Life Cycle Assessment and Environmental Impact Evaluation of the Parabolic Solar Cooker SK14 in Madagascar

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***Abstract*—The main cause of deforestation in Madagascar is the collection of firewood for cooking. Research cooking alternatives that would reduce firewood and charcoal use has been undertaken by NGOs. In this context, south Madagascar experiences more than 320 sunny days per year and has close to ideal conditions for the use of solar energy. Currently a variety of solar cooker models are sold at a subsidized price for the poorest household. The paper explains advantages and disadvantages of solar cooking and the challenges faced to change traditional cooking habits, in order to fight the ongoing deforestation, preserve the environment and fight poverty. To optimize the success of this project, the use of solar cooker has been compared to two alternatives - firewood and charcoal cooking and on the topics of primary energy utilization and CO_2 gas emission. The whole life cycle analysis of the alternatives and accompanying devices has been examined. As results parabolic solar cooker is less usable in cloudy or rainy weather. A reduction of about half the environmental impact has been obtained with this technology. Some backup heat source must still be available to cook meal at these times. Solar cooker, charcoal and firewood can work in a complementary fashion to meet a variety of cooking needs. The parabolic solar cooker SK14 is a very helpful instrument but less competitive compared to the traditional cooking using wood energy. It can replace firewood and charcoal cooking, reduces deforestation, improves health conditions and creates local job opportunities.**

***Index Terms*—Life cycle analysis, solar cooker, Madagascar.**

I. Introduction

Madagascar, the world's fourth-largest island, lies in south-west Indian Ocean. It is situated between latitude 20°S and longitude 47°E. Narrow coastal plain, high plateau and mountains in center define its topography. Its climate is tropical along coast modified by southeast trade winds, sub-temperate inland and arid in south. Madagascar was originally completely covered by wet or dry evergreen forest, scrub, and palm savanna. Concerning the environmental current issues, soil erosion results from deforestation and overgrazing.

A. Problem Statement

Deforestation is common in Madagascar. Waters' surface is contaminated by raw sewage and other organic wastes. Several species of fauna and flora unique to the island are endangered. Habitat destruction resulted in the reduction of native vegetation cover on the mainland (Fig. 1). Traditionally food, mainly rice, is cooked over open fire in Malagasy villages. But firewood is getting harder and harder to find. Reducing the need for firewood is becoming urgent.

Using solar energy often suggested seems ideal and could reduce by 50% the firewood and charcoal needs [1]-[3]. Introducing a new technology such as solar cooking is a long-term strategy [4], [5]. It is a challenge because it requires carefully, culturally tailored planning to get the community to accept, adopt and utilize something like solar cooking [6].

Preserving the environment, alleviating poverty and improving health care are the main goals for any Malagasy citizen and particularly for NGOs such as Zahana, ADES (Association pour le Développement de l'Energie Solaire Suisse-Madagascar), GTZ, etc., who decided to implement the use of solar cooking in the province of Toliara in south Madagascar (Fig. 1) which experiences more than 320 sunny days per year and has close to ideal conditions for the use of solar energy.

Fig. 1. Satellite imagery of Madagascar showing the study area and the main forest (in dark green)

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B. Aims and Objectives

The aim of this study is to characterize the resources consumption and the meaningful environmental aspects bound to the production of parabolic solar cooker SK14.
The goal of the survey declines itself to the following objectives:

1) to compile an inventory of the environmental life cycle impact assessment associated to the production, the use and the setting in discharge of the parabolic solar, the firewood and charcoal cooking;
2) to use the data of the life cycle inventory analysis to compare the potential impacts on the environment coming from this solar cooker and the other fashions of above stated cooking.

C. Methodology Approach for Evaluation

Life cycle Analysis or Life cycle assessment (LCA) is a methodology for assessing the environmental aspects associated with a product over its life cycle-from raw material acquisition through production, use, and disposal [7].

Performing an LCA is one of the possible methods of distributing or assessing the aspects of the environment for a product and the potential impacts on the natural environment.

The International Organization for Standardization (ISO) has developed international standards that describe how to conduct an LCA:

1) The first phase is a life cycle inventory analysis, which consists of a compilation of the energy and material inputs and the emissions to air, land, and water associated with the manufacture of a product,
2) The second phase is an assessment of the potential social, economic and environmental impacts associated with those inputs and emissions.
3) The third phase is the interpretation of the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

The results of an LCA can be used to help to choose among the alternatives in competition the one that has the most favorable attributes. Three alternatives (firewood, charcoal and parabolic solar cooker) - have been chosen for this survey.

II. Life Cycle Analysis of the Three Cooking Alternatives

A. Parabolic Solar Cooker SK14 Technical Features

SOLTEC Company is the pioneer concerning solar cooker in Madagascar and manage a shop of professional formation since more than 15 years. The SK14 is probably the most known parabolic solar cooker in Madagascar.

The average power is about 600 watts depending of the reflectors and sky. By a good sunshine, three liters of water boil in 30 minutes. The pot of 12 liters for which is conceived the SK14 permits to cook for 20 persons. The solar cooker operates one hour after the sunrise until one hour before the sunset. With its high performance, it is even efficient by a relatively short periodic sunshine.

The mirror-home distance (reflector) of the SK 14 is only of 28 centimeters (Fig. 2). It is therefore necessary to readjust the mirror all 15 to 25 minutes when one wants to reach a constant maximal performance. This cooker reaches temperatures of up to 150°C.

Fig. 2. Cooking with the parabolic solar cooker SK14

The production of solar cooker systems requires reasonable quantities of materials, insignificant amounts are also consumed during their operation; at that time the only potential environmental pollutant arises from the coolant change, which can be easily controlled by good working practice.

Currently, a variety of solar cooker models are sold in Madagascar. However, their prices make them inaccessible for most villages. In fact, per capita income in Madagascar is only about $400 per year, making it difficult for families to afford solar cooker and spend their meager income on a technology they are not familiar with. To help to solve that problem, Madagascar government has provided some additional support, partnering with ADES to promote renewable energy in the south of the island. Metal parabolic solar cookers are assembled locally for about $160 each, from aluminum and steel parts made by another local organization at an already subsidized price. The parabolic cooker is then sold at a subsidized price of about $50. Both cookers come with 7-year warranties [8], [9].

B. Calculation of Impacts

It is known that a Malagasy family needs 2.25 kg of wood for cooking a meal (kg = 10^3 grams), this has a calorific power not more than 16.8 MJ/kg [2]. This energy grid is equivalent to an energy consumed of 37.83 MJ per meal (MJ=10^6 joules).

The consumption of this energy releases into the atmosphere a certain amount of CO_2. This can be estimated with the following data. With an emission factory of about 83 kg/GJ (GJ = 10^9 joules), we obtain 3.14 kg of CO_2 emitted per food with firewood (Fig. 3).

Fig. 3. Three-stone open fires

Of the same way, we can estimate the following figures: in the hypothesis where a value of 2.51 kg of charcoal (Fig. 4) for cooking a meal is taken, it implies that the energy consumed to each meal is worth 32.5 MJ; the transportation of charcoal needs 0.35 MJ per meal and the manufacture needs 0,015 MJ per meal. With an emission factory of about 100 kg/GJ, we obtain 8.16 kg of CO_2 emitted per meal with charcoal cooking (Table I). Procedures for calculating the energy consumed by charcoal cooking in more detail are described by some authors, and can be also seen on Center for Independent Research and Energy for Sustainable Development Africa Report of 2003.

Fig. 4. Charcoal cooking

TABLE I: ENERGY CONSUMED AND CO_2 EMISSIONS OF FIREWOOD AND CHARCOAL

Kitchen and energy resources (alternatives)	Energy (MJ/meal)	CO_2 Emission (kg/meal)	Coast (Ariary)
Firewood	37.83	3.14	2 630
Charcoal cooking	81.97	8.16	529

For a family of 6 person, the annual bill for firewood and charcoal cooking is between US$ 289.628 and US$ 1439.925 including VAT but excluding subscriptions (US$=2000 Ariary).

Calculation of energy consumed by SK14 is made using the following assumptions. The energizing need of the reflector is worth 609.3 MJ per solar cooker. For a reflector with a life span of ten years, the burner contributes to a cooking of more than $10 \times 365.25 \times 2$ meals per day, which is the equivalent of 14610 meals during its life span. Therefore, when the need in energy of the reflector dishes is expressed per meal, one only gets a value of 0.04 MJ per meal. The production of the pieces of iron and aluminum for the manufacture of the cooker explains the value of 0.03 MJ per meal, whereas the contribution of the painting production is even smaller. The sum of these two values gives 0.072 MJ per meal.

For the transport, to obtain the energy spent in MJ per ton, it is necessary to multiply the browsed distance, by the value of the freight of a constituent of the cooker, according to the fashion of transportation used, then by the weight of this material.

Finally, to obtain an energizing value expressed in MJ per meal, it is necessary to divide the value gotten by 14610. While supposing that the SK14 can cook 55% of the meal, which implies a back-up or a replacement rate of 45% (that wants to say while referring to the relative data to the coal of wood); one obtain 32.5 MJ/meal $\times$ 0.45, which is the equivalent of 36.88 MJ per meal. The remaining energy use is allocated to the repair and particularly the painting.

Because of the big uncertainties concerning the stage of setting in discharge, no value of energy has been included in this stage.

For the stage of use, the considered emissions come from the use of charcoal taking into account the substitution rate and the one provoked by the painting. This calculation makes itself in the same way as previously. The majority of the emission of CO_2 is affected to this stage of use, and therefore to the replacement rate. The final emission is of 3.79 kg per meal once the production and the transportation of the cooker are taken in account.

Estimated values for the energy consumed and the CO_2 emission by the parabolic solar cooker SK14 are summarized in Table II.

TABLE II: ENERGY CONSUMED AND CO_2 EMISSION OF PARABOLIC SOLAR COOKER SK14

Stage of the life cycle	Energy consumed (MJ/meal)	CO_2 emission (kg/meal)
Manufacture	0.07	0.005
Production	0.03	0.004
Transport	0.04	0.002
Utilization (usage)	36.92	3.78
Total	37.06	3.79

C. Estimation of CO_2 Emissions by One Malagasy Family Per Year in South Madagascar

Knowing the CO_2 emitted per meal, it is possible to estimate the CO_2 emitted per year for a Malagasy household. Calculations are estimated as follow:

Alternative 1: Firewood cooking

$\Rightarrow$ 3.14 kg of CO_2 emitted per food $\times$ 3 meals per day = 9.41 kg of CO_2 emitted per day per household

$\Rightarrow$ 9.41 kg $\times$ 365 days = 3435.02 kg of CO_2 emitted per year and per Malagasy family cooking with firewood.

Alternative 2: Charcoal cooking

$\Rightarrow$ 8.16 kg CO_2 emitted per meal $\times$ 3 foods per day = 24.49 kg of CO_2 emitted per day per household

$\Rightarrow$ 24.49 kg $\times$ 365 days = 8940.13 kg of CO_2 emitted per year per Malagasy family cooking with charcoal.

Alternative 3: Parabolic solar cooker SK14

The disadvantage of the solar cooker is that it cannot be used to cook breakfast and meals in the evening when there is no sun. For the calculation, one can only cook two meals per days and the estimation of the sunny days per year is about 330 days.

$\Rightarrow$ 3.79 kg of CO_2 emitted per meal $\times$ 2 foods per day =

7.58 kg of CO_2 emitted per day per household

$\Rightarrow$ 7.8 kg $\times$ 330 days = 2500.74 kg of CO_2 emitted per year and per Malagasy family cooking with SK14.

III. Results

The comparative study between the three cooking alternatives shows that a reduction of about 50% of the environmental impact has been obtained through the use of this solar cooker.

A. Environmental Impacts

Solar energy technologies such as SK14 provide obvious environmental advantages in comparison to the conventional energy sources, thus contributing to the sustainable development of human activities. Their main advantage is related to the reduced CO_2 emissions and, normally, absence of any air emissions or waste products during their operation.

The use of solar cooker has additional positive implications such as:

• Reduction of the greenhouse gases emissions (mainly CO_2) and prevention of toxic gas emissions (SO_2, particulates);
• Improvement of the quality of water resources;
• Reduction of indoor air pollution coming from smoke of traditional fireplaces;
• Protection of soil fertility, biodiversity and coastal areas;
• Reclamation of degraded land;
• Prevention of desertification;
• Reducing risks of fires caused by open fireplaces.

B. Socio-Economic Impacts

Socio-economically the benefits of the use of solar cooker in Madagascar consist of:

• Increase of the regional/national energy independency;
• Making the country independent from energy imports;
• Diversification and security of energy supply;
• Support of the deregulation of energy markets;
• Acceleration of the rural electrification;
• Powerful instrument in the fight against poverty, by alleviating the burden in providing fuel costs that increase continuously;
• Provision of significant work opportunities;
• Providing employment;
• Supporting domestic economies;
• Instructive instrument for environmental education through self learning and experience.

One of the main positive impacts of the project will be the leverage of public awareness of environmental challenges that can be implemented through educational program and the transferred sustainable technology.

C. Parabolic Solar Cooker SK14: Advantages and Disadvantages

A parabolic concentrator solar cooker has a collector, which consists of either a reflecting or transmitting concentrator concentrating the solar irradiation onto a focal point (Fig. 2). The cooking pot is placed at the focal point. The advantage of this type of concentrator system is that they can reach high useful temperatures. On the other hand, the need for frequent tracking forces the user to work in the sunshine under particularly strenuous conditions of heat and glare.

Parabolic concentrator has good thermal efficiency and reach high temperatures, but requires frequent "tracking" - that is, changing the position of the device according to the sun's position. In field studies, the concentrating cooker is not generally chosen due to its need to closely follow the sun (characterized by a low acceptance angle), and safety issues as focused sunlight can cause burns or eye damage. Nevertheless, in some applications, solar concentrators can make ideal cookers. So long as direct insolation is readily available and the user is experienced and careful, the concentrator represents a highly useful and powerful cooking tool.

Similar to the panel cooker, the concentrator suffers from a strong reliance on direct beam insolation. Cloudy conditions and wind combine to make concentrating cookers highly difficult to use. In fact, this cooker has a tendency to get knocked over by a strong wind and suffer from dirt deposits on the reflective material.

There are also other disadvantages of the solar energy. It is only available during limited times and it cannot be used to cook breakfast and meals in the evening when there is no sun. Therefore it requires energy storage systems. Evening meals could be cooked in the afternoon by a solar stove and kept warm in the solar oven.

In the rainy season solar cooking is not a viable option and the solar cooker, in tandem with reforestation efforts, is a practical immediate solution.

IV. Concluding Remarks

Most of the energy used by the parabolic solar cooker SK14 could be attributed to the back-up need: the use of firewood or charcoal when this solar cooker is unusable due to bad weather conditions. The study shows that a reduction about half of the environmental impact could be obtained through the use of this solar cooker. In addition, the environmental impact analysis has shown that the SK14 is socially acceptable, but less competitive compared to the traditional cooking using firewood.

The use of solar energy to cook meal presents a viable alternative to the use of firewood, charcoal and other fuels traditionally used in Madagascar for the purpose of preparing meal. While certainly, solar cookers cannot entirely halt the use of firewood and charcoal for meal preparation, it can be shown that properly applied, solar cooking can be used as an effective mitigation tool with regards to global climate change, deforestation, and economic debasement of the Malagasy people.

It is well known that the use of solar cooker is going to increase in the coming years. There are two reasons for this trend. Firstly, sustainable development, which is a goal of Malagasy government and industries for the near future, implies a change in the operation and running of industrial processes, for a significant reduction in their environmental impact. In addition, solar cooker is an inexpensive, clean and inexhaustible resource.

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