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Solar Cells and Global Warming Reduction

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Abstract

This study proposes one way of addressing the issue of climate change and pollution using solar cells. The quality of life in developing and low-income countries is on the decline because of air pollution. Energy has a role to play in the quality of life and reduction of air pollution especially in those countries. A reduction in the usage of fossil fuels and biomass in these countries will help decrease the air pollution and emissions generated by such energy sources. About 1 million solar lanterns are capable of reducing greenhouse gas emissions by over 30 000 tons. The role of eco-friendly solar cells in elimination of air pollution cannot be overstated.

Keywords: Solar; air pollution; developing countries; fossil fuels

INTRODUCTION

The quality of human life is affected by several factors of which access to a clean and reliable source of energy is at the forefront [1]. About one-fourth of earth's inhabitants lack access to electricity with little or no change of outlook over the last 40 years [2]. Several developing countries in Africa and elsewhere are struggling to deliver affordable and stable electricity [3]. These countries still use fossil fuels (Premium Motor Spirit, kerosene) and biomass (charcoal and wood) as their major sources of energy [4]. Although some of these are cheap and easily accessible, regular exposure to their usage poses health and social risks [5]. Energy insecurity and other human interaction have created a major challenge of climate change and pollution.

Pollution, especially air pollution, is ranked the sixth-leading cause of death world-side, responsible for about 2.4 million premature deaths annually [6]. Air pollution is a leading cause of respiratory illness, cardiovascular disease, cancer, hospitalization, work-days lost, and school-days lost [7, 8]. This is because climate change boosts disease, heat, glacier melting, and ocean acidity [9]. It also causes an imbalance in ecosystems, agriculture, and water supply. Carbon dioxide gas, fossil fuel [10], soot particles from biofuel [11], methane gas, halocarbons and nitrous oxide gas are the leading causes of global warming [12, 13]. Cooling aerosol particles mask more than half of the actual global warming as shown in Figure 1. Particles containing sulphates, chloride, ammonium, potassium, nitrates, certain organic carbons, and water, primarily, are called cooling aerosol particles. Although, their sources differ they are mainly from fossil-fuel and biofuel soot. Thus, removal of aerosol particles is critical for air pollution reduction.

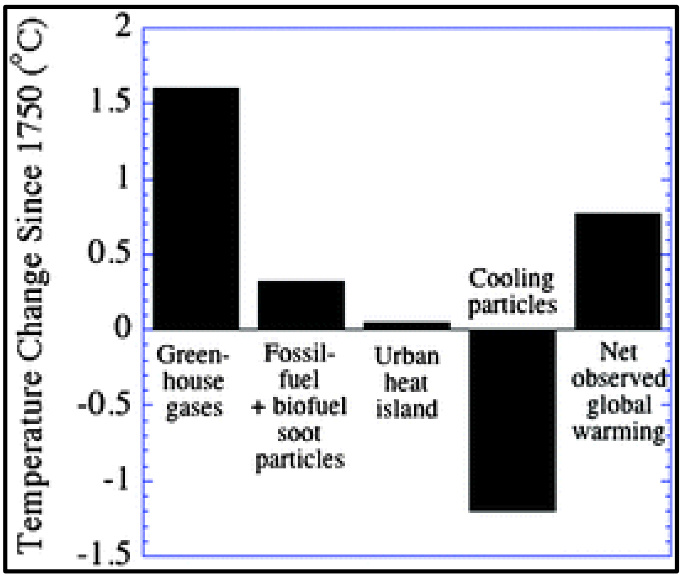

Figure 1. Primary contributions to observed global warming from 1750 to today from global model calculations

Apart from the seasonal scarcity of these fuels, they are expensive and prolonged exposure to them has adverse economic and health consequence. Kerosene is affordable and accessible in many countries due to the subsidization of the product by such countries [14]. However, kerosene lanterns emit both black carbon and carbon dioxide. Kerosene lamps emit 20 times more of these pollutants than previous estimates. They convert 7 % to 9 % of the fuel burned into black carbon particles. Black carbon particles are a major source of climate warming, second to CO_2 [15]. They do this by absorbing sunlight and heating the atmosphere. Black carbon combines with other pollutants to form 'short-lived climate pollutants' (SLCP). Table 1 illustrates the annual kerosene carbon emission in some Africa countries.

Table 1. Annual kerosene use and black carbon emissions by country

Country	Kerosene lamp-glass cover installed stock estimates (Million)			Kerosene lamp-simple wick installed stock estimates (Million)			Annual black carbon savings (tons)
	Households	Commercial	Total	Households	Commercial	Total	
Nigeria	39.8	3.8	43.6	17.8	0.3	18.1	52,680
Sudan	12.7	1.2	13.9	5.7	0.1	5.8	16,862
Kenya	14.0	1.3	15.3	6.3	0.1	6.4	19,629
Tanzania	11.7	1.6	13.3	5.9	0.2	6.1	18,335
Democratic Republic of Congo	4.1	1.3	5.4	20.3	1.2	21.5	49,964
Ethiopia	5.0	1.6	6.6	24.5	1.5	26	59,950

Fossil fuels are still being used for cooking and lighting in most developing countries as shown in Figures 2 and 3. Carbon is released when they are burnt thereby causing air pollution in the process.

(a) (b) (c)

Figure 2. Cooking with wood (a) Subsistence garri frying (b) Commercial garri frying (c) Food cooking (starch)

(a) (b)

Figure 3. Fossil fuel lightening (a) Reading with kerosene lamp (b) Suya meat vendor

At least 270 000 tons of black carbon per year is estimated to be emitted from kerosene lamps worldwide. Figure 4 shows the black carbon radiative forcing from kerosene lighting in residential. having a climate warming equivalent close to 240 million tons of CO_2, or roughly 4.5 % of the United States' CO_2 emissions. The warming impact of black carbon emissions from kerosene lamps is highest around source regions, reaching 0.5 W per square meter. Solar lanterns improve the quality of life for the people in Africa and Asia by reducing greenhouse gas emissions and providing greater access to energy.

Panasonic Electronics estimated that replacing kerosene lamps with 1 million solar lanterns will reduce greenhouse gas emissions by over 30 000 tons [16].

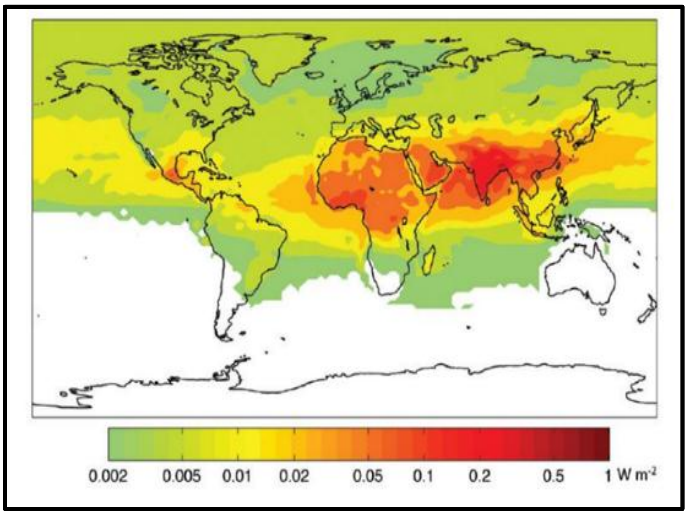

Figure 4. Black carbon radiative forcing from kerosene lighting in residential building (W/m^2)

The usage of renewable energy does not require the burning of fuels that emit carbon. This will help combat air pollution caused by fossil fuels and biomass. Sunlight has the most extensive range of applications for green households. The emerging range of materials for solar energy generation is environmentally friendly. This range includes metal oxide materials. Successful development and deployment in developing countries will help reduce the air pollution facing such countries. The impact is so noticeable that even a single household that has switched to solar energy can make a difference.

This study proposes one way of addressing the issue of climate change and pollution using solar technology.

SOLAR AND POLLUTION

Solar photovoltaics (PV)

These are arrays of cells containing a material that converts solar radiation into direct current (DC) electricity [17]. Different materials and methods are in use today. The materials include silicon (amorphous silicon, polycrystalline silicon, micro-crystalline silicon), cadmium telluride, and copper indium selenide/sulphide, metal oxides (plain or nanostructured), among others. These materials can also be doped to increase the number of positive (p-type) or negative (n-type) charge carriers. The resulting p- and n-type semiconductors are then joined to form a p–n junction that allows the generation of electricity when illuminated. Photovoltaics can be mounted on roofs or combined into farms [18].

Normalized distribution of radiation intensities for the sun and for a kerosene flame according to Planck's Law is shown in Figure 5. The non-normalized peak intensity of the Sun is a little over two orders of magnitude larger than that of kerosene [4]. Kerosene flame and sun estimated luminous efficacy values are 0.65 lm/W and 99 lm/W, respectively.

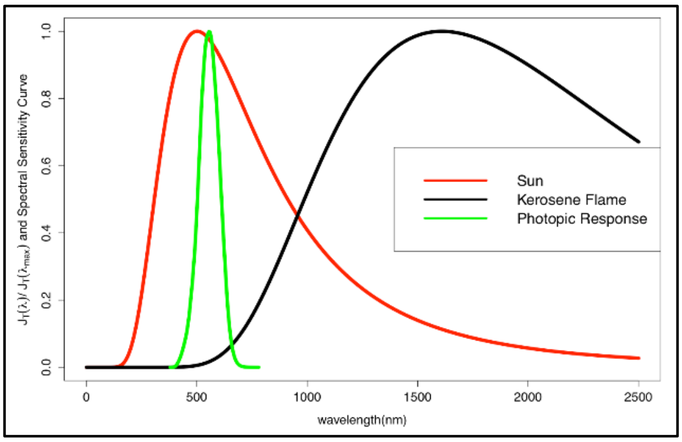

Figure 5. Normalized distribution of radiation intensities for the sun and kerosene flame according to Planck's Law, compared to the photopic spectral sensitivity of the eye

Lifecycle emissions from energy sources

Table 2 gives the ranges of the lifecycle CO_2e emission per kWh of electricity generated from most commonly used electricity sources. For the renewable electricity sources (wind, solar PV, CSP, tidal, wave, hydroelectric), climate-relevant lifecycle emissions take place only during the construction, installation, maintenance, and decommissioning of the technology. Emissions are caused by evaporation of dissolved CO_2 from hot water in geothermal flash- or dry-steam plants, but not in binary plants. Although, in the case of coal-carbon capture and storage (coal-CCS), nuclear, corn ethanol, and cellulosic ethanol additional emissions occur during the mining and production of the fuel. For biofuels and coal-CCS, emissions also occur as an exhaust component during combustion[18].

Table 2. Lifecycle emission of energy sources [18]

Technology	Lifecycle	Opportunity cost emissions due to delays	War/terrorism (nuclear) or CCS	Total
Solar Photovoltaic	19-59	0	0	19-59
Wind	2.8–7.4	0	0	2.8–7.4
Geothermal	15.1–55	1–6	0	16.1–61
Hydroelectric	17–22	31–49	0	48–71
Wave	21.7	20–41	0	41.7–62.7
Tidal	14	20–41	0	34–55
Nuclear	9–70	59–106	0–4.1	68–180.1
Coal-CCS	255–442	51–87	1.8–42	307.8–571

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ENVIRONMENTAL BENEFITS OF SOLAR ENERGY

i. SOLAR ENERGY REDUCES AIR POLLUTION. Traditional electricity generation accounts for 31 % of greenhouse gas emissions in the United States [19]. Coal is used for electricity generation in some countries because it is a cheap form of electricity generation [20]. However, coal contains the most CO_2 per British thermal unit (BTU), and is the largest contributor to global warming [21]. Coal mining also has a severe impact on the environment and health of the workers and inhabitants around the mine. This contributes to air and water pollution. Metal oxide solar cells contain little or no toxic substance that causes air pollution. Electricity generation using solar will drastically reduce CO_2 emissions that pollute the air.

ii. SOLAR ENERGY REDUCES WATER POLLUTION AND CONSUMPTION. This is because water is not required for solar-based electricity generation, unlike natural gas and coal. A coal-fired power plant produces 72 % of water pollution. Most materials and methods used for solar cells contain little or no toxic materials. This helps to reduce water pollution.

iii. SOLAR REDUCES TOXIC WASTE. About 400 million tons of hazardous waste are produced every year mainly from fossil fuels. Coal-fired power plants release trace elements that are toxic [22]. Coal residues make up 90 % of all fossil fuel combustion wastes in the USA. However, only 20 % of those wastes are used with the rest deposited into landfills [23]. This constitutes a toxic waste. Solar eliminates this because fuel is not used and there is no need for waste disposal.

iv. SOLAR ENERGY HAS INFINITE USAGE. The solar system produces about 173 000 terawatts of solar energy per second. This value is 10 000 terawatts more than the total world energy needed.

Ways solar energy can reduce pollution

i. Vehicular emission reduction: Pollution from cars comes from by-products of the combustion process of fossil fuel (exhaust) and from evaporation of the fuel as shown in Figure 6.

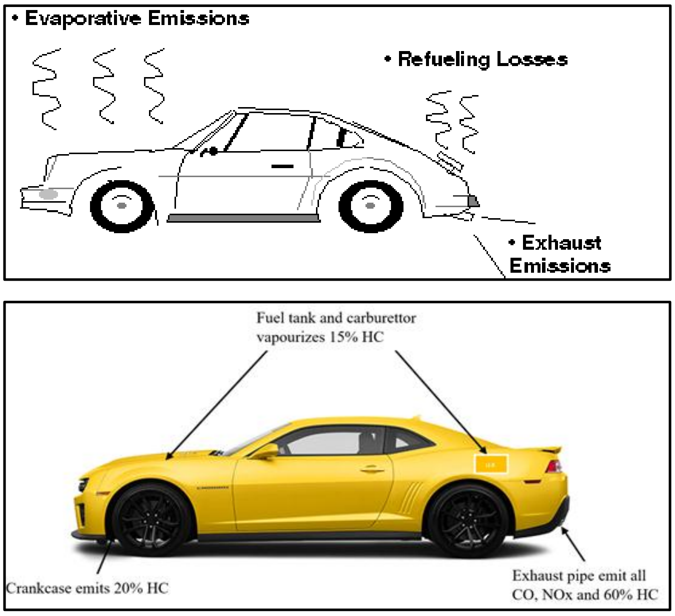

Figure 6. Sources of vehicle pollutants

The huge emission caused by fossil fuel powered cars, tricycles and motorcycles can be reduced with solar technology. Fossil fuel vehicles are sources of major air pollutants (such as carbon monoxide, nitrogen oxides, and other pollution) as shown in Table 3 [24]. Vehicles contribute about half of the carbon monoxide and nitrogen oxides emitted into the air [25, 26]. They also contribute about 25 % of the emitted hydrocarbons into the air [27, 28]. Particulate matter (soot and metals), nitrogen oxides, carbon monoxide, sulphur dioxide, hydrocarbons are the major air pollutants released by fossil fuel powered vehicles. Solar powered vehicles have little or no emissions. This will help reduced emission of the major pollutants causing global warming. Figure 7 illustrates t source of pollutants from a fossil fuel car and a solar car.

Figure 7. Vehicular emission (a) fossil fuel car emission (b) Solar car (zero emission)

Table 3. Vehicles pollutant emission factor

Pollutant	Bus	Motorcycle	Tricycle	Passenger	Luxury (car and SUV)	Commercial (Taxi)	Truck and Lorries	Goods Delivery	Heavy duty
Carbon dioxide (CO_2)	515.20	26.60	343.87	60.3	223.6	208.3	515.2	515.20	515.20
Carbon Monoxide (CO)	3.60	2.20	3.86	5.10	1.98	0.90	3.60	5.10	5.10
Nitrogen oxides (NOx)	12.00	0.19	3.89	1.28	0.20	0.50	6.30	1.28	1.28
Methane (CH_4)	0.09	0.18	0.11	0.18	0.17	0.01	0.09	0.09	0.09
Sulphur dioxide (SO_2)	1.42	0.01	1.94	0.03	0.05	10.30	1.42	1.42	1.42
Particulate matter	0.56	0.05	0.24	0.20	0.03	0.07	0.28	0.20	0.20
Hydrocarbons (HC)	0.87	1.42	0.54	0.14	0.25	0.13	0.87	0.14	0.14

ii. Solar lantern to replace a kerosene lantern. Quality of life will be improved by replacing kerosene lamps with solar lanterns. Kerosene lamps emit toxic fumes and pose a fire hazard, although the initial investment cost is more for solar lanterns compared to kerosene lamps. Figure 8 gives the cost obtained in 2005 by Mills [29].

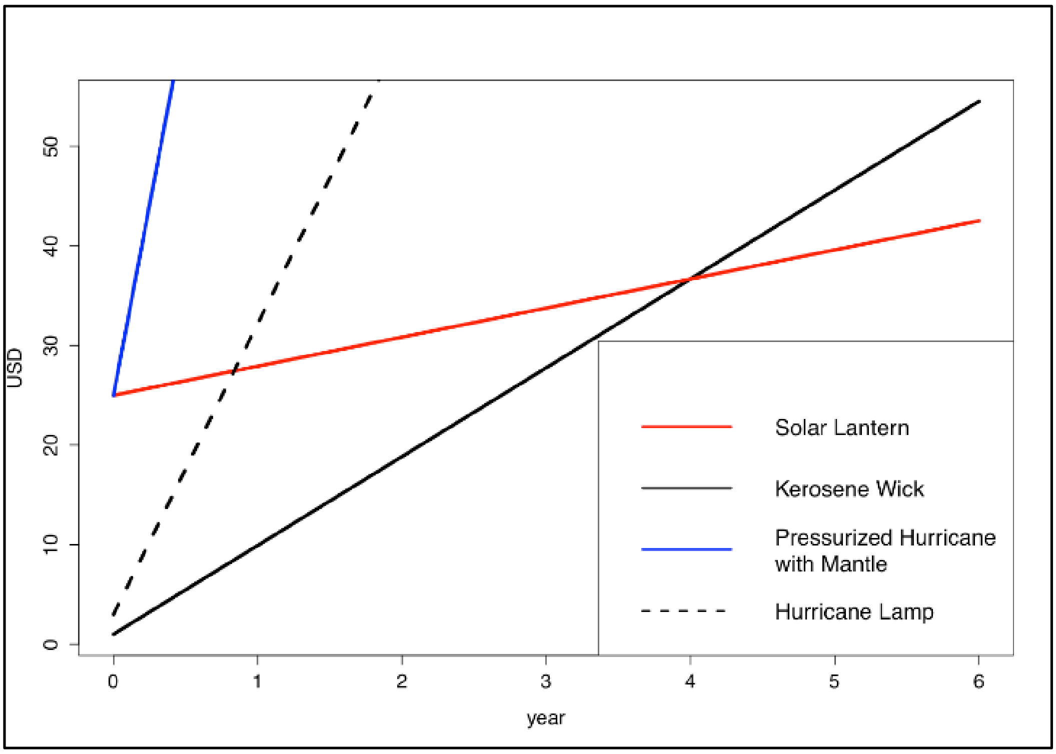

Figure 8. Accumulated costs of a solar lantern, kerosene wick lamp, hurricane wick lamp, and pressurized hurricane lamp with mantle

The health benefit of a solar lantern outweighs the costs when compared with a kerosene wick lamp. Subsidizing solar lanterns can encourage usage, and research into affordable yet efficient solar cells can help lower the cost.

iii. Cooking emission reduction: Solar cooking to replace biomass and other traditional cooking fuels. Air pollution can be reduced drastically when biomass and traditional cooking fuels are replaced with solar cookers. Solar cookers leverage on the sunlight to cook and boil water. This is achieved by using reflectors to heat an enclosed area that is different from the oven. This helps rural and low income communities that spend many hours each day searching for wood and other traditional fuels for cooking. It also encourages children to focus on studies and spend less time foraging for fuel [30]. This help saves resources, prevents health issues caused by fumes from fuels, saves money and encourages sustainable cooking. Figure 9 shows an annual solar cooking festival where people display and cook with different designs of solar cooker.

Figure 9. Solar cooking at a solar cooking festival

Solar water boiling will help reduce child mortality. It is estimated, by water.org, that a child dies every minute from disease related to water contamination [31]. Solar ovens help purify water polluted with microbes. These microbes are killed when the water is heated to certain temperatures. Water does not need to boil to eliminate dangerous microbes. Hepatitis A is killed at 65 °C, worms at 55 °C and *E. coli*, *Vibrio cholerae* (cholera) and *Salmonella typhi* (typhoid) bacteria at 60 °C. A water pasteurization indicator can be used to indicate the safety of the water. It consists of a small, less than 2-inch cylinder filled with wax. The water is safe for drinking when the wax melts. Although the water might still be brown, it will be safe to drink. Figure 10 gives an example of water boiling using solar energy.

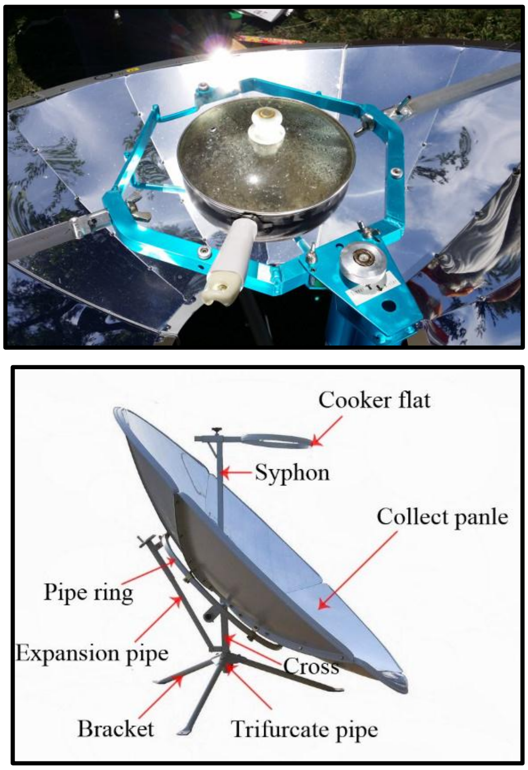

Figure 10. Solar water boiling and solar cooking panel

iv. Solar heating and cooling to replace traditional heating and cooling gas used for air conditioning: Most rural dwellers heat their water using wood collected from the farm. Urban residents heat up their home with coal during winter. These contribute to global warming. Demand for air conditioning is increasing due to the increase in global temperatures [32]. Agricultural produce and food items are stored and preserved using refrigerators and deep freezers. Air conditioners and refrigerator uses refrigerants. Refrigerants deplete the ozone and cause global warming. Refrigerants such as chlorofluorocarbons and hydrochlorofluorocarbons (HCFCS) have been replaced by hydrofluorocarbons (HFCS) in developed countries. Although HFCS do not deplete stratospheric ozone they have global warming potential [33].

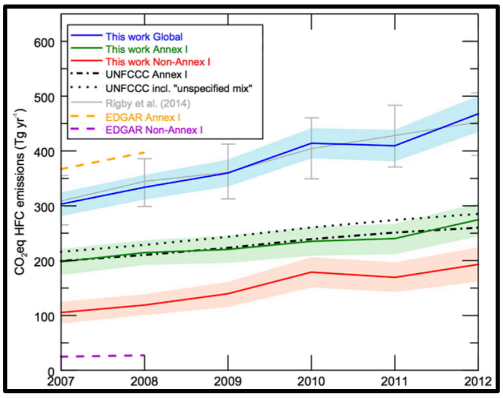

Figure 11. Hydrofluorocarbons (HFCS) from 2007 to 2012

Figure 11 shows the combined emissions of five hydrofluorocarbons from 2007 to 2012. The blue lines represent the world, green for developed countries, and a red line for developing countries. The dashed black lines and dotted gives the emissions reported to the UNFCCC (for developed countries only). The estimates from other studies are represented by grey, orange and purple lines [33]. The use of solar technology for heating and cooling will eliminate ozone depletion and greenhouse gas. Figure 12 shows solar heating for a swimming pool and for residential water heating.

(a) **(b)**

Figure 12. Solar heating (a) water heating for swimming pool (b) residential water heating

CONCLUSION

Air pollution threatens the very existence of humanity. Solar cells, and solar technology in general, are capable of reducing air pollution. Direct replacement of fossil powered cooking and lightening by solar powered cooking and lighting can mitigate this pollution. Solar cells and solar energy have a great role in reduction and even elimination of air pollution and water pollution. The emerging generation of solar cells, especially nanostructured metal oxides, can help combat global warming.

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