Sun-Powered Cooking: Reducing Environmental and Health Impacts Through Solar Cookers

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Abstract. The solar cooker represents a practical and eco-friendly solution to some of the most pressing global challenges related to energy consumption, environmental degradation, and public health. This paper investigates how solar cookers contribute to sustainability by utilizing abundant and renewable solar energy for cooking, thereby reducing reliance on non-renewable fuels such as firewood, charcoal, and fossil fuels. The adoption of solar cooking technology can significantly lower greenhouse gas emissions, decrease deforestation rates, and minimize indoor air pollution—improving health outcomes, particularly for family in low-income and rural communities. In addition to environmental and health benefits, solar cookers offer economic advantages by reducing household fuel expenses and promoting energy independence. The study also explores the social implications, technological developments, and potential policy interventions needed to support the widespread adoption of solar cookers. Overall, the solar cooker is presented as a simple yet powerful tool for achieving sustainable development and advancing clean energy solutions globally.

1. Introduction

Solar energy is the mother of all other energy sources since it is directly or indirectly linked for the cause. For example: To flow the wind from one direction to another there should be pressure variation or density, this is created by the solar rays falling on earth. It is the energy which is coming from the sun in the form of energy carrying photons falling on the earth surface, creating life on earth. Plants, trees trap the photons from sun rays to undergo photosynthesis, creating flow of wind. Sun rays are converted to heat energy, and this heat energy is utilized in various applications. One such application is the solar cooker. A solar cooker is one of the unique devices that runs with fuel that is freely available in nature. Solar cooker is used for cooking in dal, rice and other varieties, also used in animal feed, two solar cookers made of clay and vermiculite and cement tiles have been designed and tested, with efficiencies of 22.6% and 24.9% respectively. They can boil 2 kg of animal feed per day and consume 1350 MJ of fuel per year, with payback periods ranging from 0.50 to 3.47 years. Focus on solar cookers has reached a high extent due to their easy availability. Variations in solar radiation also affected the temperature inside the solar cooker. For improving the temperature performance and predicting temperature, machine learning algorithms are used, which help and boost the study in the solar cooker field.

From a fundamental human activity, cooking is what it truly is, globally, but the means in which cooking are accomplished have tremendous and generally undesirable impacts on

the environment as well as health. According to WHO (2022), an estimated three billion people still used traditional biomass fuels – mainly wood, charcoal, agricultural residues and animal dung – for cooking and heating. These problems are integrally connected because of this reliance: rampant deforestation, land degradation, accelerated climate change because of black carbon [1] and greenhouse gas emissions and an affront to health in the form of disease [2] from household air pollution (HAP).

One of the biggest causes of morbidity and mortality is HAP, mainly from the inefficient combustion of solid fuels, contributing to millions of premature deaths annually from respiratory infections, heart disease and stroke and lung cancer [4]. No other fuel promotes outdoor burning to such a level as wood or carries such health impacts: women and children, who spend the greatest amount of time indoors near cooking fires, are worst affected. Biomass fuels cannot be collected in a sustainable fashion which contributes to deforestation, fuelling biodiversity loss, soil erosion and desertification in the process. These fuels, furthermore, are burned with the emission of large amounts of greenhouse gases and short lived climate pollutants that directly contribute to global warming [3].

1.1 Green cooking with solar cookers.

By using the sun's own energy, directly, solar cooking is a viable, sustainable alternative to traditional cooking. This is the basic principle: it concentrates sunlight on a cooking pot and heats its contents. Their operating range is typically in the 90 °C to 150 °C range and suitable for boiling, simmering and baking a very wide variety of foods.

1.1.1. Category of Solar Cookers

There are three main types of solar cookers described broadly. The most common kind are Box Cookers which are the simplest type. It consists of an insulated box with a transparent lid (usually glass or polycarbonate) which traps solar radiation. A dark coloured pot inside the cooking vessel, absorbs heat. To increase the incoming sunlight reflectors are employed. Box cookers are good for slow cooking, simmering and baking, they hold heat well so are good for unattended cooking.

Panel Cookers are usually constructed from reflective panels (e.g. cardboard or foam board covered with a layer of aluminium foil) which are put together to bring sunlight into contact with a cooking pot. They are light weight, can be carried to a site and are relatively inexpensive to manufacture. Basic box cookers are good for boiling water, but panel cookers can go to higher temperature and are good for making meals that require moderate heat.

Parabolic Dish Cookers: Harness sunlight using a large curved parabolic reflector to concentrate sunlight to a focal point, in which is placed the cooking pot. Conventional stovetops can reach such high temperatures so quickly that parabolic cookers are very usable for frying, boiling and rapid cooking. The bad news is that they must be adjusted frequently in order to follow the sun and can cause more burns if not used safely.

A thorough explanation of how electric pressure cookers (EPCs) operate explains why cooking African food on a charcoal stove uses 15 times as much energy. Energy ratios serve as a foundation for calculating household cooking expenses as well as the reductions in carbon emissions linked to switching to contemporary cooking fuels. According to studies on fuel and electricity costs, cooking with an EPC can only cost 20% as much as cooking with charcoal. This suggests that contemporary, energy-efficient electric cooking appliances have the potential to defy the energy ladder's conventional wisdom [5]. Bailis et al. [6] estimated the amount of greenhouse gas emissions associated with wood fuels in 2009, compute the extent to which demand for wood fuels surpasses regrowth, and provide a spatially explicit assessment of pan-tropical wood fuel supply and demand. With this

there was an increase in price of solid fuel for every year [7]. In rural areas, the percentage of solid-fuel users is particularly high, at over 80%. Furthermore, the use of solid fuels will continue to be high even in 2030 if the current rate of progress is not accelerated [8], which will hinder the achievement of Sustainable Development Goal (SDG) 7. The incidence and cost-of-illness of acute respiratory illnesses, the relative fuel costs, time and fuel use efficiencies, and the cost of cooking time in the home all have a significant impact on the costs and benefits [9]. The other energies [10] used for generating electricity, cost high compared to solar energy. From the world bank data, it is concluded that only African country is utilizing less source of electricity with the other parts of the world [11]. Table 1 shows the types of solar cooker and its approximate cost, panel type cooker is the cheapest cooker from all the types.

Table 1: shows the types of solar cookers, its components and the approximate cost.

Type of Solar Cooker	Components	Approximate Cost
Box Solar Cooker	Insulated box	$20 - $50
	Transparent glass or plastic cover	
	Reflective panel, Black pots	
Panel Solar Cooker	Reflective panels (cardboard, foil)	$10 - $30
	Transparent cover (plastic bags or plastic sheet)	
	Dark cooking pot with lid	
Parabolic Solar Cooker	Parabolic reflector (metal or aluminum foil-covered surface)	$50 - $200 (depending on reflector material)
	Cooking stand or support	
	Black pot or cooking vessel	
Hybrid Solar Cooker	Reflective panels	$100 - $300
	Insulated box	
	Transparent glass or plastic cover	
	Electric or auxiliary heating element (optional)	
	Black cooking pot	
Vacuum Tube Solar Cooker	Vacuum tube (double-walled glass tube)	$50 - $150
	Reflective panel or parabolic mirror	
	Insulated frame and support	
	Cooking tray or tube for food	

Fresnel Lens Solar Cooker	Fresnel lens (plastic or glass)	$50 - $100
	Adjustable support frame	
	Heat-resistant cooking pot or pan	

2. Experimental Methodology

Fig. 1 showing the methodology used to compare the traditional and solar cooking methods. Truncated conical solar cooker (TCSC) is fabricated using aluminium sheet metal, coated with black colour shown in fig. 2. For collecting the data, a temperature indicator with thermocouples are used and wind speed is measured using anemometer.

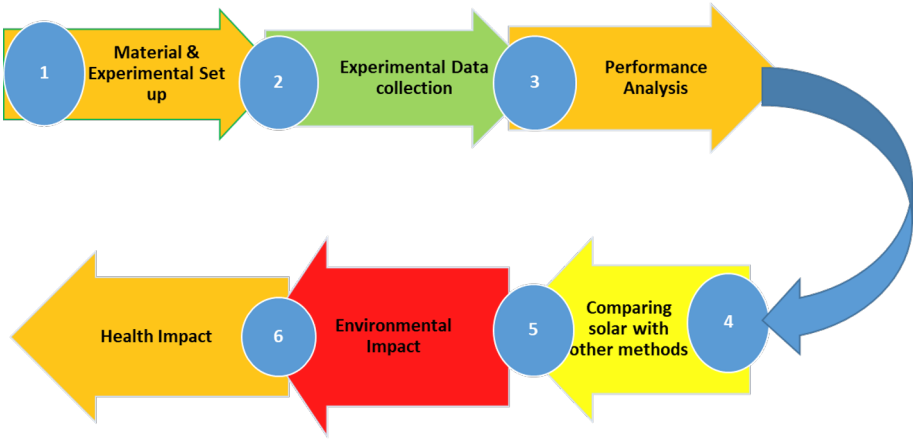

Fig 1: Methodology followed for comparing the performance of traditional and solar cooking.

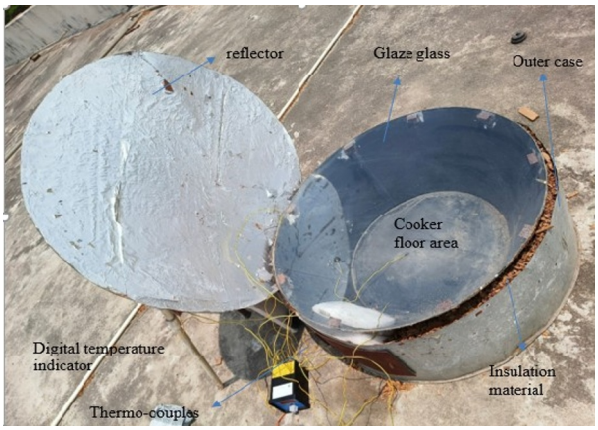

Fig. 2: Truncated conical solar cooker experimental set-up

Table 2 shows the experimental data of various days of the month is collected and used for finding out the efficiency for solar cooker using equation (1) and compared with other cooking methods.

Table 2: shows the Experimental data collected

Date	Time	Cooker inside air temperature	solar radiation w/m^2	Wind speed m/s
18.02.2025	13:30	78	947	2.22
18.02.2025	13:40	80	967	2.22
19.02.2025	13:30	69	960	1.94
19.02.2025	13:40	72	970	1.94

3. Results and discussions

LPG has a comparatively high thermal efficiency and the greatest instantaneous cooking power. Ideal for high-heat and rapid boiling tasks. The cost, supply chain, and greenhouse gas emissions (fossil CO_2) are the main drawbacks. Conventional biomass has the highest emissions (PM, CO) and the lowest efficiency, significant negative effects on health (indoor air pollution), low cooking power delivered in comparison to fuel used. There are environmental and health advantages to switching from Traditional cooking stove TCS to better stoves or non-combustion alternatives. Better than TCS but still producing combustion emissions, improved biomass cook stoves can achieve a thermal efficiency of approximately 15–35%, making them appropriate for locations with easy access to biomass fuels.

Overall efficiency $$\eta_{av} = \frac{mc_f\left(T_{w2} - T_{w1}\right)}{G_{n,av} A_a \Delta t} \quad (1)$$

Table 3: shows the comparison of present solar cooker with the other cooking methods.

Cooking Method	Thermal Efficiency
LPG [12]	40 – 60%
Biomass [13]	10 – 25%
Present TCSC	25-30%

Present TCSC cooker thermal efficiency is in the range of 25 to 30% which shows the good performance compared to the other mode of cooking shown in Table 3, benefiting to the user and to the environment.

3.1 Traditional Cooking: A problem of Environmental and Health Impact

3.1.1 Environmental Degradation is the second division of attestation: waste, resource consumption, damage to foundations of life (water, soil, air), climate change, etc.

Deforestation is an alarming rate driven by demand for fuelwood and charcoal particularly in parts where high population density had little access to alternative energy sources [14]. Forests are important carbon sinks and their demise put all that CO_2 into the atmosphere and thus contribute to climate change as well. Also, deforestation results in:

i. Habitats are destroyed which threatens countless species.
ii. Tree cover removal exposes soil to the wind and water leading to the depletion of nutrients and thus reduced productivity in agriculture.
iii. Deforestation: Deforestation can heighten the process of desertification in arid and semi-arid area to be unusable.
iv. Water Scarcity: Forests also help to balance the water cycle and when they are destroyed they can alter rainfall patterns and lead to greater water stress.

In addition to deforestation, biomass fuels that are not totally burnt release high emissions of black carbon, methane and other particulate matter. Particularly black carbon

is a potent, short (lifetime of 20 days), lived climate pollutant with a warming potential of many thousands of times that of CO over a 20 years' period. Atmospheric warming, glacial melt and regional climate disruption ensue as a result of these emissions.

Fig. 3 represents the impact of household cooking from the year 1990 to 2025, which has declined in mortality rate per 1,00,000 in women and children. Traditional cooking releases harmful gases that are detrimental to the health of women and children who spend much of their time at home. Due to this we can see the increase in solar cooker adoption, which runs directly from the solar rays; no harmful gases are evolved from it. Fig. 4 shows the country wise carbon emissions from household cooking.

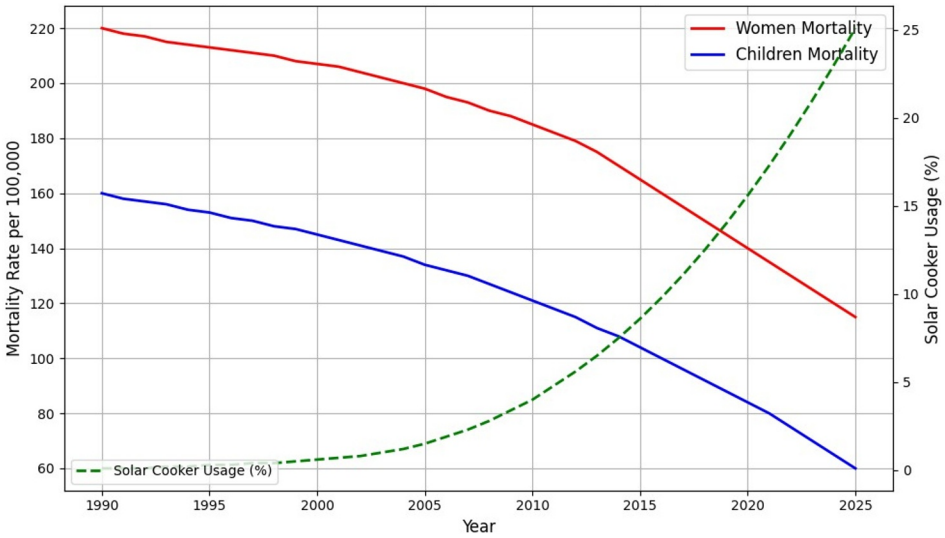

Fig. 3: Shows impact of household cooking vs solar cooker adoption (1990-2025)

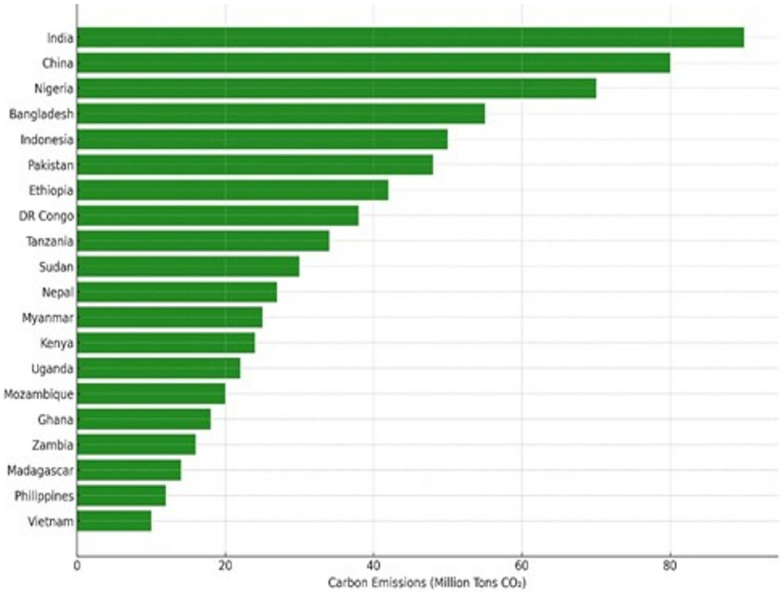

Fig.4: Country-wise Carbon Emissions from Household cooking

3.2 Household air pollution (HAP): Health impacts.

Biomass combustion used for inefficient cooking, leads to household air pollution which has become a global health crisis [15]. Fig. 5 shows Health and Environmental Impact on traditional cooking and clean cooking adoption. A complex mixture of harmful pollutants that are in smoke include particulate matter carbon monoxide, polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs). Breathing these pollutants in can cause:

- ALRI (acute lower respiratory infections) like pneumonia is a leading cause of death, especially in young children.
- Adults are at significant risk for developing Chronic Obstructive Pulmonary Disease (COPD) from long exposure to fossil fuels.
    - Cardiovascular Disease: Those with HAP are at greater risk of ischemic heart disease and stroke.
    - PAHs in cooking smoke are a known carcinogen and exposure to PAHs increases the risk of lung cancer.
    - Aside from respiratory illness, HAP can cause other health issues such as adverse pregnancy outcomes (low birth weight and preterm birth) and cataracts and is associated with tuberculosis (WHO, 2022).

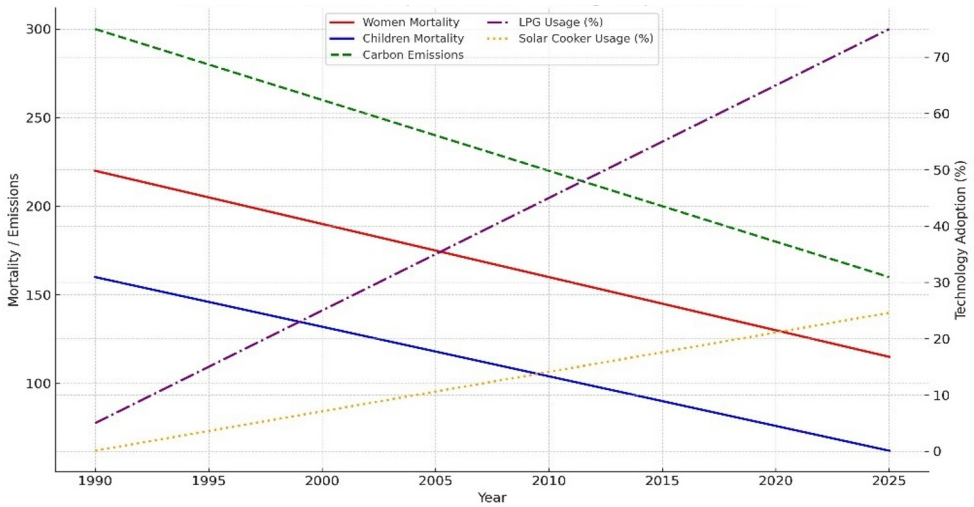

Fig. 5: shows Health and Environmental Impact on traditional cooking and clean cooking adoption.

Fig. 6 shows the non-renewable energy sources, whose cost is rapidly increasing over the years, which also makes them extinct or deficient in the future due to their availability from mother earth and the time it takes for to form new ones. Fig. 7 shows the price of the fuel used for solar cooker, which is almost zero.

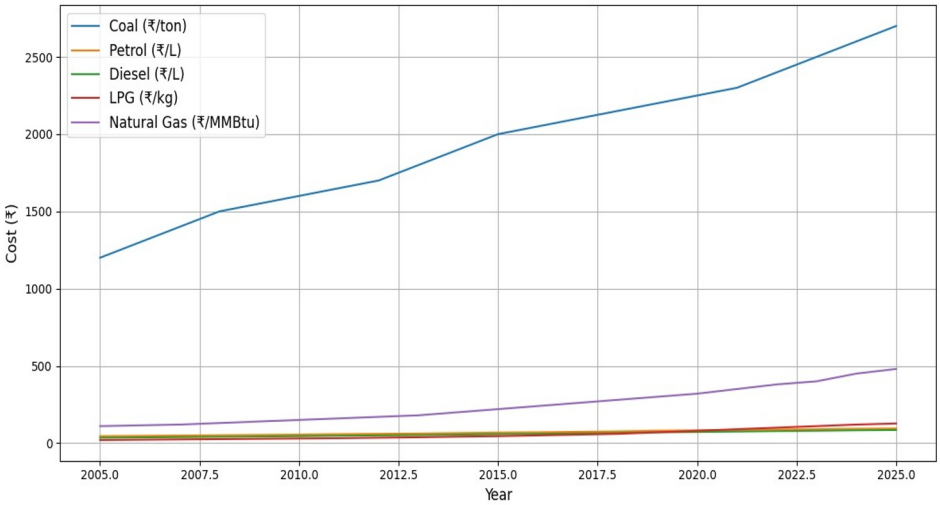

Fig. 6: shows the trend in fuel price for solid, liquid and gaseous fuel over the 20 year's.

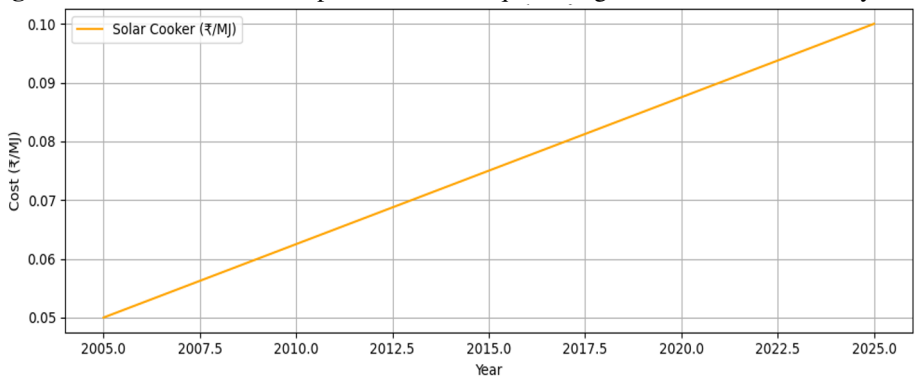

Fig. 7: shows the price of solar cooker fuel estimated cost which is almost zero.

3.3 Challenges for implementing solar cookers in Household purpose

Solar cookers have enormous potential, but a number of obstacles prevent their widespread use:

• Sunlight Dependency:

Sunlight is necessary for solar cookers to function; they cannot be used at night or on overcast days. This restricts their use as a cooking solution alone and frequently necessitates the use of an additional cooking technique.

• Weather Variability: In some seasons or locations, performance is impacted by cloud cover, precipitation, and a lack of daylight.

• Cooking Time: Most box and panel cookers have longer cooking times than traditional methods, which can be inconvenient for users used to quick cooking, even though some parabolic cookers are quick.

• Cultural and Culinary Preferences: Certain cooking techniques, such as frying particular foods, call for high heat or particular cooking methods that might be difficult to modify for solar cookers. Other obstacles may include dietary practices and the requirement for quick cooking.

• Initial Cost: Although a solar cooker uses no fuel over time, low-income households may find the initial cost prohibitive.

• Awareness and Acceptance: Adoption may be constrained by a lack of knowledge about solar cooking technology, deeply rooted cultural customs, and scepticism about novel approaches.
• Maintenance and Durability: Quality varies, and some inexpensive models might not hold up over time. Another problem may be a lack of access to repair services or replacement parts.
• Education and Training: Users must receive adequate instruction on how to operate, maintain, and modify their cooking methods for solar cookers.

Various key benefits of solar cooker are shown in fig.8. includes environmental, health and socio economic parameters. Fig. 9 illustrates the sustainability of the present work.

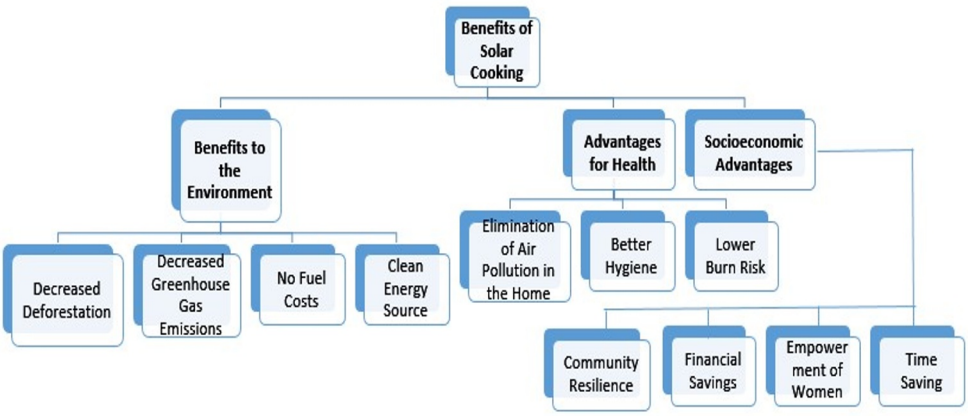

Fig. 8: Illustrates the benefits of solar cooker to Environment, Health and Socioeconomic needs.

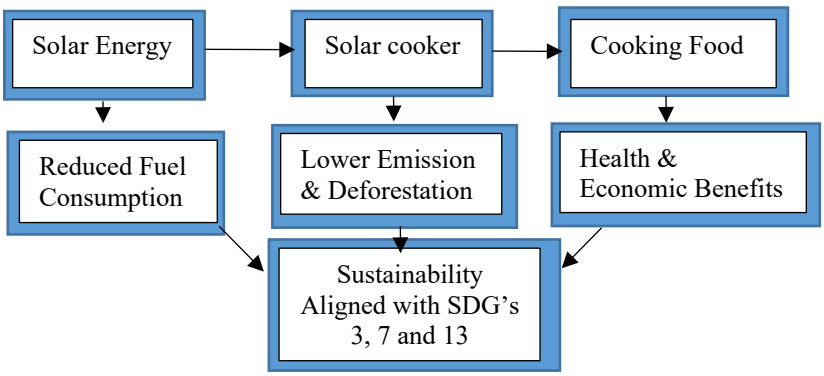

Fig. 9: Flow representation of the solar cooking process and its associated sustainability benefits.

4. Conclusion:

An elegant and potent answer to the traditional cooking problems is solar cooking, which offers a sustainable, affordable, and clean substitute. Although there are still issues with reliance on sunlight, cooking time, and initial cost, these are not insurmountable.

The world can realize the full potential of solar cookers by adopting strong legislative frameworks, encouraging design and manufacturing innovation, and funding extensive awareness and education campaigns.

Encouraging sun-powered cooking is about more than just a change in cooking techniques; it's about empowering communities, protecting the environment, reducing climate change, and ultimately enhancing the health and well-being of billions of people. Utilizing the most plentiful energy source on the planet for a healthier, cleaner, and more promising future, solar cooking is proof of humanity's capacity for innovation and adaptation.

A comparison of LPG stoves, biomass chulhas, and solar cookers shows that although LPG provides high cooking power and thermal efficiency (40–60%), it also raises fuel prices and greenhouse gas emissions. With a lower efficiency (10–25%), biomass chulhas contribute significantly to indoor air pollution, which can have negative health effects. Solar cookers, on the other hand, are environmentally sustainable because they run without fuel expenses or emissions, despite having a moderate thermal efficiency and cooking power. They lesser reliance on non-renewable resources by utilizing freely available solar energy. Considering all the factors, solar cooking is the most environmentally and health-conscious choice for sustainable cooking methods.

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5. References:

[1] Bond, T. C., Doherty, Fahey, D. W., Forster, Berntsen, DeAngelo, Zender, C. S, et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres*, 118(11), 5380–5552. https://doi.org/10.1002/jgrd.50171

[2] Solar Cookers International (SCI). (Ongoing work and resources). Available at: https://www.solarcookers.org/ (Accessed June 4, 2025).

[3] United Nations Environment Programme (UNEP). (2011). *The Global Cook stove Crisis: Addressing the Health and Environmental Impacts of Cooking with Solid Fuels*. UNEP.

[4] World Health Organization (WHO). (2022). *Household air pollution and health*. Available at: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health (Accessed June 4, 2025).

[5] Nigel Scott, Matthew Leach and Will Clements, "Energy-Efficient Electric Cooking and Sustainable Energy Transitions", Energies 2024, 17, 3318.

[6] Bailis, R.; Drigo, R.; Ghilardi, A.; Masera, O. The carbon footprint of traditional woodfuels. Nat. Clim. Change 2015, 5, 266–272.

[7] USAID. Alternatives to Charcoal (A2C). Cost of Cooking Study; USAID: Washington, DC, USA, 2022.

[8] Paudel, D.; Jeuland, M.; Lohani, S.P. Cooking-energy transition in Nepal: Trend review. Clean Energy 2021, 5, 1–9.

[9] Jeuland, M.A.; Pattanayak, S.K. Benefits and costs of improved cook stoves: Assessing the implications of variability in health, forest and climate impacts. PLoS ONE 2012, 7, e30338.

[10] Uma Reddy, K., Deb, B., & Roy, B. (2023). A numerical and experimental study on the performance of a conventional H- Darrieus wind rotor with auxiliary blades. Ocean Engineering, 280. https://doi.org/10.1016/j.oceaneng.2023.114697.

[11] World Bank Database. Access to Electricity (% Population). Available online: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS.
[12] Wenxue Gao, Yingjie Hu,* Rongsong Yan, Wentao Yan, Mingchang Yang, Qingwei Miao, Lin Yang, and Yan Wang, "Comprehensive Review on Thermal Performance Enhancement of Domestic Gas Stoves", ACS Omega 2023, 8, 26663−26684. https://doi.org/10.1021/acsomega.3c01628.
[13] Maulin P. Shah Pardeep Kaur, "Biomass Energy for Sustainable Development", CRC Press, Taylor and Fracis Group, ISBN: 9781003406501, DOI: 10.1201/9781003406501.
[14] Batchelor, S., Scott, N., Leary, J., Sumanik-Leary, J., & Leach, M. (2021). *Transitions to modern energy: A review of the impact of clean cooking technologies*. Energy for Sustainable Development, 60, 43–52.
[15] Rehfuess, E. A., Puzzolo, E., Stanistreet, D., Pope, D., & Bruce, N. G. (2014). Enablers and barriers to large-scale uptake of improved solid fuel stoves: A systematic review. *Environmental Health Perspectives*, 122(2), 120–130. https://doi.org/10.1289/ehp.1306639