article=2023/view=116711/ .
5. Dhiman A,Sachdeva G (2023) Experimental investigation of an indirect-type solar cooker for indoor cooking based on a parabolic dish collector. Heat transfer 52:378-394. https://doi.org/10.1002/htj.22699
6. Doda DK (2024) Economic Consideration of an Off-Grid Hybrid Power Generation System using Renewable Energy Technologies: Case Study of an Institutional Area in the State of Rajasthan.Advanced Technologies for Science and Engineering, ISSN: 978-981-5079-1 (Print) and ISSN: 978-981-5079-5 (Online), 3: 103-117. https://doi.org/10.2174/9789815196269124030010.
7. Doda DK, Bundele M, Shrivastava A and Kandpal TC (2021) Financial Feasibility of Solar PV Lanterns for Households of a Remote Village Cluster without Access to Electricity. International Journal of Environment and Sustainable Development, ISSN: 1478-7466 (online)/ 1474-6778 (print), 20: 354-365.10.1504/IJESD.2021.116865.
8. Gakhar P, Manglani T and Doda DK (2013) Advancement & Role of DG Technology in Distribution System. International Journal of Recent Research and Review, 6: 22-31.
9. Gawand TK, Ingole DS (2023) Analysis of Energy storage system for Cooking.Fluid mechanics and fluid power 3:37-41. https://doi.org/10.1007/978-981-19-6270-7_7
10. Gothwal N, Manglani T, Doda DK, Somvanshi DK and Bundele M (2019) Design and Optimization of PV-Wind-DG and Grid based Hybrid System for an Educational Institute in India. International Conference on Artificial Intelligence: Advances and Applications, Algorithms for Intelligent Systems. Springer, Singapore, 131-139. https://doi.org/10.1007/978-981-15-1059-5_16.
11. Gothwal N, Manglani T and Doda DK (2018) Importance of Off-Grid Power Generation using Renewable Energy Resources-A Review. International Journal of Computer Application, 179 (28): 38-41.
12. Indora S, Kandpal TC (2018) Institutional and community solar cooking in India using SK-23 and Scheffler solar cookers: A financial appraisal. Renewable Energy 120: 501-511. https://doi.org/10.1016/j.renene.2018.01.004
13. Indora S, Kandpal TC (2018)Feasibility assessment of using solar pre-heated water for institutional cooking in India. International Journal of Ambient Energy 39: 852-862. https://doi.org/10.1080/01430750.2017.1354325
14. Indora S, Kandpal TC (2018)Institutional cooking with solar energy: A review. Renewable and Sustainable Energy Reviews 84: 131-154. https://doi.org/10.1016/j.rser.2017.12.001
15. Indora S, Kandpal TC (2019) Financial appraisal of using Scheffler dish for steam based institutional solar cooking in India. Renewable Energy 135: 1400-1411. https://doi.org/10.1016/j.renene.2018.09.067
16. Khatri R, et al. (2022) Solar cooking in India: Implementation, barriers & improvement aspects. Materials Today: Proceedings 63:309-313. https://doi.org/10.1016/j.matpr.2022.03.136
17. Kumar S, et al.(2024) Design of solar cooking models to enhance energy utilization and environment protection with their cost–benefit analysis: a case study of an institutional area in the state of Rajasthan, India. Environ SciPollut Res. 10.1007/s11356-024-35010-1
18. KuznetsovS, et al. (2022) A Study of Solar Cooking: Exploring Climate-Resilient Food Preparation and Opportunities for HCI. CHI '22: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems 1-8. https://doi.org/10.1145/3491102.3517557
19. Mishra. N, et al. (2023) Box-Type Solar Cookers: An Overview of Technological Advancement, Energy, Environmental, and Economic Benefits. Energies 16:1-32. https://doi.org/10.3390/en16041697
20. Patel R, Patel VB (2024) Scheffler reflector based solar cooking system with dual sensible heat storage material for night cooking application: an experimental investigation. International Journal of Design Engineering 13:33-49. https://doi.org/10.1504/IJDE.2024.138944
21. PatelR, PatelV (2022) Scheffler reflector for cooking application: a review. International Journal of Ambient Energy 43: 2606-2618. https://doi.org/10.1080/01430750.2020.1758778
22. Ranjan R, Doda DK,Lalwani M and Bundele M (2019)Simulation and Optimization of Solar Photovoltaic-Wind- Diesel Generator standalone Hybrid system in Remote Village of Rajasthan, India.International Conference on Artificial Intelligence: Advances and Applications, Algorithms for Intelligent Systems. Springer, Singapore, 279-286. https://doi.org/10.1007/978-981-15-1059-5_31.
23. Ranjan R, Modi B and Doda DK (2016) Distributed Generation of Power using Renewable Energy Resources-A Comparative Review of Grid-connected & Stand-alone System. International Journal of Engineering Science & Research Technology, 5(3): 641-646.
24. Sarangi A, et al (2024) Advancements and global perspectives in solar cooking technology: A comprehensive. Energy Nexus 13:1-35. https://doi.org/10.1016/j.nexus.2023.100266
25. Saxena A, Sagade AA, et al. (2025) A thermodynamic review on concentrating type solar cookers. Solar Energy. 286
26. https://doi.org/10.1016/j.solener.2024.113159
27. Sharma HM, Doda DK and Bundele M (2018) Proposed an Optimize Off-Grid Hybrid Model using Solar Photovoltaic-Wind-DG Technologies for the Climate Conditions of the State of Rajasthan, India. IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2018).
28. Sharma HM and Doda DK (2017) Scope of Decentralized Power Generation using Renewable Energy Resources at Global Level-A Review & Survey at a Glance. Journal of Automation & Systems Engineering, 11 (4): 280-294.
29. Sharma AK, Doda DK, Soni BP, Bansal RC and Palwalia DK (2023)A Systematic Approach to improving Consumers' Comfort through On-Grid Renewable Energy Integration and Battery Storage. Electric Power Components and Systems, ISSN: 1532-5008 print / 1532-5016 online, 0(0): 1-25. https://doi.org/10.1080/15325008.2023.2291126.
30. Shekhawat K, Doda DK, Gupta AK and Bundele M (2019) Decentralized Power Generation using Renewable Energy Resources: Scope, Relevance and Application. International Journal of Innovative Technology and Exploring Engineering, ISSN: 2278-3075, 8: (9): 3052-3060. https://www.ijitee.org/wp-content/uploads/papers/v8i9/I8595078919.pdf.
31. Thakur A, et al. (2023) Solar cooking technology in India: Identification and prioritization of potential challenges. Renewable Energy 219. https://doi.org/10.1016/j.renene.2023.119437