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Technical note

Technical and economic studies on lighting systems: A case for LED lanterns and CFLs in rural Ghana

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ABSTRACT

Studies have shown that 50.1% of Ghana's 22,900,927 population use kerosene as fuel source for lighting. Statistics further established that 75.6% of Ghana's rural population and 19.9% of the urban population use kerosene as fuel for lighting. This situation has brought about diverse problems of poor indoor air quality. For instance, a survey conducted among 113 non-electrified households in 16 rural communities, located in six regions in Ghana that use kerosene lanterns established that 69% of the households observed soot particulates in a household member's nostril in the morning.

In light of the known health effects of kerosene usage for lighting in poorly ventilated structures and the recent global increases in the prices of petroleum products, this study is designed to assess the suitability of solar-powered LED and CFL lighting systems as replacement for kerosene lanterns. The technical analysis was done by measuring the luminous flux of each lighting system on a flat surface measuring 1 m by 1.2 m using a portable lux meter. The economic analysis was based on a two-year simple payback period.

Results from the study showed that the cost of illumination ranges from \$0.061 per thousand lux-hours (klxh) for Goshen solar lantern to \$0.261 per klxh for Gentlite solar lantern with kerosene lantern costing \$0.227 per klxh. The analysis established that switching to the solar-LED and CFL systems (lanterns A, B and D) would have a payback time of less than two years when replacing the wick-type kerosene lantern with between \$11.60 and \$61.60 to save annually. When evaluated in terms of total cost of ownership (fixed and variable), the solar-powered LED and CFL systems emerged as the most cost-effective solution.

Emissions analysis conducted revealed that the solar-powered systems save between 80.15 and 256.49 kg CO_2/year. The annual CO_2 emissions per kerosene lantern were estimated to be 60.99 kg.

Therefore, the most significant deduction from the study is that the solar-powered LED and CFL lighting systems are a viable and cost effective off-grid lighting alternative for fuel-based lighting systems in rural Ghana.

1. Introduction

Access to electricity for households is currently about 54%, with rural access being only 24.9% compared to 81% in urban households [1]. The consequence is that in Ghana where about 56.25% of the 22,900,927 national population reside in rural areas, 75.6% of the rural households use kerosene as the main fuel source for lighting. Table 1 shows fuel for lighting in Ghana.

The Ghana Core Welfare Indicators Questionnaire Survey (CWIQ II) put the total percentage of Ghana's population which use kerosene as their main source of fuel for lighting at 50.1% as at 2003 [2]. It is reported that [3] Ghana spends as much as 20–30% of its export earnings on crude oil and petroleum products importation, depending on the world market prices of these products.

Poor indoor air quality is widely recognized as a problem in rural households mainly as a result of the reliance of low-income households on woodfuel for cooking and fossil fuel for lighting. According to a DfID report [4], indoor air smoke contributes to respiratory infections that account for up to 20% of the 11 million deaths in children each year. A WHO research indicated that [5] acute exposure to NO_2 (which is a by-product of kerosene combustion) is associated with respiratory irritation and can lead to long term changes such as pulmonary oedema, pneumonitis, bronchitis and bronchiolitis obliterans. A survey [6] conducted among 113 non-electrified households in 16 rural communities,

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Table 1
Fuel for lighting in Ghana (2003).

Administrative area	Kerosene (%)	Electricity (%)
Ghana	50.1	48.9
Rural	75.6	23.8
Urban	19.9	78.7

Source: [2].

located in six regions in Ghana that use kerosene lanterns established that 69% of the households observed soot particulates in a household member's nostril in the morning.

The market price of kerosene in Ghana has been on the increase in tandem with the global crude oil prices, although there are some subsidies to cushion poor rural households that depend on it for lighting. The ex-pump price per litre of kerosene increased by 119.80% between January 2003 and September 2007. Currently, the ex-pump price of kerosene per litre is GH¢0.67 (as at July 2011). In addition, petty traders purchase kerosene in gallons at the pump from petrol filling stations and retail in beer, fanta as well as APC bottles at exorbitant prices to households who are unable to purchase the kerosene in gallons.

An average household in Ghana with about 5 persons and 2 sleeping rooms uses two (2) kerosene lanterns which consume approximately four (4) beer bottles of kerosene per month. A survey conducted at Kotei, a village at the periphery of KNUST in Kumasi (in July 2011) showed that a beer bottle (650 ml) of kerosene is retailed between $1.33 and $1.67. The implication is that an average household would spend between $64.00 and $80.00 on kerosene annually. For a household on the upper poverty line of $365 per annum, kerosene alone constitutes between 17.53% and 21.92% of annual income.

Solar-powered compact fluorescent lamps (CFLs) and solar-powered LED lanterns are promising off-grid lighting alternatives to kerosene lighting systems in terms of quality of light output, economics, health and environmental impacts. However, the power consumption of CFLs is higher and this reflects in higher capacity solar modules, storage batteries and ultimately higher initial and replacement costs. LED lamps have the advantages of compactness, longer life, lower cost per unit of light output, lower initial and replacement.

This paper presents the results of technical and economic studies of selected solar-powered LED and CFL lanterns available on the Ghanaian market. The purpose of the studies is to assess their suitability as replacement for kerosene lanterns. The technical analysis was done by measuring the luminous flux of each lighting system on a flat surface measuring 1.2 m^2 using a portable lux meter. The economic analysis was based on a two-year simple payback period within which it is assumed that there would be no replacement of parts.

1.1. The case for solar-LED and -CFL lighting

Fig. 1 shows a comparison of achieved and projected bulb efficiencies of white LEDs, with other white light sources [7]. A strong increase is projected for LED efficiencies, while those of the other sources have saturated.

For over a decade, the state-of-the-art alternative to fuel-based lighting for the developing world has been solar photovoltaic panels powering relatively efficient compact fluorescent lamps (CFLs). The high wattages of these lamps necessitate costly lighting systems, the price of which are dominated by the solar panel and battery components, and scale with the power output needed. The retail costs of these systems to the end-user are often prohibitive; they may be on the order of the annual household income of the world's poorest households. As a result, the potential for these systems has remained highly dependent on subsidy. However,

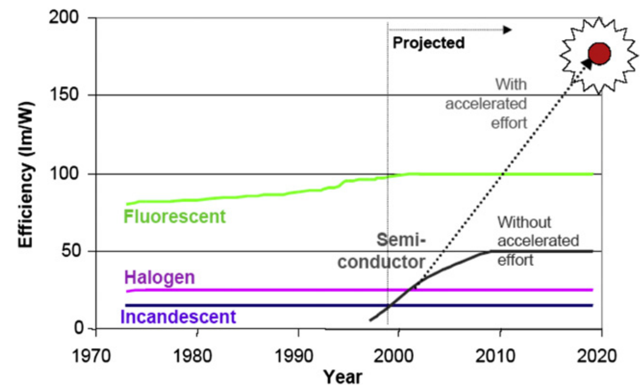

Fig. 1. Comparison of achieved and projected efficiencies of white LEDs with other white light sources [7].

recent advances in solid-state lighting technologies may afford a dramatic shift in the design and economics of solar-powered lighting, by requiring significantly less power and thus smaller solar panels and storage batteries.

The efficiency (lumens of light emitted per watt of power input) of solid-state LED lamps has increased dramatically in recent years, with white sources entering the market in the mid-1990s. The prototypical 1960s-era red indicator LEDs produced only about 0.1 lumens per watt (lpw), while today's best white LEDs approach 50 lpw. Sub-watt white LEDs attaining 100 lpw are expected in 2005. In contrast, the first-generation "keychain" white LEDs with which most consumers are familiar produced only 5 lpw.

LEDs providing over 200 lm/W have been demonstrated in laboratory tests and expected lifetimes of around 50,000 h are typical [8]. The luminous efficacy of available LED lamps does not typically exceed that of CFLs. The United States Department of Energy (DOE) testing of commercial LED lamps designed to replace incandescent or CFL lamps showed that average efficacy was still about 31 lm/W in 2008 (tested performance ranged from 4 lm/W to 62 lm/W) [9].

The only property of compact fluorescent lamps that could pose an added health risk is the *ultraviolet* and blue light emitted by such devices [10]. The worst that can happen is that this radiation could aggravate symptoms in people who already suffer rare skin conditions that make them exceptionally sensitive to light.

The UV radiation received from CFLs is too small to contribute to skin cancer and the use of double-envelope CFL lamps "largely or entirely" mitigates any other risks [10].

LEDs are also non-toxic unlike the more popular energy efficient bulb option: the compact fluorescent light (CFL) which contains traces of harmful mercury. While the amount of mercury in a CFL is small, introducing less into the environment is preferable.

2. Description of lanterns

The lanterns used in the study are shown in Fig. 2(a) and (b). They are designated (from left) as A (The Logic solar lantern), B (Goshen solar lantern), C (3 W LED Camping lantern), and the wick-type kerosene lantern. A fourth lantern used in the study, known as the Gentlite solar light and designated D, is shown in Fig. 2(b). The wick-type kerosene lantern is designated as K. Beside the main CFL lamp lantern D has three white LEDs for bedtime. Each of the lanterns has a power button with which it can be switched to low or high power mode. Lantern C is a LED lantern that runs on dry cell batteries (requiring four 1.5 V dry cell batteries to operate). Rural households often use the conventional wick-type kerosene lantern for domestic chores (cooking, heating, washing plates, micro-commercial activities, etc.) done before bedtime in high power