Off-Grid Country Lighting Assessments

Modelling Methodology for Energy and Financial Savings Potential from Switching to Solar LED lanterns

UNEP/GEF en.lighten initiative
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FOREWORD:

This report summarises the inputs and methodology followed in developing an estimate of the energy savings potential from switching to solar LED lanterns in 80 countries around the world. The Excel model developed for this purpose generates energy savings estimates based on electrification rates, population demographics and replacement of present off-grid technology mixes by solar LED lanterns. The authors respectfully request that any expert reviews of the model assess the reasonableness of the estimates and assumptions used as inputs to the model, particularly those relating to the market data.

For comments or questions about the off-grid CLA model, please contact:

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1 INTRODUCTION

The UNEP/GEF en.lighten off-grid lighting market model estimates the fuel-based off-grid lighting energy consumption and savings potential from switching to solar LED systems on a one-for-one replacement basis. The model attempts to quantify the savings potential and benefits for 80 countries around the world as their markets leap-frog from fuel-based lighting to efficient solar-LED solutions. The model is based on electrification rates and population demographics, and assigns off-grid technology mixes on a per-person basis based on a small collection of in-depth country studies.

This document presents some detail on the methodology utilised in Version 1.0 of the energy-use estimates. Reviewers are invited to comment below with suggestions for improvement, including supporting documentation (reports, spreadsheets, links, etc.) wherever possible.

The countries included in this first model are those with electrification rates less than 90% and a total population greater than 500,000. In addition, country reports were developed for Brazil, China, Mexico, the Philippines, Ukraine and Vietnam because although these countries have electrification rates higher than 90%, they also have a large population base so there are a large number of off-grid households.

Due to a lack of specific country-level data regarding critical inputs such as technology mix and luminaire price, we decided to clustered the countries modelled into five country groups (Ethiopia, Zambia, Ghana, Kenya, Tanzania), matching purchasing power parity (PPP) adjusted gross domestic product (GDP) per capita and numbers of off-grid population with the five countries that has data available. The clusters of countries is then manually adjusted based on the known status of a specific country (e.g. if a candle is accessible in the country).

The output from the model is a series of 80 country reports, each of which are two pages long, providing the country-level (i.e., national) savings potential, inputs and references used in the model. A screen capture showing one of the two-page reports is given below.

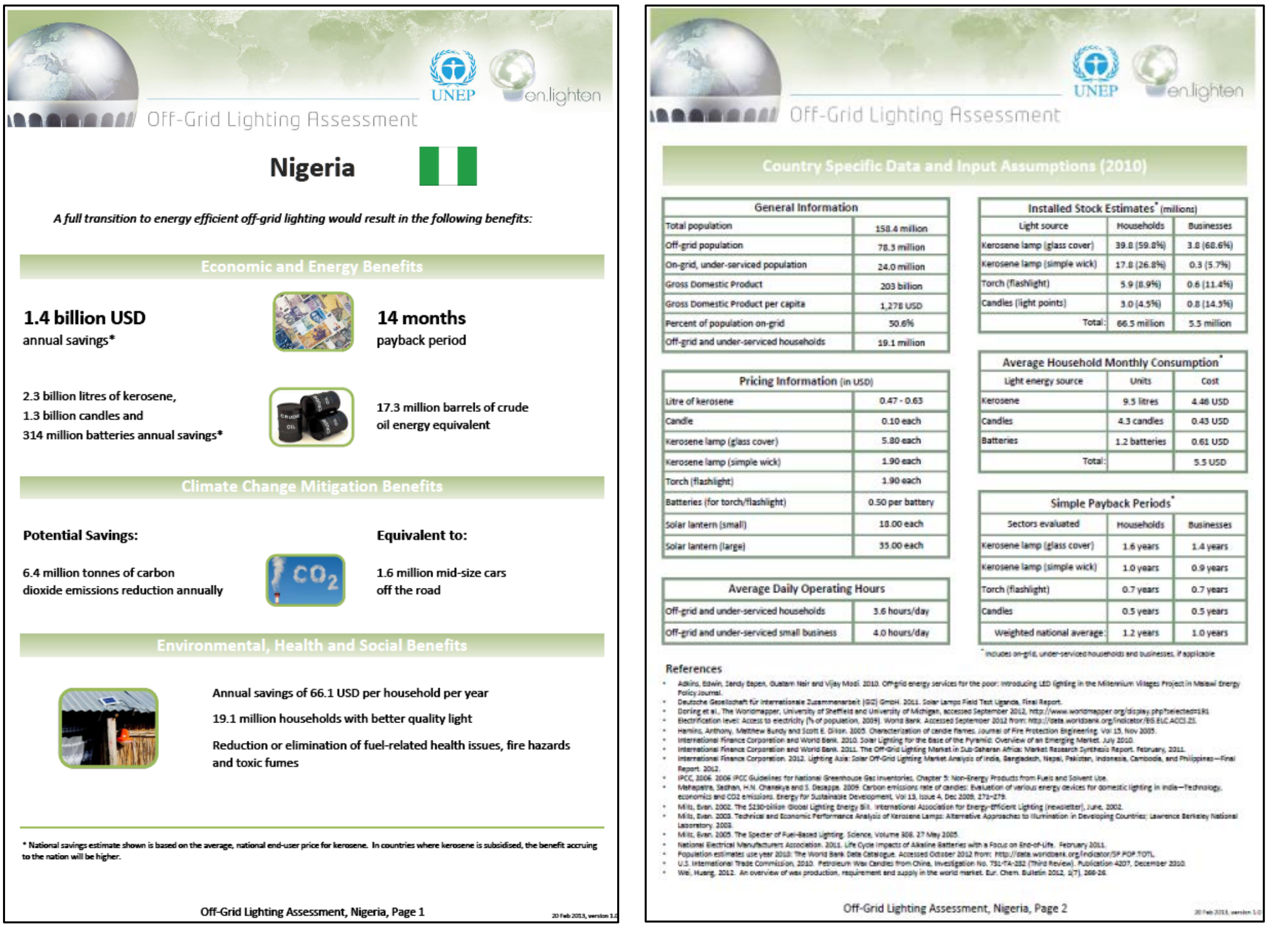

Figure 1-1. Sample Two Page Country Report on Off-Grid Lighting Assessment

2 MODEL INPUTS AND ASSUMPTIONS

This section describes some of the key input variables and assumptions used in the model.

POPULATION DATA

Population data - the population estimates are for the year 2010 and are taken from the World Bank Data Catalogue, visited October 2012.

HOUSEHOLD SIZE

The average household size (i.e., number of people per household) is estimated from data published by the Worldmapper Project, a collaborative effort of the University of Sheffield and the University of Michigan. These estimates are used to determine the number of households that are off-grid. It enables the easy conversion between the units of per person and per household, and for assessment of the 'reasonableness' of resultant estimates.

ELECTRIFICATION RATE

The electrification rates are for 2010 and are taken from the World Bank Data Catalog, visited October 2012 and the International Energy Agency's World Energy Outlook 2010. These data are supplemented with recent, reliable input from industry and national surveys. The electrification rate is used to determine whether a country is included in the study and (with the population data) to ascertain the number of people living off-grid in a particular country.

KEROSENE PRICE

The kerosene prices used in the model are meant to represent national average end-user prices. For government subsidized kerosene (as in India), the subsidy portion is not accounted for in the model or the financial benefits calculation, however it will be calculated and reported in the revised version of the model (v.2). Kerosene prices are gathered from numerous sources, including the Lighting Asia Report: Bottom of the Pyramid, the GTZ 2009 Regional Report, UNEP internal sources and national surveys. For countries where there no data is available on kerosene prices, a universal price of US$1.00 per litre is used. The model also considers a high-kerosene price scenario, meant to be representative of rural markets or others with distribution challenges that can increase price. For this sensitivity, a 35% increase over the reference price is applied. Results are therefore presented as a range, from the reference price to the high-price sensitivity.

OPERATING HOURS

The model estimates daily average operating hours for the lamps being used in domestic and small commercial applications. For the domestic sector (i.e., households), it is assumed that the average operating hours varies with the number of light points per household. As more light points become available, each light point on average will have lower operating hours. The range of operating hours was established after reviewing studies by Lighting Africa and other experts / organisations, quantifying the operating hours per day. The shape of the curve is defined by an S-curve function, with around 4.4 hours/day for households with one lamp and 3.0 hours/day for households with ten lamps. The shape of the curve is given below, and the operating hours used for each country are presented in the country reports. The equation for the S curve is:

$$OH = OH_{\max} - f_{s-curve} \times (OH_{\max} - OH_{\min})$$

$$f = \frac{1}{1 + e^{0.7 \times (3.25 - LH)}}$$

Where:

OH stands for Operating hours per day, $OH_{\min} = 3.0 hr / day$, $OH_{\max} = 4.5 hr / day$;
LH stands for lamps per household.

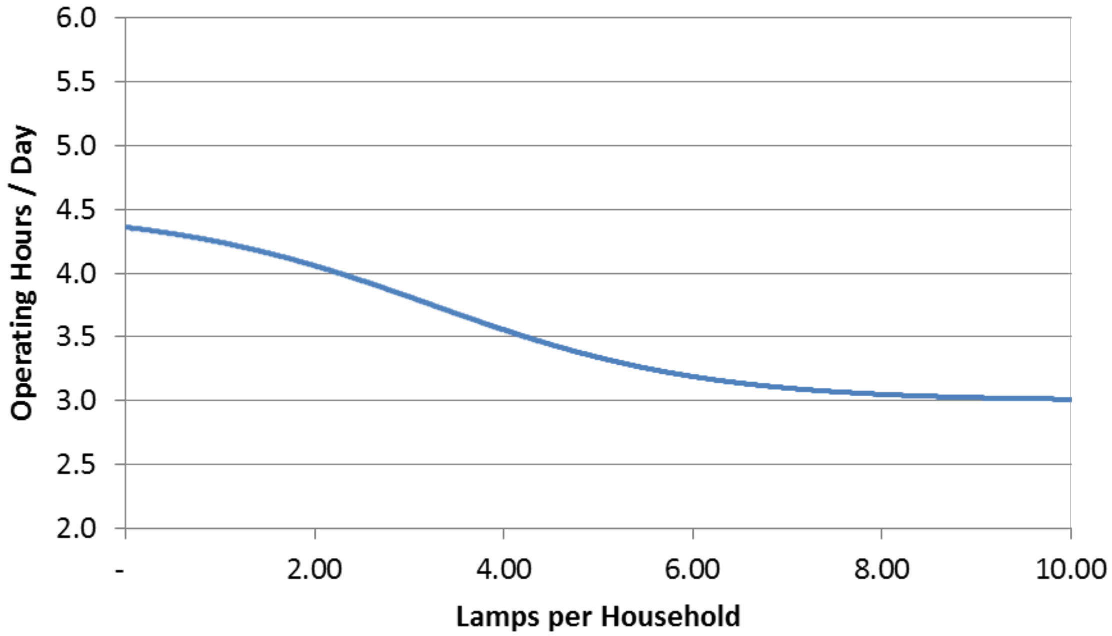

Figure 2-1. Estimate of Relationship between Operating Hours and Lamps per Household

For the commercial sector, it is assumed that lamps operate 4 hours per day.

TECHNOLOGY MIX

Technology is one of the most important assumptions in the model. It assigns a share of a particular technology to a household based on the clustered group of the country. The share of technology is based on Lighting Africa data from a detailed study of five African countries (Ethiopia, Ghana, Kenya, Tanzania, Zambia). Other studies were also assessed, but did not provide the same granular data that would have enabled these type of estimates.

The set-up for six off-grid lighting technologies of present technology mix are: kerosene with glass cover (hurricane lamp), kerosene with a simple wick, torch (flashlight), a battery-powered lightbulb on a wire and candles. It is assumed that in 2010 (the model baseline year), solar lantern market penetration is less than 1% and therefore is negligible. Data was used for both the residential sector (i.e., households) and the commercial sector (e.g., small businesses, market stalls).

The share of a particular technology to a household for the five countries are calculated based on a Lighting Africa survey of the potential lighting devices for those countries.

Table 1. Technology Mix for Five Country Groups, 2010 Estimates

Segment	Group Tech-mix	Kerosene with glass cover	Kerosene simple wick	Torch	Lightbulb	Candles	Nothing
Consumer	Ethiopia	12.1%	59.5%	8.6%	6.9%	3.4%	9.5%
	Ghana	62.6%	4.3%	10.4%	5.2%	15.7%	1.7%
	Kenya	55.8%	25.0%	8.3%	6.7%	4.2%	0.0%
	Tanzania	44.8%	22.4%	6.0%	7.5%	14.2%	5.2%
	Zambia	5.6%	7.5%	2.8%	5.6%	73.8%	4.7%
Small Business	Ethiopia	38.8%	35.5%	12.4%	5.8%	5.8%	1.7%
	Ghana	54.7%	6.3%	15.6%	8.6%	8.6%	6.3%
	Kenya	52.7%	4.4%	8.8%	11.0%	11.0%	12.1%
	Tanzania	62.5%	5.8%	7.5%	10.0%	10.0%	4.2%
	Zambia	8.9%	8.9%	13.3%	31.1%	31.1%	6.7%

LIGHTING POINTS PER PERSON

Light points per person (consumer segment only) - the number of light points per person living in the household for the five African countries is calculated using data from Lighting Africa study. The lamps per room are first calculated using the average lamps per room of a specified technology and the share of the technology of the household lighting. Rooms per household and person per household are then used to get the lighting points per person. The resultant number of light points per person is given for each of the five groups:

Ethiopia and Zambia	0.56 lamps/person;
Ghana	0.88 lamps/person;
Kenya	0.70 lamps/person;
Tanzania	0.65 lamps/person.

LIGHTING EQUIPMENT PRICES

Estimates of the end-user retail prices (in USD) for lighting equipment for seven different off-grid lighting technologies were prepared, based on Lighting Africa data from the detailed studies of five African countries (Ethiopia, Ghana, Kenya, Tanzania and Zambia) as well as other sources. These prices are only used for the pay-back period analysis and are not part of the total cost of lighting services calculation. The off-grid technologies are: kerosene with glass cover, kerosene with a simple wick, torch, a battery-powered light bulb on a wire, candles, and two solar LED lanterns - small and large. All of these prices are presented in the country reports, and are meant to represent national average retail prices.

Table 2. Luminaire Prices for Five Country Groups, 2010 Estimates

Group Lum. Price	Kerosene & Glass Cover	Kerosene Simple Wick	Torch	Batteries (per unit)	Candles (per unit)	Solar LED - Small	Solar LED - Larger
Ethiopia	$ 2.30	$ 1.20	$ 1.50	$ 0.50	$ 0.10	$ 18.00	$ 30.00
Ghana	$ 5.80	$ 1.90	$ 1.90	$ 0.50	$ 0.10	$ 18.00	$ 35.00
Kenya	$ 8.90	$ 0.80	$ 2.00	$ 0.50	$ 0.10	$ 18.00	$ 35.00
Tanzania	$ 5.00	$ 0.60	$ 1.50	$ 0.50	$ 0.10	$ 18.00	$ 35.00
Zambia	$ 2.50	$ 2.00	$ 1.30	$ 0.50	$ 0.10	$ 18.00	$ 35.00

Note that biomass fuels are currently not accounted for, but will be in revised edition of the model.

ENERGY CONSUMPTION RATE

A national average luminaire fuel consumption rate, the energy consumed by the light source in operation, is used. The model is set-up to track five fuel-consuming off-grid lighting technologies. The rate of fuel consumption is based on an hourly unit of service. However, because different forms of energy (e.g., battery, kerosene, wax) are used by different types of luminaires, the energy consumption rate and the lighting service rendered is different for different technologies. The unit for kerosene lamp with glass cover and kerosene lamp with a simple wick is litre of kerosene per hour, for torch is battery per hour (D-cell size) and for candles is litres of wax per hour.

Table 3. Energy Consumption rates for the Lighting Technologies

Segment	Kerosene with glass cover	Kerosene simple wick	Torch	Candles
	(litre/hour)	*(litre/hour)*	*(battery/hour)*	*(litre/hour)*
Consumer	0.030	0.025	0.036	0.007
Small Business	0.030	0.025	0.036	0.007

FRACTIONAL DISPLACEMENT OF FUEL BY OFF-GRID ELECTRIC LIGHTING

The model works by calculating the current consumption of kerosene, batteries and candles at a household level, and then substituting a solar LED lamp to replace each of those light points. In calculating costs, payback periods and CO2 reductions, this model is a one-for-one replacement assumption, and does not take into account the possibility of the fuel-based light source continuing to be used elsewhere in the household (note: where data are available on this effect, it would be most welcome). Thus, the savings estimates should be regarded as a technical potential, contingent on the efficacy of the underlying technologies as well as policies and deployment programmes.

DATA GAPS

The model does not take into account any of the public health costs associated with fuel-based lighting, such as poisonings, burns, explosions, house-fires, respiratory disease and so on. Any data or estimates on the frequency of this on a household basis per year or a fuel consumption basis per annum would be welcome. In addition, the model calculates the CO2 savings potential as an indicator of the benefits mitigating climate change, but the model does not yet incorporate the heat-adsorbing effect of black carbon (i.e., soot), which will be included in the revised edition of the model (v.2).

3 CALCULATIONS

The off-grid luminaire stock is calculated using the population, lamps per person and technology mix for each country. The number of off-grid users (OGU) is calculated as:

$$OGU = (1 - ER) \times P + \alpha \times ER \times P$$

Where:

OGU is off-grid user, representing the population using off-grid lighting
ER stands for electrification rate (percentage of those connected to the grid)
P stands for population
α stands for the percentage factor of under-serviced electrified households

The national stock of luminaires in the residential sector is then calculated using the estimated lamps per person:

$$TL_R = LPP \times OGU$$

Where:

TL_R is the total number of luminaires in the residential sector
LPP stands for lamps per person
OGU is the off-grid user, is the number of people using off-grid lighting

The national stock of luminaires in the commercial sector is set as a proportion of the national stock of luminaires in the residential sector.

$$TL_C = \beta \times TL_R$$

Where:

TL_C stands for total amount of luminaires in the commercial sector,
β stands for the proportion factor, which is set as 10% in the model

The off-grid stock of different technology for the residential and commercial sector is then calculated separately using the technology shares and the national stock of luminaires. Based on the off-grid stock, energy saving, CO_2 emission savings and the financial savings are then calculated.

ENERGY SAVINGS

Because the solar LED lantern uses solar energy for lighting, the energy saving potential is equal to the current energy consumption (the fuel consumption associated with lighting is displaced by solar energy and LEDs). Due to the fact that the kerosene lamp, torch and candle use different energy source (i.e., kerosene, battery and wax), the annual energy savings are calculated separately using the same methodology:

$$ES_T = \sum_S TL_{S,T} \times ECR_{S,T} \times OH_{S,T}$$

Where:

ES	energy savings
TL	total number of luminaires
ECR	energy consumption rate
OH	operating hours
S	sector
T	technology

The kerosene savings from kerosene with a glass cover and kerosene with a simple wick are summed together for the total kerosene savings potential in each country.

CO_2 SAVINGS

The annual CO_2 savings have been determined as follows:

$$EmS = \sum_T EF_T \times ES_T$$

Where:

EmS	Annual Emission Savings
EF	Emission Factor
ES	Annual Energy Savings
T	Technology

The emission factors were determined from referenced sources to be 2.6 kg CO_2 per litre kerosene, 3.81 kg CO_2 per litre candle, and 0.35 kg CO_2 released through the manufacturing of a D-cell battery.

COST SAVINGS

The cost savings are calculated from the operating cost of the light sources in the business as usual case. In other words, because the solar LED lanterns have no operating cost (i.e., free sunlight), the cost savings accruing to a household (and then rolled up to the country as a national savings estimate) equals the annual expenditure on kerosene, candles and batteries used to operate the poor-quality luminaires. The equation for this calculation is given below, taking into account three different off-grid energy sources for lighting.

$$CS = (K \times P_K) + (C \times P_C) + (B \times P_B)$$

Where:

CS	is the cost saving in USD per annum
K	is the annual consumption of kerosene in litres
P_K	is the average annual price of a litre of kerosene
C	is the annual consumption of candles
P_C	is the average annual price of a candle
B	is the annual consumption of batteries
P_B	is the average annual price of a battery

These and all the results of the off-grid lighting market analysis are then summed together and presented in a series of 80 two-page country reports.

4 REFERENCES USED FOR THIS MODEL

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