Dissemination of Sustainable Cooking: A Detailed Review on Solar Cooking System

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Abstract. Cooking sector is considered as one of the major energy consuming sector in developing and underdeveloped countries. From the primitive age, humankind largely rely on biomass for their cooking energy need, even though there has been a tremendous upgradation in cooking methods. Due to hazardous effects and energy inefficiencies of conventional biomass cooking system, unconventional cooking energy (method) is becoming popular day by day. Dependency on ever depleting fossil fuel has forced us to switch over to renewable energy options and amongst all; solar energy seems best option due to its inherent reasons. In this study, efforts have been made to review the entire solar cooking systems incorporating with and without thermal energy storage available hitherto. The study reveals the different thermal performance parameters of solar cooking system and attempts to highlight the adaption factors of solar cooking system in the designated market.

1. Introduction
Energy consumption reflects the living standard of any country. Global energy demand is increasing very fast with the upgradation in living standard and development of the country. World energy consumption is growing with a fast rate as shown in Fig.1. [1].

Scarcity of fossil fuels and their harmful effects on environment are the two major challenges for today’s world. As these fossil fuels are the major source of energy being utilized by the human, hence the energy demand depends on the availability of fossil fuels. Hence, with the increase in energy demand, risk the survival and sustainability of life support system. In this regard depletion of fossil fuel reserves, energy scarcity, global warming, and increase in pollutants in atmosphere are matters of great concern today.

In the era of global warming, climate justice has become the need of hour. Renewable energy is gaining popularity day by day by not only seeking attention of its researchers and end users, but also reasonably affects its policy makers, as the energy demand is growing very fast and supply is limited.

The thermal application of solar energy is seeking attention very rapidly in sustainable cooking by knowing the fact of inefficiencies of conventional cooking and ever rising cost of fossil fuels. Apart from that cooking energy also contributes 36% in the world’s total primary energy consumption. Rural folks usually use wood, charcoal, agricultural residues and dung cakes as a cooking fuel.
Figure 1. Energy consumption of the world for the period 1990–2040 (in quadrillion Btu) [1]

86.1% of the rural households uses fuel wood and cow-dung for cooking [3]. In order to get, this cooking fuel around 16 million hectares of forest are destroyed annually [4]. These cooking fuels also inherently associated with indoor air pollution which results hazardous effect on rural folks.

Table 1. World energy consumption by country / region (in quadrillion Btu) [1]

|        | 2012 | 2020 | 2025 | 2030 | 2035 | 2040 |
|--------|------|------|------|------|------|------|
| OECD   |      |      |      |      |      |      |
| America| 118  | 126  | 128  | 131  | 134  | 138  |
| Europe | 81   | 85   | 87   | 90   | 93   | 96   |
| Asia   | 39   | 43   | 45   | 46   | 47   | 48   |
| NON-OECD |  |      |      |      |      |      |
| Europe | 51   | 52   | 55   | 56   | 58   | 58   |
| Asia   | 175  | 223  | 246  | 270  | 295  | 322  |
| Africa | 22   | 26   | 30   | 34   | 38   | 44   |
| Middle East | 32 | 41 | 45 | 51 | 57 | 62 |
| America| 31   | 33   | 37   | 40   | 43   | 47   |
| Total  | 549  | 629  | 673  | 718  | 765  | 815  |
This paper will perform a state-of-the-art review about solar cooking system and the objective was kept in mind while performing this study is to identify availability of different solar cooking system and provide a framework for researchers and policy makers in solar cooking areas to increase its adaptability in concerning area.

2. Solar Cooker

**Definition**: Solar cooker term usually associated with the device or combinations of devices that are utilised for cooking processes like boiling, frying, baking and grilling processes, which involve its prime heat energy by solar radiation directly or indirectly.

2.1. History:
History of solar cooking is very old, it had been started in 1767, when Nicholas de-Saussure was first attempted as usage of solar energy for fruit cooking [16]. In 1876, in India, Adams developed a solar cooker which consists of an octagonal oven with 8 mirrors and it was designed for 7 soldiers. Secretary of the A.S.I., Abbot, was the first recorded inventor of solar cookers in which the solar heat receiver was outside the house but the cooking stove was inside. Heat energy was transferred from solar receiver to stove by thermic fluid [17]. In 1940s, in the U.S.A, Telkes investigated different types of solar cookers, which also involved the heat storage type [18]. In 1945, in India, Ghosh’s solar box cooker was commercialized, which was first of its kind [19]. In 1973, in the USA, Kerr fabricated several solar cookers, by using simple low cost and high thermal inertia material, which involve focusing i.e. concentrating type and non-focusing i.e. box type solar cookers [20]. In 1980s, the governments of India and China expanded national promotion of box cookers. A lot of researches have been carried out in this era. Brace Research Institute, McGill U., Canada, researched and field tested solar cookers. Prof. S.S. Nandwani in Costa Rica researched solar cookers. Box cookers were distributed to 20,000 Afghan refugees in Pakistan by SERVE (Serving emergency Relief and Vocational Enterprises). M.H. Gurley Larson wrote first U.S. solar cookbook, Solar Cooking.
Naturally, in 83 Metcalf. In 84 Metcalf published his 9-page instructions for building solar box cookers. ULOG was started by Ulrich and Lisel Oehler to promote box and parabolic cookers in many countries. With Kerr–Cole instructions, solar cookers were built in Kitui, Kenya in ‘85[21]. In 1987, in India, Mullick presented two TPP (Thermal Performance parameters) i.e. two figure of merits (F1 and F2) for box-type solar cookers [22]. In 2000, Funk presented universally adopted international standard i.e. cooking power (W) for thermal assessment of solar cooker. It is more generic that means applicable for box type and concentrating type solar cooker and useful for comparison of dissimilar designs also. It is also recognized by ASAE (American Society of Agriculture Engineers) [23].

2.2. Classification:
There are many type of solar cookers found in the literature. Although there are no fixed criteria for classification of solar cooker, however some researchers have classified. In this review study, an attempt has been made to classify all the solar cooker available hitherto with the help of a hierarchy chart as shown in figure 3.

The first broad classification is based on mode of heat transfer to cooking vessel from cooking system and are classified as direct type and indirect type. In direct type of solar cooking system, solar radiation directly take part in cooking process. In indirect type of solar cooking system, solar radiation gives its heat to a particular fluid i.e. thermic fluid, then this thermic fluid transfers the heat to cooking vessel. Direct type of solar cookers are again classified as concentrating and non-concentrating type. Concentrating type further classified on the basis of nature of concentrator i.e. opaque and non- opaque. In non-opaque type solar cooker, sun rays transmits through concentrator and focus on a single point i.e. cooking vessel. In opaque type solar cooker, solar radiation reflected by its concentrator to an appropriate point i.e. cooking vessel. Paraboloid, Scheffler, and Fresnel type are the most common examples of opaque type concentrating solar cooker. Different designs of Box type solar cookers are the most common examples of non-concentrating type solar cooker.

Indirect type solar cookers are of concentrating type only, as intense heat is required to heat the thermic fluid which transport its heat to cooking vessel. Indirect type is again classified as single generation and multi generation system. Single generation system is designed for cooking only while in case of multi generation system excess heat would utilised for another process apart from cooking. Single and multi- generation are both again classified on the basis of their focus i.e. point and line focus. Parabolic Trough Collector (PTC) is most common example of line focus solar cooker.

3. Performance Assessment
Performance assessment parameters was first available for box type then concentrating type solar cooker. Several advances are done on box type solar cooker by researcher especially in tropical country like India due to better availability of solar radiation [5-10]. These countries are having better solar radiation e.g. many Indian regions receive 5–7 kWh/m² as average daily solar radiation. Number of clear sky days per year in India is greater than 275 [24]. This implies solar cooking seems high adaptability capacity in these countries and can provide a feasible alternate in the households.

In 2000, Funk presented TPP like Cooking power (P), Standardized cooking power (P_s), Adjusted cooking power (P_a) and Heat loss coefficient (U_L) [12]. In 1987, Mullick presented TPP like First figure of merit (F_1), Second figure of merit (F_2), Heat loss factor (F’U_L) and Optical efficiency factor (F_η_o) [13]. In 1994, in Germany, ECSCR (European Committee on Solar Cooking Research) testing standard presented different factors like thermal testing regime, safety factors, ease of cooking, cooking pot access and estimated durability [14]. In 2002, Shaw presented several factors (associated with assessment) in Ph.D. thesis. These factors are factors due to environment e.g. “wind, ambient temperature, insolation, and precipitation; controlled factors e.g. cooking vessels, tracking, time, thermal loading, data collection, and recording; thermal figures of merit” e.g. “cooking power, standard cooking power, standard stagnation temperature, standard sensible heating time, heating time, and unattended cooking time and utility figures of merit” e.g. “cooking power per kilogram and aperture area per kilogram” [15].
Figure 3. Detailed Classification of Solar Cooker
4. Conclusion
From the past several decades sustainable/solar cooking gradually receiving new advances in energy deprivation. However, paucity of actualisation of solar cooking is still there. Adoption of solar cooker is still far below their potential.

There can be several reasons for the lack of dissemination of solar cooker in the designated market. Study reveals some factors are more prominent e.g. intermittent nature of sunshine, suitable cooking place, suitable cooking pots, cost, ethnic and geographical issues, different region different cooking pattern/practice and micro level cooking are more preferred as compared to community cooking.

Rural area is also a concerning area for researchers as they constitute a significant portion of country’s population and quenching of energy deprivation in that area has to coincide with the requirements of the rural folks for their overall socio-economic development.

Finally, the study recommends for researcher and policy makers to incorporate some factors like suitable cooking place, suitable cooking pots, cost effectiveness, different region different cooking pattern/practice and adaptability of micro level cooking over macro level in the solar cooking system to reduce the reluctance to acceptance or risk of dissemination in the designated market.

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