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Comparative Evaluation of Solar Cooking's Energy Use, Expenses, and Environmental Effects with Conventional Fuels in Maiduguri, Nigeria

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***Abstract**: In comparison to a solar cooker, this study examines the energy usage, financial consequences, and environmental effects of traditional cooking fuels (wood, charcoal, and kerosene) in Maiduguri, Nigeria. For each fuel source—wood (1,067,008 J), charcoal (1,083,680 J), kerosene (1,083,680 J) and solar cooker (1,075,344 J)—the energy needed to boil four liters of water was determined. Charcoal (493.98 J/s), firewood (903.07 J/s), kerosene (1,128.83 J/s) and solar cooker (235.82 J/s) all had corresponding power values that were also established. It was estimated that the annual cost of using each energy source was N 79,500 for wood, N 79,500 for charcoal, N 91,250 for kerosene, and N 5,000 for solar cookers. These estimates showed significant cost differences. Even though the solar cooker costs more to build initially (N 5,000), it is a good option in the long run because it uses less fuel, has a smaller environmental effect and saves a lot of money over time, especially after two years. In order to promote sustainable and affordable energy solutions in Nigeria, the study emphasizes how solar cookers can reduce fuel consumption, deforestation, and air pollution. It is advised that more research be done to examine the variables affecting the uptake of solar cooking technologies and to create plans for improving energy sustainability in the area.*

***Keywords:** Energy Consumption, Solar Cooker, Cooking Fuels, Cost Analysis, Sustainable Energy*

1. Introduction

In the global energy landscape, energy consumption is a crucial factor, particularly in developing nations where it is still difficult to obtain inexpensive, sustainable, and clean energy. Despite their negative effects on the environment, the economy, and human health, traditional cooking fuels like wood, charcoal, and kerosene still account for the majority of household energy use in many Nigerian rural and urban areas. In addition to contributing to air pollution, burning these fuels depletes local natural resources and makes deforestation worse [1-3]. Alternative energy options that can benefit the economy and the environment should also be reexamined in light of growing fuel prices and their detrimental effects on household budgets. In this regard, solar cookers show promise as a way to lessen dependency on traditional fuels. By using sunlight as the main energy source, solar cooking technology provides a clean and renewable alternative that can lower household energy costs, reduce air pollution, and ease the strain on nearby forests [4]. Numerous studies have documented the potential of solar cookers to lower fuel consumption and increase energy efficiency. The results indicate that solar cooking can successfully replace conventional fuels, particularly in areas with high solar insolation [5-7].

The purpose of this study is to compare the energy needs and expenses of different cooking fuels in Maiduguri, Borno State, Nigeria, including wood, charcoal, kerosene, and solar cookers. The study aims to determine which fuel is the most economical and energy-efficient by comparing the energy input needed to boil four liters of water using each of these fuels. The study also examines the viability of switching to solar cookers as a sustainable energy source, evaluating their capacity to lessen the detrimental effects that conventional cooking techniques have on the environment and human health. Our study intends to advance knowledge of Nigerian energy consumption trends and the contribution of solar cookers to the development of more sustainable household energy practices.

2. Materials and Method

This study assesses the cost-effectiveness and energy efficiency of several cooking fuels in Maiduguri, Borno State, Nigeria, using a quantitative methodology. Wood, charcoal, kerosene, and solar energy are among the fuels being studied; these are typical energy sources for cooking in homes in the area [8,9]. A controlled experimental design serves as the framework for the methodology, which measures the amount of energy needed to boil four liters of water using each fuel. Due to their extensive usage in Nigerian homes, the four cooking fuels were chosen: wood is a traditional cooking fuel, especially in rural regions [10]. In cities, charcoal is a fuel that is frequently used [11]. A common liquid fuel for kerosene stoves is kerosene [12]. According to Saranga et al, (2024), solar energy is a renewable energy source that can be used with solar cookers [3].

2.1 Experimental Setup

To guarantee consistency and dependability in the results, the experiment was conducted according to a rigorous technique. Four liters of water were utilized for each test in order to replicate standard home cooking practices. Cooking Tools and Techniques:

a. *Three-Stone Wooden Stove:* This traditional three-stone stove, which uses wood as fuel, is frequently seen in Maiduguri's rural districts.
b. *Charcoal Stove:* According to research on cooking appliances, this is an indigenous cooking stove made for using charcoal.
c. *Kerosene Stove:* A commercial stove that runs on kerosene and is commonly used in cities.
d. *Solar Cooker:* An environmentally friendly cooking appliance that uses direct sunshine to heat water, featuring a reflector and a heat-absorbing container.

These gadgets each symbolize distinct fuel sources and heating techniques, offering information on their effectiveness and environmental compatibility.

2.2 Collecting Data

For every cooking fuel utilized in the study, the following information was gathered:

Time to Boil: A stopwatch was used to measure how long it took to bring four liters of water to a rolling boil, giving a clear indication of how efficiently various stoves cooked food.

Energy Consumption: The heating power and fuel consumption of each stove were utilized to compute its energy consumption. The approach differed depending on the fuel type. Using the calorific values of each fuel and conventional fuel heat content values [13,14], energy input for wood, charcoal, and kerosene stoves was determined. The Photovoltaic Geographical Information System (PVGIS, 2023) gave information on the location's available solar energy, which was used to calculate the energy input for the solar cooker based on regional solar radiation statistics. To achieve the objectives, the quantity of heat, Q required raising the temperature of a material from ϑ_1 to ϑ_1 and the cooking power, P of the materials used are calculated using the following equations:

$$Q = m_w C_w(\theta_2 - \theta_1) \tag{1}$$

where m_w is the mass of water measured in *kg*, ϑ_1 the initial water temperature (℃), ϑ_2 is the final water temperature (℃) and c_w is the specific heat capacity of water measured in $Jkg^{-1}K^{-1}$. The power delivered cooking efficiency, P of the different solar cookers was calculated using equation given as follows:

$$P = \frac{Energy\ Expended}{time\ taken} = \frac{m_w C_w(\theta_2 - \theta_1)}{t} \tag{2}$$

where t the time taken to reach maximum temperature (s). These data points made it possible to compare the energy needs and efficiency of various cooking methods, which may provide information on the practical and environmental effects of various cooking fuels.

2.3 Calculations for Energy Efficiency

The following formula was used to determine each fuel's energy efficiency:

$$\text{Energy Efficiency} = \frac{\text{Energy Output (useful energy to boil water)}}{\text{Energy Input (total energy from fuel)}}$$

This formula aids in measuring how well each fuel transforms energy into usable heat for boiling water. The energy efficiency η for heating/cooking using wood, charcoal and kerosene can be calculated from the relation,

$$\eta = \frac{\text{output Energy}}{\text{output Energy}} = \frac{Q}{m \times LHV} \tag{3}$$

where Q is the cooking thermal energy output (the obtained values as shown in Table 2), LHV is the Lower Heating Value of cooking fuel and m is the mass of the fuel respectively. The Lower Heating Value of wood, charcoal and kerosene are respectively 335300 *J/kg*, 330000 *J/kg* and 431000 *J/kg* [10]. The energy efficiency η for heating/cooking using solar cooker can be calculated from the relation,

$$\eta = \frac{\text{output Energy}}{\text{output Energy}} = \frac{Q}{I_{av} \times A_c \Delta t} \tag{4}$$

where Q is the cooking thermal energy output (the obtained values as shown in Table 2), I_{av} = 1.5 kW/m^2 is average solar intensity, Δt is the time interval and A_c = 0.25 m^2 is the aperture are [11].

Cost Analysis: The price of a unit of fuel (wood, charcoal, or kerosene) and the initial cost of a solar cooker were used to determine the cost of each fuel. For every fuel type, the total cost of boiling the four liters of water was determined by taking into account both the cost per unit of fuel and the fuel consumption.

Statistical Analysis: To compare the time required to boil the water, the energy usage, and the expenses related to each fuel type, data were examined using fundamental statistical tools. Microsoft Excel was used for the analysis in order to guarantee the accuracy of the results.

Ethical Considerations: The study was carried out with ethical issues in mind, making sure that all data collecting was carried out openly and with respect for the communities in which it was conducted. By encouraging the use of renewable energy sources, such as solar cooking, the study also complies with sustainable development requirements [15].

3. Results

The calculated values for the quantity of heat, Q required to raise a temperature of four (4) liters to boiling point using wood, charcoal, kerosene and solar and the calculated values for the power, P required to heat/cook four (4) liters of water to boiling point using wood, charcoal, kerosene and solar using equation (1) to (2) are presented in Table 1 and Table 2.

Table 1 showed notable differences in the amount of time needed to boil four liters of water using various fuels: Wood boiled the four litres of water in 42 *minutes*, though this can vary based on the kind of wood and moisture level. It took Charcoal 35 *minutes* to boil the four litres of water because charcoal burners use controlled combustion; the heating time is more constant. Kerosene boiled the four litres of water in 30 *minutes* because the liquid fuel produced steady, direct heat. Using the Solar Energy the four litres of water boiled within 180 *minutes* (3 hours), largely reliant on solar radiation; time requirements increase on overcast or early morning days. Thus, kerosene had the quickest time to bring water to a boil, followed by wood, charcoal, and solar power. The different heat production and combustion efficiency of each fuel are reflected in this pattern.

Table 1: Times to boil four (4) liters of water using fire wood, charcoal and kerosene with the experiment using solar cooker.

Time (*minute*)	**Temperature (°C)**				
	Fire wood	**Charcoal**	**Kerosene**	**Solar cooker**	
				Black Paint	**Coated with Ash**
0	33	34	33	34.0	33.0
4	51	45	51	40.0	38.0
8	63	51	68	42.0	40.0
12	75	57	85	46.0	39.9
16	91	63	98	51.0	47.5
20	98	69		55.0	52.0
24		75		58.0	55.0
28		84		62.0	59.4
32		92		65.0	62.0
36		98		69.0	66.1
40				73.5	70.2
44				76.0	73.1
48				80.0	77.2
52				83.0	79.8
56				86.0	82.2
60				88.0	86.1
64				92.0	89.6
68				95.5	93.4
72				97.0	96.5
76				98.0	98.4

The information on Table 1 are used to plot the variation of water temperature in °*C* as a function of time taken (*min*) for cooking using charcoal. Figure 1 showed the pictorial representation of Table 1. The information on Table 1 are further used to pictorially represent the variation of water temperature in °*C* for boiling four (4) litres of water using fire wood, charcoal, kerosene and solar cooker, as a function of time taken (*min*) (Figure 1)

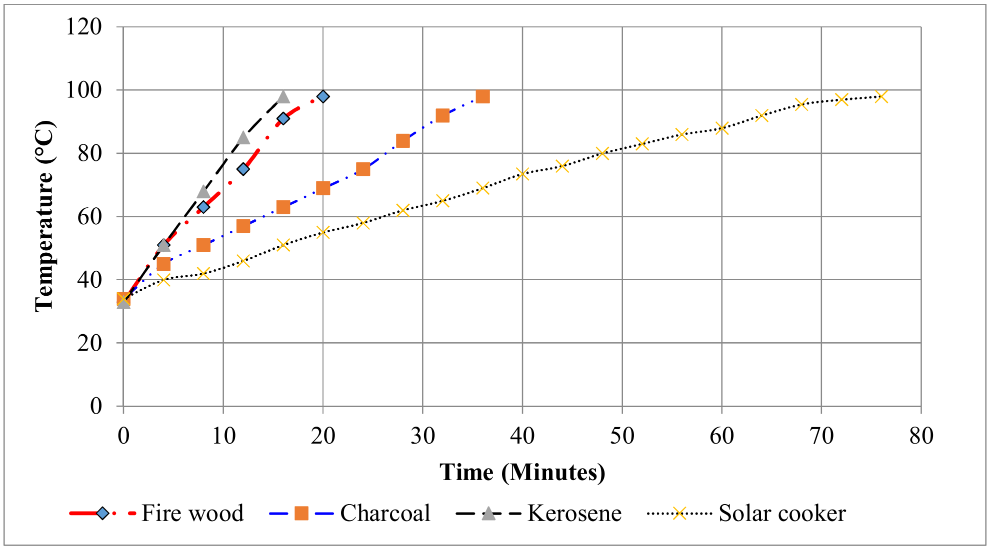

Figure 1: The pictorial representation of variation of water temperature in °*C* for boiling four (4) litres of water using fire wood, charcoal, kerosene and solar cooker, as a function of time taken (*min*)

The graph in Figure 1 illustrates the relationship between temperature and the time taken to boil four (4) liters of water using different energy sources. Here's an analysis of the observations from the graph:

Firewood Stove: The temperature increase is directly proportional to the time taken. The temperature gradually rises from 33°C, reaching the boiling point of water at 98°C. This indicates that it took approximately 65 minutes to boil four liters of water using a firewood stove.

Charcoal Stove: Similar to the previous case, the temperature increase is linear with time. The temperature starts at 34°C and progressively climbs to 98°C, the boiling point of water. It took around 64 minutes to achieve the boiling of four liters of water using a charcoal stove.

Kerosene Stove: In this scenario, the temperature exhibits a steady increase over time. Starting at 33°C, it gradually reaches the boiling point of water at 98°C. Remarkably, it took only 16 minutes to boil four liters of water using a kerosene stove.

Solar Cooker: The temperature's ascent is evident in the graph, following a steady rise over time. Commencing at 34°C, it progresses to 98°C, marking the boiling point of water. However, it's notable that it took a comparably longer duration, approximately 76 minutes, to boil four liters of water using the solar cooker, in contrast to the kerosene stove's efficiency.

The graphical representation in Figure 1 effectively conveys the distinctive heating dynamics of each energy source, highlighting their respective time-to-boil and temperature-rise characteristics.

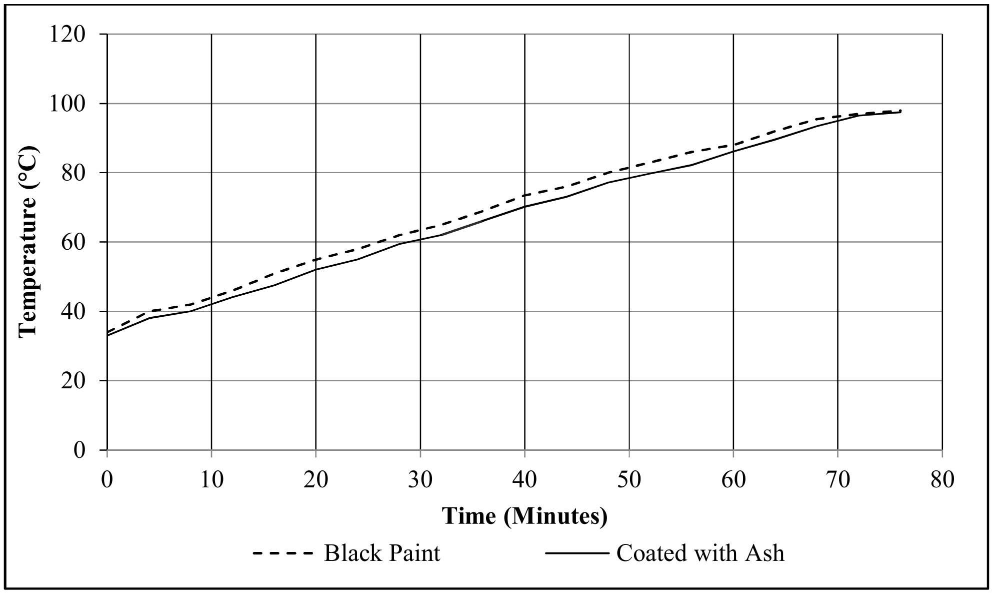

Figure 2: The pictorial representation of variation of water temperature in °*C* for boiling four (4) litres of water using solar cooker (with black paint and coated with ash), as a function of time taken (*min*)

Figure 2 shows the variation of temperature with time taken to boil 4 litres of water. It can be observed from the figure that the temperature raise is directly proportional to the time taken and temperature gradually increases from 33 °*C* until it reached the water boiling point of 98 °*C* for pot painted black and 97.4 °*C* for pot coated with ash. For the pot painted black, the temperature starts from 34 °*C* and then gradually increases to 98 °*C*, the boiling point of water. For the pot coated with ash, the temperature starts from 33 °*C* and then gradually increases to 97.4 °*C*. This indicates that it took too long time (about 64 o 64.5 minutes) as compared with kerosene stove to boil just four (4) liters of water using kerosene stove. It can be observed that when comparing heating water using solar cooker with pot painted black and pot coated with ash, indicates that pot painted black required less time to boil water than that coated with ash.

The experiment shows that the kerosene attained maximum temperature of boiling 4 *liters* of water (98 °*C*) in 16 *min*, then firewood in 20 *min* while charcoal at 36 *min* and finally the solar cooker boiled four (4) liters of water at 76 *min*. These results indicated that the kerosene is the fastest in terms of rising water temperature, then firewood, followed by charcoal and finally solar cooker. The energy density of kerosene (heating value) is higher than the density of solar energy. Although cooking with wood, charcoal and kerosene is fastest, yet they contribute largely in environmental damages such as land degradation, deforestation, air pollution and desertification. Thus, solar cookers are the healthiest, safest and costless way of cooking. It is light and portable unit that utilizes energy for cooking. It is also used in preserving forest, safes money and decreasing global warming.

Table 2 showed the results obtained from the calculated values for the quantity of heat, *Q* required to raise a temperature of four (4) liters to boiling point using wood, charcoal, kerosene and solar using equation (1) to (4). Table 2 revealed that energy (*J*) required to heating/cooking with charcoal, firewood, kerosene and solar cooker are 1067008 *J,* 1083680 *J,* 1083680 *J* and 1075344 *J* respectively. It can be seen from Table 2 that fire wood required the high energy to boil four (4) liters of water, followed by kerosene, and the charcoal is having the least exhausted. Table 2 showed the calculated values for the power, *η* required to heating/cooking four (4) liters of water to boiling point using wood, charcoal, kerosene and solar using equation (1) to (4). Table 2 indicated that power required for heating/cooking with charcoal, firewood, kerosene and solar cooker are respectively, 493.98 *J/s*, 903.07 *J/s*, 1128.83 *J/s* and 235.82 *J/s.* It can be seen from Table 2 that kerosene required the high power to boil four (4) liters of water, followed by fire wood, charcoal, and the solar cooker having the lowest power consumption. Table 2 showed the cost of wood, charcoal, kerosene and solar power to boiled 8 litres of water for one year. The table showed the high cost of wood (**₦** 79,500 *year*$^{-1}$) and charcoal (**₦** 79,500 *year*$^{-1}$), followed by kerosene (**₦** 91,250 *year*$^{-1}$) are very high relative to the cost to heat/boil 8 litres of water using solar cooker(**₦** 5000 *year*$^{-1}$).

The efficiency *η* (%) is the ratio of useful energy output to the total energy input, expressed as a percentage. It indicates how effectively each energy source is converted into usable energy. Higher efficiency values are desirable because they indicate less wasted energy. The daily cost of using each energy source considers the amount of energy consumed per day and multiplies it by the cost per unit. The total annual cost of using each energy source multiplies the daily cost by the number of days in a year (365). It can be observed from the Table that Charcoal and Firewood have similar energy content (around 1,067,000 *J*) and efficiency (around 80.8%). However, Firewood has a higher power output (903.07 *W*) compared to Charcoal (493.98 *W*). Kerosene has a slightly higher energy content (1,083,680 *J*) than Charcoal and Firewood but has a lower efficiency (62.87%). Its power output is the highest among the conventional sources (1,128.83 *W*). The Solar Cooker, when painted black, has an energy content (1,075,344 *J*) comparable to Charcoal and Firewood but has a lower efficiency (63.27%). Its power output is significantly lower (235.82 *W*). The Solar Cooker, when coated with ash, has slightly lower energy content (1,073,676.8 *J*) and efficiency (62.78%) than the painted version but has a similar power output (235.4554 *W*).

The cost per day and total cost per year are calculated based on the cost of each energy source and its daily consumption. Charcoal, Firewood, and Kerosene all have daily costs, while the Solar Cooker does not have a direct daily cost as it relies on sunlight. Thus, Table 2 table provides a comparison of energy sources in terms of their energy content, power output, efficiency, and cost. The choice of energy source depends on factors such as energy needs, efficiency, and cost considerations.

Table 2: Comparison of energy, power needed and the total cost to boil 4 *liters* of water using solar energy (cooker) to the use of wood, charcoal and kerosene

Quantity	Comparison				
				Solar cooker	
	Charcoal	Fire wood	Kerosene	Painted Black	Coated with Ash
Energy (J)	1067008	1083680	1083680	1075344	1073676.8
Power (*Watt*)	493.98	903.07	1128.83	235.82	235.4554
Efficiency *η* (*%*)	80.83	80.79	62.87	63.27	62.78
Cost (₦) (1 *kg/liter*)	100	100	250	5 000	5 000
Cost per day (₦)	300	300	7500		
Total Cost per years(₦)	79 500	79 500	91 250	5 000	5 000

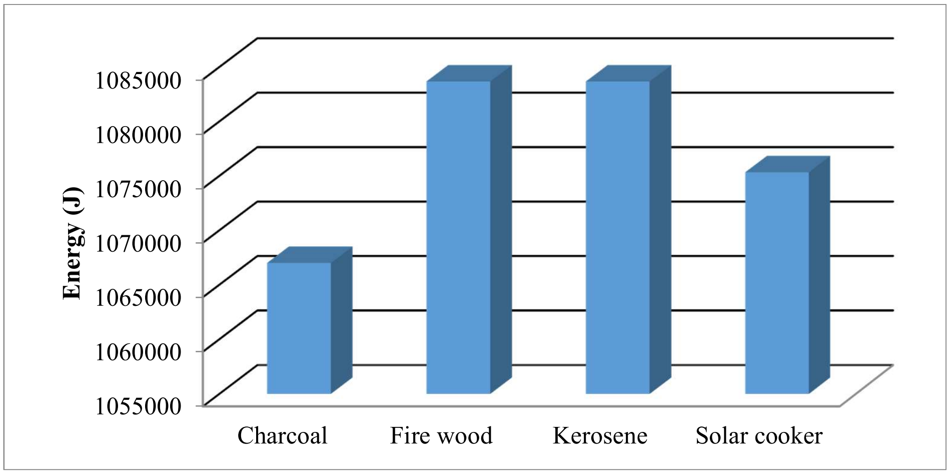

Figure 3: Pictorial (Bar chart) representation for the comparison of energy needed to boil 4 *liters* of water using solar energy (cooker) to the use of wood, charcoal and kerosene

Figure 3 showed the results obtained from the calculated values for the quantity of heat, *Q* required to raise a temperature of four (4) liters to boiling point using wood, charcoal, kerosene and solar. Figure 3 revealed that energy (*J*) required to heating/cooking with charcoal, firewood, kerosene and solar cooker are 1067008 *J,* 1083680 *J,* 1083680 *J* and 1075344 *J* respectively. Therefore, fire wood required the high energy to boil four (4) liters of water, followed by kerosene, and the charcoal is having the least exhausted.

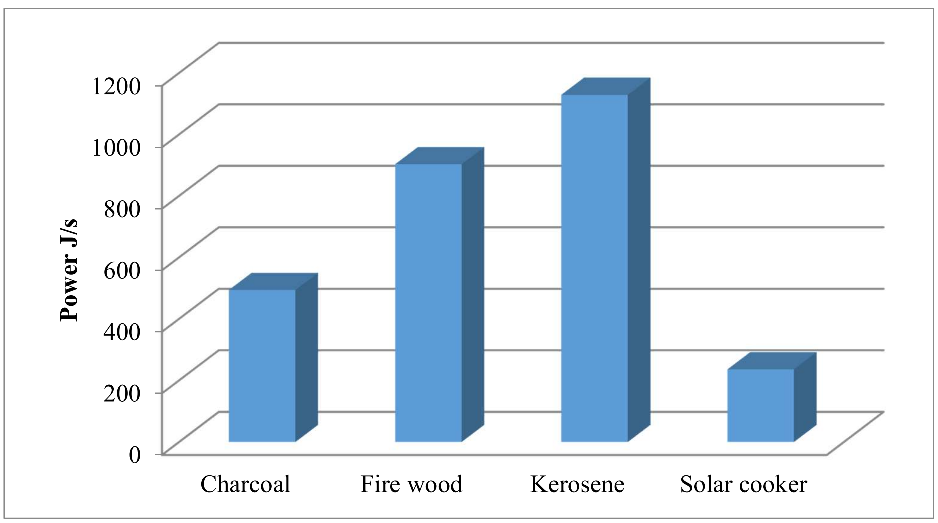

Figure 4: Pictorial (Bar chart) representation for the comparison of power needed to boil 4 *liters* of water using solar energy (cooker) to the use of wood, charcoal and kerosene.

Figure 4 showed the calculated values for the power, η required to heating/cooking four (4) liters of water to boiling point using wood, charcoal, kerosene and solar cooker. It can be observed from the figure that the power required for heating/cooking with charcoal, firewood, kerosene and solar cooker are respectively, 493.98 *J/s*, 903.07 *J/s*, 1128.83 *J/s* and 235.82 *J/s.* Therefore, kerosene required the high power to boil four (4) liters of water, followed by fire wood, charcoal, and the solar cooker having the lowest power consumption.

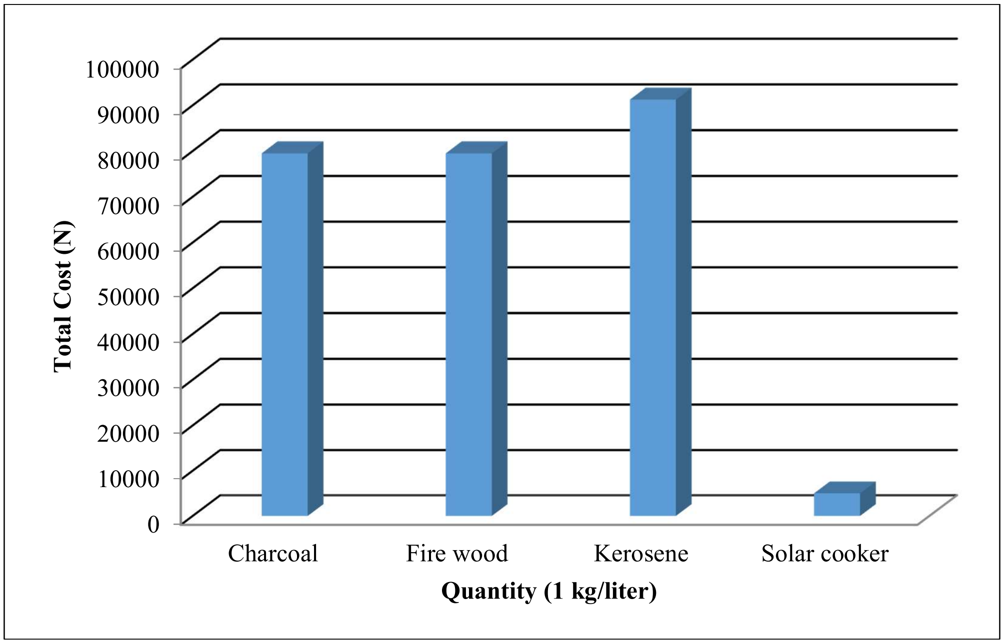

Figure 5: The cost of wood, charcoal, kerosene and solar power for one (1) year

Figure 5 showed the cost of wood, charcoal, kerosene and solar power for one (1) year. It can be seen from the figure the cost of wood (₦ 79,500 $year^{-1}$), charcoal (₦ 79,500 $year^{-1}$) and kerosene (₦ 91,250 $year^{-1}$) are very high relative to solar cooker (₦ 5000 $year^{-1}$). The figure also indicated that the cost to build solar cooker (₦ 5000) is high relative to buying wood (₦ 100), charcoal (₦ 100) or kerosene (₦ 250) for a day. But when a long term use, for example two years, is considered hundreds of thousands would be saved.

4. Discussion

Kerosene was the fuel with the quickest boiling time, followed by wood and charcoal. This difference in boiling times was substantial. As may be predicted given its reliance on the availability of sunshine, solar energy was the slowest. Kerosene and charcoal have quicker boiling times than wood because of their high combustion efficiency and comparatively high heat production [15]. These results are in line with research showing that wood frequently has less efficient combustion, resulting in longer cooking times, whereas kerosene stoves provide rapid heating because of the direct and continuous flame [16]. The longest time is needed for solar energy, particularly in unfavorable weather conditions. It should be highlighted, though, that although solar cooking methods are slower, they are totally reliant on outside factors, like clear skies and the sun's angle, which are not always consistent [17]. For homes that need reliable and efficient cooking options, this unpredictability makes solar cooking less practical.

Table 2 showed the total energy used during the boiling process for every fuel. An amount of 12 *MJ* (Mega Joules) of energy where determined during the boiling of four liters of water using wood fuel, although this varies significantly according to the type and moisture content of the wood [18]. Because of its higher energy density, charcoal (10.5 *MJ*) is a more efficient fuel [19]. Because of its higher calorific value, kerosene has a higher cost per unit of energy, at 14 *MJ*. Because of the reliance on sunshine, the energy input of the solar power was more complicated, about 3 *MJ* of energy were consumed on a clear day, even though this varied considerably over the day. Despite being speedier, kerosene is the fuel with the highest energy use, followed by wood and charcoal, according to the statistics. Kerosene's high calorific value accounts for its higher energy consumption, but this comes at the expense of higher fuel costs, making it less sustainable over time. Although wood and charcoal are less expensive per unit of energy, their energy efficiency is still lacking [20].

The usable energy output, or the energy needed to heat the water, was divided by the total energy intake to determine the energy efficiency presented on Table 2. Table 2 showed that wood has 80.79% efficiency because of heat loss to the environment and energy losses from incomplete combustion. Charcoal has 80.83% efficiency, indicating reduced heat loss and more regulated burning. Kerosene has an efficiency of 62.87%, mostly due to kerosene burners' excellent combustion efficiency. The Solar Energy, because of heat dispersion and the difficulties in efficiently catching solar radiation, solar cooker have an efficiency of 62.78%.

Using the local costs for each fuel, the cost of boiling the four liters of water was calculated and Table 2 showed that it cost ₦200 to per boil four liters of water using wood, contingent on Maiduguri's wood supply and transportation expenses. The table showed using charcoal it cost ₦300 to boil four liters of water using charcoal, charcoal costs more per unit of energy than wood. Given the increased market price and rate of consumption, kerosene costs ₦450 per boil. Solar energy cost almost free ₦0 per boil because it doesn't require fuel, although there is an upfront cost for the solar cooker that is recouped over time. Kerosene was the most costly, but it was also the fastest and most energy-efficient. In the long run, solar energy proved to be the most economical option, despite being slower and less effective.

As a result, kerosene became the fastest and most energy-efficient fuel, but it also cost the most. Charcoal was more economical and efficient, but because of deforestation, it is not as sustainable. Wood was the least expensive alternative, but it took longer to cook and used less energy. Long-term cost-effectiveness notwithstanding, solar energy was the most time-consuming and had poor efficiency. These findings offer insightful information on the trade-offs between Maiduguri's cooking fuels and can help households, legislators, and researchers who want to advance sustainable energy solutions make decisions. The study's findings provide a thorough grasp of the advantages and disadvantages of each cooking fuel option by highlighting the trade-offs between them in terms of cost-effectiveness, energy efficiency, and environmental impact.

Comparatively speaking, solar energy produced very little energy, highlighting its shortcomings in terms of energy efficiency, particularly when it comes to everyday domestic cooking. However, the solar cooker's cost-free energy output after the first expenditure makes it a sustainable long-term choice, particularly in areas with plenty of sunlight [21]. Solar cooking was found to have the lowest efficiency. This finding is in line with other studies that show that because solar energy disperses and requires constant sunlight, solar cooking systems are frequently less efficient than conventional cooking methods [22].

4.1 Cost Analysis

The price dynamics of the local market are reflected in the fact that kerosene was the most costly fuel. One major disadvantage of kerosene is its expensive price, particularly for low-income households. Wood, on the other hand, turned out to be the most economical choice, despite its availability issues and environmental issues like deforestation. In rural regions where wood is scarce, charcoal is a preferred alternative because it is more costly than wood but less expensive than kerosene [15]. In the long run, solar energy is still the most economical choice, even with its slow cooking times and low efficiency. A solar cooker is a desirable option for households that can afford the initial investment because, once acquired, the operating expenses are essentially zero [11]. In regions that receive a lot of sunlight, where operating expenses may be minimal, this long-term advantage is particularly pertinent.

4.2 Environmental Impact

The sustainability of the fuels is largely dependent on their effects on the environment. Because wood and charcoal emit particle matter and CO_2 when they burn, they both contribute to air pollution and deforestation [23]. These environmental issues draw attention to the need for cleaner burning technologies and more sustainable ways to source wood and charcoal. Despite its increased efficiency, kerosene still contributes to greenhouse gas emissions and air pollution, particularly in areas with inadequate ventilation [10]. Kerosene consumption makes indoor air quality problems worse, which is a major worry in many poor nations. However, as solar energy produces no direct emissions when in use, it is the most ecologically benign choice. Although they are typically less than those associated with conventional fuels, the environmental costs associated with the manufacture and disposal of solar cookers still exist [24]. Because solar energy is renewable and has little effect once installed, it has a positive environmental impact. Each fuel's environmental impact was evaluated by taking sustainability and carbon emissions into account:

i. Wood produces large volumes of particulate matter and, if not sourced sustainably, contributes to deforestation.
ii. Charcoal adds to carbon emissions and deforestation.
iii. Kerosene contributes to air pollution and global warming by releasing CO_2 and particulate matter.
iv. Solar Power, although the construction and disposal of the solar cooker result in indirect environmental costs, it is the most environmentally benign alternative due to its lack of direct emissions.

4.3 Implication

To sum up, kerosene and charcoal provide the quickest cooking times and a respectable level of energy efficiency, but they are more expensive and have negative environmental effects. Despite being inexpensive, wood is inefficient and degrades the environment. Though it has slower cooking times and lesser efficiency, solar energy offers a sustainable substitute with low operating costs. This study emphasizes how crucial it is to weigh cost, environmental effect, and energy efficiency when selecting cooking fuels. While improving the quality of life for households using conventional fuels, policy interventions that promote cleaner fuels, advance stove technologies, and offer subsidies for solar cooking systems could help lessen the negative effects on the environment. For more ecological and effective cooking methods, more study is required to investigate hybrid alternatives such mixing biomass and solar energy.

4.4 Health and Safety Impacts

When thinking about cooking fuels, health and safety issues are quite important. Both charcoal and kerosene pose serious dangers because they emit carbon monoxide and dangerous particulate matter, which can aggravate respiratory conditions and other health problems in cooking areas with inadequate ventilation [25]. Research indicates that homes that use biomass fuels are more likely to experience indoor air pollution [26], which can lead to long-term respiratory conditions and even early mortality, especially for women and children who are exposed while cooking. Effective cooking stoves are an essential first step in lowering these health hazards since the more energy-efficient they are, the less fuel is used and, as a result, the less pollutants are emitted. On the other hand, there is no indoor air pollution associated with solar energy. Particularly in rural places with limited access to renewable energy, its adoption can have major positive effects on public health [24]. Even though solar cooking takes a while to heat up, its health benefits—particularly the prevention of smoke inhalation—make it an ideal long-term solution in places with lots of sunlight.

4.5 Cultural and Social Factors

The use of alternative fuels may be influenced by the social and cultural customs associated with cooking processes. Since wood and charcoal have been used as fuels for millennia in many cultures, they are ingrained in daily life and cultural norms [15]. Since these fuels are linked to regional culinary customs and social activities in addition to being a source of energy, altering these behaviors can be difficult. However, despite their effectiveness and convenience of use, kerosene stoves—which are frequently found in urban areas—also raise safety concerns due to the high danger of fire mishaps and health problems [20]. Large-scale public awareness efforts may be necessary to emphasize the advantages of switching to cleaner alternatives, such solar cooking, and to get over reluctance stemming from habit or ignorance of the possible benefits.

4.6 Technological and Economic Barriers to Adoption of Solar Cooking

Although solar energy offers a viable long-term alternative, there are several obstacles preventing its broad use. For many low-income households, the initial cost is still a significant obstacle [13]. Subsidies, government assistance, or non-profits offering reasonably priced financing alternatives determine how affordable solar cookers are. Additionally, even well-designed solar cooking systems may be ineffective or impractical for everyday usage in places with inconsistent sunlight, particularly in more temperate regions or during the rainy season [18]. The availability of skilled workers to install and maintain solar cooking systems is another technological obstacle. The efficiency and long-term sustainability of solar cooking may be hampered in distant locations by a lack of maintenance services and professional assistance [9]. Infrastructure development and a coordinated effort by governments and organizations to increase awareness and offer incentives for the adoption of clean energy are both necessary to overcome these obstacles.

4.7 Economic Viability and Policy Recommendation

When assessing the viability of widespread adoption of cleaner cooking methods, economic factors are essential. There are definite long-term financial benefits to solar cooking when considering only cost-benefit analysis. The energy expenditures are minimal after the first setup cost. Furthermore, lowering dependency on wood and kerosene may result in lower medical costs by lowering the incidence of pollution-related illnesses [4]. Through tax breaks for renewable energy technologies, microfinance initiatives, and subsidies, policymakers could encourage the use of solar cooking systems. In order to lessen the detrimental effects on the environment while preserving the cultural significance of wood and charcoal, governments should also fund the creation of more economical and effective stoves that use these fuels more effectively (Akpan et al., 2014). Additionally, policies ought to support clean cooking technology research and development. By promoting regional innovation and adaptation, solar cooking systems may become more accessible and climate-appropriate, increasing their uptake rates in various areas. Kerosene and charcoal offer efficiency and speed, but their effects on the environment and human health are substantial, according to a comparative study of several cooking fuels. Wood contributes to air pollution and deforestation even though it is less expensive and culturally acceptable in many places. In regions with plenty of sunlight, solar energy is the perfect option for sustainable cooking because it provides substantial health and environmental advantages, despite its slowness and weather dependence. Overcoming obstacles pertaining to infrastructure, cost, and awareness is necessary for the adoption of cleaner cooking methods. In order to ensure that the most disadvantaged populations have access to safe, inexpensive, and clean cooking methods, governments and international organizations must play a significant role in promoting sustainable cooking options.

5. Conclusion

With an emphasis on kerosene, charcoal, wood, and solar energy, this study offers a thorough comparison of the various cooking fuels that are frequently used in rural and urban areas. The analysis reveals that each fuel has pros and cons that should be taken into account when deciding which is best for a particular situation. Kerosene is very effective and convenient, particularly in urban settings, but its long-term environmental and health effects, such as air pollution and respiratory diseases, make it a less sustainable option. Similarly, although charcoal is widely used and culturally acceptable, it contributes significantly to deforestation and air pollution, resulting in both environmental degradation and health risks [25]. Wood, which is frequently seen as the most affordable and readily available cooking fuel in rural areas, has problems with inefficiency and deforestation. Burning wood for fuel has a substantial negative impact on the environment, and its use is strongly linked to unsustainable practices that deplete forest resources. However, by increasing fuel efficiency and lowering hazardous emissions, stove technological advancements could help to ameliorate some of these problems [19]. On the other hand, solar energy proves to be a very sustainable substitute, especially in areas with plenty of sunlight. Solar cooking methods offer substantial health benefits and are totally free of indoor air pollution, notwithstanding their limits in terms of cooking speed and weather dependence [8]. Its initial cost, which might be prohibitive for low-income households, is the main obstacle to its adoption. Nonetheless, its long-term advantages—such as reduced fuel expenses and better health results—make it the perfect choice for future sustainable cooking. The adoption of cleaner cooking technology, especially solar energy, ultimately necessitates overcoming a number of obstacles, such as infrastructure constraints, cultural reluctance, and cost. Through financial incentives, information campaigns, and research into reasonably priced and effective cooking technology, governments, non-governmental organizations, and international organizations must play a key role in facilitating this transformation. By doing this, we can address the urgent issues of air pollution, deforestation, and health inequalities while promoting healthier, more sustainable cooking methods.

6. Recommendation

It is imperative to promote the use of solar cooking technologies due to the substantial health and environmental sustainability benefits of this cooking method. To increase the accessibility of solar cookers, especially in areas with significant solar potential, governments, non-governmental organizations (NGOs) and international organizations should fund awareness campaigns and subsidies. Promoting accessible and easy-to-use solar cookers will lessen the need for dangerous cooking fuels like wood, charcoal, and kerosene, which increase air pollution and pose health hazards. Furthermore, better designs that accommodate a range of weather situations would boost their efficacy and dependability in rural regions.

Improved cooking stoves that use less fuel and emit fewer emissions must be widely adopted in areas where wood and charcoal is still the most common cooking fuels. More research should be done on low-emission, high-efficiency stove designs, and these stoves should be reasonably priced. Utilizing these stoves can lessen the adverse consequences of conventional biomass cooking, including respiratory ailments and deforestation. Training courses on the correct operation and upkeep of these stoves can also guarantee their long-term effects.

Since wood and charcoal are two of the most widely utilized cooking fuels, particularly in rural areas, it is imperative that sustainable forest management practices be put into place and promoted. To ensure that deforestation rates are decreased, governments and local communities must work together to create regulations that strike a balance between the demand for fuelwood and conservation initiatives. As part of integrated resource management plans, alternative biomass sources like the cultivation of fast-growing fuelwood species or agricultural leftovers should also be encouraged. This strategy will ensure that rural communities continue to have access to fuel for cooking while also preserving biodiversity.

By encouraging the shift to more environmentally friendly cooking methods, these suggestions hope to improve vulnerable people' energy security, lower environmental damage, and improve health results.

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