Why the Developing World is the Perfect Market Place for Solid State Lighting

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ABSTRACT

Much has been written about the daily challenge for survival faced by countless millions of developing world families and the overdeveloped world has offered a number of solutions by which those at the base of the economic pyramid (BOP) can help themselves. Light Up The World (LUTW), the global leader in bringing Renewable Energy (RE) based Solid State Lighting (SSL) to the developing world, offers yet another solution, and one that comes with a very high probability of success. In this paper we discuss: the critical role played by micro credit (banking for the poor); a typical example of a developing world community and their lighting needs and expenditures; how SSL can contribute positively to all eight of the Millennium Development Goals; the micro and macroeconomics of SSL at the BOP, its numerous societal benefits and its potential perverse outcomes; and thought there will always be a role for the donation based model, it is only through the market model that safe, healthy and affordable SSL will reach the majority of the BOP, such are the staggering numbers involved. LUTW's fundamental goal, through the facilitation of RE based SSL, is to improve the quality of life of those, who through no fault of their own, find themselves trapped in a cycle of poverty.

Keywords: solid state lighting, MDGs, microcredit, renewable energy, poverty alleviation

1. INTRODUCTION

One of the hottest topics of discussion around the world these days is that of energy efficiency, particularly electrical, and it is not before time! Unfortunately many of those who should be part of such discussions are themselves virtually without electrical energy of any sort, and particularly for lighting. In 1997 LUTW set out to try and rectify this situation since almost one third of humanity (i.e. approximately 2 billion people) have no access to electrical lighting. Its goal was to focus on lighting and lighting only, and not electricity since the term electricity brings up visions of televisions, electrical cooking, computers etc. and they all require much greater energy than simply lighting. The guiding principles from day one were that the form of electrical lighting to be offered to the BOP would have to be safe, healthy, rugged, affordable, and energy efficient, and in the main it would use renewable energy, since the majority of the BOP are not serviced by the electrical grid. LUTW developed its own primitive form of SSL using multicolored LEDs but it was Shuji Nakamura and his Nichia White LED that provided the eureka moment and the foundation upon which LUTW would truly start to light up the world. By 1999 LUTW had field tested their SSL systems in Nepal and with such an overwhelming level of success that in 2000 they permanently lit four Nepali villages – a world first. In 2001 villages were lit in Nepal, India and Sri Lanka and LUTW partners were simultaneously lighting villages in Guatemala, Irian Jaya and Bolivia and the rest is history!

LUTW facilitates the provision of safe, healthy, efficient and affordable home lighting systems to the developing world using RE based SSL in anticipation of promoting literacy, education, equality, and economic and human development. Working with local partners and international industry leaders around the globe, LUTW has demonstrated beyond question the economic feasibility of using SSL for BOP lighting and it has over 16,000 systems installed in 44 countries[1].

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1.1 Fuel Based Lighting

A typical kerosene wick lamp (Fig. 1 (a,b)) with a consumption rate of about 0.05 liters/hour will have a light output of approximately 10 lm (lumens) and this translates to an operating luminous efficiency of 0.02 lm/W. This is roughly one five hundredth of the efficiency of an incandescent bulb, the electric lighting source with the lowest efficiency (12lm/W)[2]. A few years ago researchers estimated that the global fuel based lighting cost was about US$38 billion/year or US$77/year per household[3]. LUTW's own data in, e.g. Afghanistan, Ghana, Pakistan and South Africa , show that families are spending well in excess of US $100 per year on kerosene, and unfortunately this is bound to increase given the dramatic rise in oil prices during 2008. On average the spending on lighting fuels can be as high as 20% of the monthly household income[4, 5]. Kerosene is frequently heavily subsidized in order to insulate the users from rising fossil fuel prices, and the level of subsidies can be as high as 50%. This imposes burdens on the national economy of a country because in order to provide subsidies the government must increase borrowings, raise additional revenue or reduce spending on other public goods and services. Fuel based lighting is very poor in light quality, quantity, it is unhealthy and extremely hazardous, and as we all know now, very expensive!

1.2 Solid State Home lighting systems

Since its invention by Shuji Nakamura the White Light Emitting Diode (WLED) has undergone dramatic improvements in terms of efficiency, lumen output and reliability. WLED efficiencies are presently in the range of 80-100 lm/W and the mean time to failure (MTTF) for a good quality WLED can be as high as 50,000 hours. Considering the power loss at the WLED driver circuit and the light loss at the luminaire, a 12V/1W WLED lamp can provide about 70-90 lm of light. It is very important to know the overall system, i.e. Wall Plug, efficiency, since this is what the user actually obtains and not the WLED efficiency. When one considers introducing SSL into developing world communities it is also important to appreciate that the costs and savings can not necessarily be compared directly with those occurring in the developed world, since SSL brings with it significant components of health, safety and increased disposable income. A typical SSL system consists of WLED lamps, a renewable energy source and an energy storage device (Fig. 2). Due to its universal availability and simplicity of use, the Photovoltaic (PV) panel is the preferred option as the power source for off grid applications. For storing the energy the 12 V, 7 Ah sealed lead acid battery is generally the best value for money[6]. A typical rural household can be illuminated to an acceptable level by using 2-3 WLED lamps each giving a light output of approximately 100 lm. Sufficient energy to operate a system with two 1W lamps can normally be obtained using a 5W PV module, assuming 4-5 hours of average lamp usage per 24 hours depending on the available solar energy resources. As WLED efficiencies will no doubt reach 140 – 150 lm/W in the very near future there is definitely a place for a "Pico" SS home lighting system consisting of, e.g. a single bright lamp with AA NiMH batteries and a 2 Watt PV panel or even smaller, since this will enable SSL to penetrate affordably even deeper into the BOP. All of LUTW's lamps have dimming as it is much desired by the users and focusing will follow[5]. Without the advantages of economies of scale the present hardware cost of a typical 2 lamp LUTW SSL system is approximately $150, with the average installed cost rising to around $200.

1.3 Health hazards and environmental impacts of fuel based lighting

The fuel based lighting sources can potentially cause severe health hazards in the form of burn accidents and indoor air pollution. Fires sparked by knocked over kerosene lamps are a major cause of bodily injury, death or property destruction among the rural villages in developing countries. Surveys conducted by LUTW in Nepal and Sri Lanka reported burn accidents of some degree once in every month due to kerosene lamps, where in most cases the victims are small children and women[4, 7]. Compared to burn accidents, a much greater health risk caused by kerosene lamps is the indoor air pollution. Kerosene lamp emits harmful gases such as carbon monoxide (CO), sulphur oxides (SOx), and nitrogen oxides (NOx) and also particulate matter (PM)[8, 9]. These pollutant emission rates of typical kerosene lamp are shown in Fig. 3(a). Of these pollutants CO is lethal to human and the others cause chronic respiratory illnesses and kerosene lamp users are continuously exposed to them (Fig.4 (a)). Kerosene lamps also emit greenhouse gases, mainly carbon dioxide CO_2. A liter of kerosene burnt emits 2.5kg of CO_2. Thus a household that uses about 5 liters of kerosene per month for lighting emits a tonne of CO_2 in about 6.5 years and a village of 100 houses emits 15 tonnes of CO_2 annually. SSL systems are emission free in their use phase and by replacing kerosene lighting with SSL the aforementioned health hazards can be avoided (Fig. 4(b)). Furthermore the avoided CO_2 emissions can be used as carbon credits and may be traded either in formal markets (e.g. Clean Development Mechanism), or in growing voluntary carbon market (e.g. Google, Nike, Yahoo), and thus they could be used to finance SSL implementations in the developing countries. It is most informative to appreciate both the initial energy required, and the CO_2 produced, during the manufacturing of the kerosene (Fig. 3(b)) since the use of SSL also removes these negative aspects.

2. SURVEY OF A 'TYPICAL' RURAL AFRICAN COMMUNITY

LUTW conducted a baseline assessment survey in a community in the bordering area of Rwanda, Uganda and the Democratic Republic of Congo in 2006. As a reference for this particular community the families have been categorized into three distinct income groups as follows[10]:

- Low Income: $0 to 40 per month ($480/year)
- Moderate Income: $40 to 100 per month ($480 - $1,200/year)
- High Income: greater than $100 per month ($1,200+/Year)

To get a sense of how important electricity was, or could be, to daily life the respondents were asked to rank order issues common to the entire community. Obtaining food and educating children ranked very highly a majority of the time. Health, water and security were ranked with secondary importance. Road transport was often given as another important issue. Electricity was ranked very highly by the majority of residents coming just after food as a top priority. Education was of great importance in nearly all households and it was very informative to learn that a majority of households (60-65%) with students indicated that kerosene lamps are used nightly for studying purposes. There is no question that household residents are universally concerned about the health effects of smoke in their homes and almost 90% of households reported a concern for the health effects. Comments often reflected a concern for the smoke of conventional kerosene lamps and a hope that electric lighting would relieve this source of pollution.

Source of Light: As is typical in the developing world households use a variety of lighting sources ranging from an open hearth fire to candles, from kerosene wick lamps and lanterns to flashlights (or torches). Kerosene wick lamps are significantly different from kerosene lanterns with the former consisting of a simple wick extruding from a container, such as a bottle or a tin can, partially filled with kerosene. The level of household income is a fairly accurate predictor of the type of lighting source used and although all income groups use open hearth fires for light in equal proportion, the High Income households are twice as likely to use kerosene lanterns and torches with batteries as are the Low Income households. All households in all income groups use wick lamps but their proportional use tends to drop in High Income households in favour of lanterns.

Expenditures on Lighting: The proportion of households using a specific type of light source and their expenditures were as follows: on average, 19% of all households use candles and 41% use torches and households pay an average of $1.02 for candles and $1.44 for batteries every month. Not surprisingly income level is a significant determinant of the amounts paid. A Low Income household using a wick lamp or lantern would spend on average $1.60 a month for kerosene; a Middle Income house would spend almost twice that ($3.00), while a High Income house nearly 4 times that amount ($6.00). With respect to lighting used for home businesses it was determined that households spend $3.23 a month on average, with spending ranging from $1.95 a month for Low Income houses to $8.21 for High Income houses.

Kerosene Lighting: The survey focused on kerosene lighting from wick lamps and lanterns since these would be the light source replaced in the main by the introduction of a LUTW Solar based Solid State Lighting (SSL) system. Most houses in the study area use kerosene for lighting; on average about 90%. Although houses have 4 to 6 rooms only High Income houses generally have more than 2 lamps or lanterns per house. Lamps are used an average of 3 hours a night. This is important since the LUTW SSL system comes with two WLED lamps which will operate up to 4 to 6 hours. These, therefore, can potentially replace all kerosene use in Low and Moderate income houses and this would result in monthly savings of $1.60 for Low Income, $2.13 Moderate Income and (assuming total kerosene replacement) $6.10 in High Income households. As a comparison it has been estimated that the average African household uses 55 or so liters of kerosene per year for lighting, at an approximate cost of £80 (US $158)[11].

Use of Lighting: Most of the families used light for household chores especially in the kitchen and bedroom and a majority of them also used light for socializing. Light is important particularly in High Income homes for studying, writing and / or reading. Lighting appears to have an important influence on income since only 10% of Low Income homes used light for income generation, whereas a significant 31% of High Income homes used light for income generation. This finding reinforces the intuitive belief that the more disposable funds that are available then the more entrepreneurial people can and will be! This has been confirmed to a high degree of confidence in other studies in various parts of the world. Lights are used in a variety of ways for income generation from preparing lessons, writing reports, serving and making beer, selling goods, tending animals, keeping potatoes, cutting hair, operating a health centre and more. One household used a solar panel to charge cell phones for profit indicating a growing trend in the region. Although respondents had difficulties ascribing a fixed sum of income attributable to having light, the data indicate that those reporting placed significance on income generation characteristics. Not only that, but the income generation potential of light has a greater impact in poorer houses. Comparing average income in the three groups indicates that households that used lights for income generation ascribed as much as 86% of their income to lighting in Low Income houses, and 32% in High Income houses. Income generation with lighting appears to have more impact in lower income classes.

Lighting Issues with Kerosene: Respondents were asked to identify problems and issues with their present lights. Responses were similar across all income groups and in the main people are concerned with first the cost and second the health and danger issues in using kerosene light. Poor luminosity and the lack of dependability are tertiary issues that around 50% of families identified. Other issues related to the inconvenience in having to clean and replace chimneys on lanterns.

Expectations of Electricity and Lighting: A small portion of the survey was used to gauge people's desires and expectations for electricity and especially improved lighting. Respondents were asked to name 3 ways in which they would use electricity if it were available. The highest number of responses was for lighting. People responded 31% of the time that they wanted "light". Others inferred the use of light in their response; reading, studying and writing (10%), security and health care (3%), socializing (2%). This means that over 45% of responses indicated that lighting would be a primary use of electricity if it was available. The category of Income Generation encompasses a further 6% of responses and at least part of these responses inferred lights used in commercial and retail establishments.

3. REFUGEE CAMPS AND THE USE OF SOLID STATE LIGHTING

By the end of 2006, the total population of concern to United Nations High Commission for Refugees (UNHCR) was estimated at 32.9 million persons, which included 9.9 million refugees; 744,000 asylum-seekers; 12.8 million internally displaced persons (IDPs) protected/assisted by UNHCR; 1.9 million IDPs who had returned to their place of origin in 2006; some 5.8 million stateless persons; and some 1 million others of concern[12]. As history has shown us time and again, today’s host may be tomorrow’s refugee. There is only one lesson to be taken from this—we ought to treat refugees as we ourselves would want to be treated. Refugee camps are supposed to provide adequate safety along with food and shelter but it is often the case that the ‘temporary’ homes in the camps are very poorly lit with kerosene wick lamps and there is typically no street lighting, thus allowing crimes such as robbery, assault and rape to be committed under the cover of darkness. It is therefore important to examine the appropriateness of using Renewable Energy based SSL in refugee camps from both an illumination and a cost viewpoint. Since most of the refugees are not likely to be earning any money the direct lighting costs must be borne by the relief community and this includes the purchase of kerosene, electrical generators, lamps, batteries etc., plus the associated transportation and distribution (air & road). A typical kerosene lamp operating for 4 hours per 24 hour period may consume around 60 liters of fuel per year, and as many refugee camps contain thousands, if not tens of thousands, of homes then supplying fuel based lighting 12 months per year is a nontrivial and very expensive task, especially with the price of oil almost doubling in the last year. It is well known from bitter experience that fuel based lighting is the source of numerous tragic shanty town fires every year and the air quality in such homes is very unhealthy to say the least. Given the overall costs, dangers and problems associated with fuel based lighting it is not difficult to intuitively conclude that SSL may be quite appropriate for use in refugee camps. The reality is that SSL is in fact an almost perfect fit for use in refugee camps, because it can be used for both homes and street lighting, it is safe, healthy, rugged, durable and very cost effective, and the Solar Panels and SS lamps are good for 20 years with the batteries only required to be replaced every three or four years. Table 1 shows a comprehensive list of lighting objectives and considerations for refugee camps and it shows how well SSL fits such an environment (Table 1 is developed based on the refugee camp lighting considerations presented by Mills[13]) .

Table 1 – Lighting objectives of refugee camps and considerations (based on [11])

Refugee camp objective	SSL Lighting Considerations
Provide adequate and durable administrative, outdoor, common area services	Administrative, outdoor, and common areas require illumination. Solid State Lighting systems (using white LEDs) are longer-lived, more rugged and less expensive to operate than traditional lighting solutions.
Minimize reliability on external resource imports.	Typical light sources require a steady stream of "imports" to the camp, including kerosene fuel, wicks, batteries, replacement bulbs, etc.
Sustain family and other social cohesion.	Social interaction typically requires lighting. Temporary family shelters often have no light.
Provide for schools, places of worship, and play areas for Children.	Adequate illumination is essential for schools, places of worship, and safe play areas. Flame based light is inadequate for reading and many other learning tasks.
Preserve individuals' dignity.	Individually controlled lighting provides control of privacy.
Ensure refugee safety, both inside and outside of shelters.	Lighting is a very important element of personal safety, especially for women and children. SSL systems eliminate fire-risks from kerosene lighting and are easily portable.
Support efforts at re-establishing livelihood.	The availability of lighting supports home based cottage industry after daylight hours.
Promote self-sufficiency.	PV-powered LED systems require a minimum of externally provided parts (batteries every second or third year) and no fuel.
Minimize vulnerability to disasters affecting camps.	PV-powered LED systems are not susceptible to disrupted kerosene or electricity supply lines.
Fortify occupants for future disasters.	If camp residents take the LED systems back to their permanent settlements, they will be better prepared for future disasters.
Minimize environmental impacts of establishing, operating, and decommissioning refugee camps.	Electric, fuel-based, and (non-rechargeable) battery-based lighting entail significant environmental impacts, including generator emissions and noise pollution, fuel spillage, and solid waste production/disposal.
Minimize vector and other disease risks.	Illumination in the yellow-red spectrum assists mosquito control, which is a need in many camps. LEDs can be 'tuned' to virtually any wavelength and intensity of light output. WLED lighting tends to decrease the presence of insects, lizards etc. as it has virtually no UV and IR energy.
Provide culturally responsive conditions for burial.	Some cultures require a period of continual light on the graves of the deceased. SSL systems would provide a lower-cost alternative.
Place priority on sheltering disaster victims "in-place", with relocation to remote encampments as a last resort.	While not a panacea, pre-disaster distribution of SSL systems would support the shelter-in-place goals of disaster response.
Cost-efficiently provide essential relief services.	SSL systems eliminate the need for camp space dedicated to power production, storage and distribution of batteries, fuel, etc. They also reduce the volume and weight of material requiring air and ground transport.
Mobile lighting at night.	WLED torches offer great costs savings, are effectively unbreakable and batteries and bulbs last 'ten' times longer.
Street lighting.	SSL has many advantages over fluorescent and incandescent due to its lower energy usage, long life, low maintenance and constantly increasing efficacy (brightness). It also enhances safety at night.
Fresh vegetables.	LEDs of various wavelengths may be used to grow vegetables in winter months at low energy cost.
Improved health.	SSL is healthier than fuel based lighting since there is no exposed flame and smoking wick. Serious visual and breathing problems are endemic in countries where fuel based lighting is used.

3.1 Refugee camps in Sri Lanka and Nepal

In 2005 LUTW demonstrated the appropriateness of SSL for refugee camps when it supplied 3,000 complete lighting systems to displacement camps in the coastal regions of Sri Lanka immediately after the tragic and devastating tsunami. In partnership with a local company, Crystal Electronics, every single lighting system was manufactured in Colombo, thus keeping the majority of the funding in country and creating additional skilled employment. The typical LUTW

"Light in a Box" system consisted of a 5 W solar panel; two 1 W white LED (WLED) lamps with low voltage cut-off to increase the life of the battery, and a dimming capability which the users loved; and one 12 V - 7 Ah sealed lead acid battery with short circuit protection. Considering the exceptional circumstances and the need to work as quickly as humanly possible, it is estimated that the average cost of lighting each displacement camp home was around $140 and it could have been so much smaller if LUTW had been able to achieve some reasonable economies of scale.

In 2006, in partnership with local Kathmandu company, Pico Power Nepal (PPN), a LUTW initiated project led to the lighting of a significant number of street junctions in the Damak ('Butanese') refugee camp on the eastern border of Nepal (Fig. 5). Each stand alone system consisted of a 21 W Kyocera solar panel, a 12 V - 30 Ah Trojan deep cycle lead acid battery, a lamp containing 6 x Luxeon Star WLEDs, charge controller and low voltage cut-off circuits, and it was placed on top of a 5 meter pole. The intensity specifications were based on using the full moon as a reference and this is approximately 0.5 lux. The PPN street lamp gave 0.5 lux on the ground at a distance of 75 meters from the light pole, which is enough to see relatively small objects and persons. This project increased night time safety in the camp very significantly and it was deemed a complete success by the UNHCR and Lutheran World Federation partners. The average installed cost of lighting each street junction was approximately $427.

A recently completed LUTW in house project has shown that a PV powered SSL street lamp incorporating 6 x Cree XLamp XR-E WLEDs, will provide an acceptable performance for use in rural areas in the developing world, and can be built at a Total Life Cycle Cost of approximately $570[14].

It is also important to keep in mind that an appropriate SSL package for a refugee home may be in fact be smaller than the classic LUTW "Light in a Box", thus it may consist of: one 3 W solar panel, one 1 W WLED lamp and one 4 Ah SLA battery, plus one WLED torch. In today's market the hardware cost of such a SSL system would be less than $60.00 in small numbers, and the cost of the WLED torch would be approximately $3.00.

4. SOCIO-ECONOMIC IMPACT OF SSL

The social and economic impact of solid state lighting in communities not connected to the electrical grid is multi-dimensional and complex. To more effectively evaluate the many affects of SSL on communities, the analysis is divided into three parts: the microeconomic impact, macroeconomic impact and the political economy of SSL. Evaluation of the microeconomic impact is further disaggregated by exploring the household and community affects separately. The focus on the household looks at the impact of SSL on the family as a social unit. The community level assessment attempts to aggregate the various household level affects, and by doing so, make inferences about how changes may affect the community as a whole. The community level investigation also comments on how SSL in the home may influence other institutions in the community. The macroeconomic impact focuses on how changes at the community level, in particular to consumption habits, may influence macroeconomic conditions in a country. The political economy of SSL explores how the political and economic organizations around SSL may interact with those set up around goods and services related to existing forms of lighting. The social impact is discussed throughout these sections.

In evaluating the socio-economic impact of lighting in developing countries, it is critical to be aware of the types of lighting which are being used and how lighting is used in the home and in communities. The impact of solar powered LED lighting systems on a community depends, to a large extent, on the features of the source of lighting it is displacing. For this paper, the affects of SSL are evaluated as if they were to replace kerosene as the primary source of lighting in the home.

The economic affects discussed below are based on households obtaining SSL systems through microcredit loans delivered by microfinance institutions (MFIs). For households that purchase SSL systems with borrowed funds, repayment schedules for loans are designed to match kerosene expenditure levels that the household maintained prior to obtaining the SSL system. This is critical to understanding the range of social and economic impacts of SSL. For instance, if SSL systems were donated to communities where the cash economy is less mature and households do not pay for lighting in the home, a switch to SSL on its own would not generate any of the financial benefits that it does for households who pay for lighting. For this reason, it is crucial to acknowledge the role of micro credit.

4.1 Microeconomic Impact

Many of the benefits from an improved lighting source in the home are immediate. Other advantages of the system, however, do not begin to take hold until the loan for the SSL system is repaid in full by the household. For this reason, the immediate and laggard economic impacts are discussed separately. Understanding and even predicting the social and economic outcomes requires an awareness of the institutions, values, power structures, resources, geographical features of the community as well as the transactions that take place around lighting. The economic impact of SSL systems depends on the features and structures of the economy and the established supply networks in the area where it is being introduced. The impacts also depend on how consumption habits of the community change. For these reasons it is not unreasonable to expect that the outcomes of introducing SSL will be different between societies and even villages in the same society. Fig. 6(a) shows the approximate annual lighting expenditures in US $ for various LUTW countries.

4.1.1 Household level

a) Immediate Impact

By replacing poor quality lighting in the home, SSL first and foremost, provides the conditions for people to be active for more hours over a 24 hour period. During this time, individuals and families will either take part in new activities or spend more time on activities that they engage in normally. By adding more productive hours in which activities can be done, SSL is transformational as it alters the habits and practices of people. This change leads to the various other immediate affects discussed below.

Impact on Education: Better lighting in the home will immediately improve conditions for education for students in the home. As Mills found that even in “optimal” conditions, kerosene provides approximately 6 lux (at one metre distance), which is far below recommended levels[3]. With approximately 100 lux at one metre distance, the LUTW SSL system offers superior conditions for activities such as reading, which is a key component of formal education. As one user of a LUTW designed SSL system in Sri Lanka stated: *“the doctor told me not to let my son study at night, because the smoke from the kerosene would make his asthma worse. Now that we have LEDs he can study at night”*.

Impact on Health and Safety: As the burning of kerosene causes a significant amount of air pollution in the home, switching to a SSL system promises significant health benefits. Kerosene ingestion is another negative health affect that can take place when kerosene is mistaken for a consumable drink. The cost of visiting a clinic to receive treatment for kerosene ingestion can be substantial for low-income families. It is also accepted by some that LED are less likely to attract insects than other types of lighting because they emit little infrared and ultraviolet light. Attracting fewer mosquitoes into the home, which may be carrying malaria, is another impact of SSL that is noteworthy. Kerosene is highly flammable and has been the cause of many fires in homes: causing destruction, loss of property, injury and in some cases, death. The chance of starting a fire with a SSL system is marginal and would only be possible by tampering with the battery. Lighting in the home is likely to improve home security as it may deter undesirable activities taking place in areas that are well lit.

Impact on the Environment: Compounding the positive affects for the family, avoiding burning kerosene for lighting has clear benefits for the environment. As discussed above, the environmental impact of LED lighting is far lower than that of kerosene based lighting[15]. Some other positive affects are the reduction of deforestation required as the industry for matches for lighting experiences lower demand.

Impact on Opportunities for Home Enterprise: The general outcome of SSL is that it provides a higher quality and quantity of lighting in the home at a lower average cost, which increases the number of productive hours in the day. As this time may be used for entrepreneurial activities, it is arguable that another outcome of SSL systems in the home are the increased opportunities for home business. More opportunities for home businesses may translate into greater earning potential for families, which may lead to greater financial wealth of the family.

Perverse Outcomes: It must be acknowledged that while there are many immediate positive outcomes that may result from the introduction of SSL, there are also others which may be viewed as less positive by some members of society. For instance, greater opportunities for microenterprise in the home may be attractive to some family members, but others may not welcome the change if more time working result s in less time for leisure or family. Signs of wealth in the home may also have the unintended outcome of attracting unwanted attention from criminal elements in society.

b) Laggard Impact

As the micro credit loans that were disbursed to pay for the lighting systems are repaid in full, the impact of SSL becomes more financial in nature. This takes place as households save money that they were habitually spending on kerosene for lighting, and for a period of time, were using to pay down their loan for the SSL system. The expenditure on kerosene can be as high as 20% of the monthly income of the household yet the quality of the lighting is very poor and inadequate for many uses[5]. A poor rural family in the developing world pays approximately the same of what a North American family pays for lighting services, but receives less than 0.2% of the light (Lumen-Hours). The long life of SSL, low power requirements and low ongoing maintenance costs result in significant savings for poor families. This is referred to as the laggard impact of SSL. Stemming from the cost savings, the laggard affects complement the immediate affects of SSL. Cost savings translate into greater disposable income for the household. Cost savings depend on many community and household specific factors; however, the most important is the amount of money that is expended on a regular basis for kerosene to light the home. For low-income households, the cost savings resulting from changing to SSL from fuel based lighting, in many cases, are arguably the most overwhelming affects. This has been demonstrated in the Shanty Towns of South Africa where a significant amount of a household's resources are expended on kerosene and candles for home lighting. In most cases, households spend between 10 - 15 Rand (approximately $1.25 - $2 USD) per week on fuel based lighting. In some households, however, kerosene expenditures can exceed 30 (approximately $4 USD) Rand per week. In addition, many people also spend around 8 Rand (approximately $1 USD) per week to charge their cellular phones at street kiosks. Consequently, SSL systems that are designed to have an auxiliary output for other devices, such as cell phone charging, have the potential to amplify the positive economic impact as users are able to save a greater proportion of their income.

Impact on Savings: With a greater proportion of disposable income with which to use to improve the welfare of the household, it is likely that most households would save at least a portion of their disposable income that is the product of their investment in SSL. As poverty can be characterized in part as an inability to respond to crises due to a lack of financial resources, by holding more savings, households are likely to be better equipped to avoid the negative outcomes associated with economic strife. By maintaining resources that can facilitate a response in times of financial difficulty, low income households may be able to reduce some of the volatility in their lives, making them less vulnerable to the vagaries of life. In general, higher saving rates would have a positive impact on the household.

Impact on Food Intake and Nutrition: Another likely outcome is for households to spend a portion of their new disposable income on food consumption. By increasing the average caloric intake of each family member, the family is likely improving the chances that family members will achieve greater success in their profession or studies. Better nutrition may have multiple positive effects on the family, society and hence the local economy. For instance, if children are eating healthier, they are likely to have more energy, which is likely to have a positive impact on their studies. Similarly, a more healthy working population may achieve more in the workplace, leading to greater productivity and possibly greater incomes.

Impact on Education: Greater disposable income may also be spent in part on educating a child to a greater level than would have been possible otherwise because of financial limitations. With economic theory arguing that education is critical to economic growth, it is arguable that the useful amount of light provided by SSL will stimulate additional economic activity at the community level over the long term.

Impact on Health: Extra money in the home will enable households to be better able to respond to medical emergencies as they will have more financial resources to care for family members that are ill. Greater financial resources may also entice families to purchase mosquito nets, better quality medicines, and treadle water pumps which can provide access to clean water thus decreasing the incidence of many water borne diseases.

Impact on Investing and Wealth Creation: Fig. 6(b) shows the cumulative savings with the introduction of SSL to a shanty town household in South Africa. Households may accumulate this disposable income to invest in physical assets or real estate. Such investments may provide people with a safety blanket for challenging economic times and provide an opportunity to earn additional income and escape extreme poverty. The SSL system is itself a physical asset with a long functional life. Possessing this asset provides additional benefits to the household that owns it as the SSL system could be sold in case of family crisis. In contrast to kerosene lighting, which is expended entirely upon use, (i.e. entirely up in smoke) the SSL system has a significant advantage over the petroleum product. The overall laggard affect on the household will vary based on how they choose to allocate the greater portion of the extra disposable income that is the result of their investment in SSL. In practice, the breakdown of expenditures on consumable goods and services such as food, education, other household assets, equipment, medical bills, cultural celebrations will depend on the priorities of the household, their values, and influences in their society.

4.1.2 Community level

As this section assumes that SSL would be replacing kerosene as a source of lighting, those in the community that depend on the sale of kerosene for lighting will likely be opposed to any program that jeopardizes their source of income. This is discussed below in the Political Economy of SSL.

a) Immediate Impact

Impact on Business Activities and Employment: The impact of SSL on business activities in the community is multi-faceted. As households change their primary source of lighting fuel from kerosene to SSL, demand for kerosene will drop. Lower kerosene consumption levels, in isolation of other economic activity, would result in lower sales revenue for those involved in the sale of the commodity in the community. Fewer sales would result in lower incomes. Lower incomes would start at the retail level and work its way up the supply chain up to the companies that are involved in the extraction of the resource. That is, if the only outcome to take place in a community following the introduction of SSL is an increase in savings and no new economic activity is established, then an economy will contract. The chances of this happening in practice, however, especially with the transformational change in a society such as the advent of widespread community and home lighting, are highly improbable. For instance, by providing a more affordable and efficient source of lighting SSL systems provide businesses with the means to operate later into the evening. The brighter light may also give the impression to customers that markets are a safe place to go to in the evening, resulting in higher sales. SSL may also result in the creation of new business opportunities that did not exist in the community before electric lighting was available.

Entrepreneurs with a technical background may develop their own SSL products to meet other lighting needs of residents in the community. PPN and Crystal Electronics are examples of this. This transfer of technology may have other multiplier effects and a significant portion of the value added during the manufacture of the product would increase incomes in the community.

Impact on Social and Cultural Enrichment: There is some field evidence which suggests that communities may choose to spend the extra hours in which they have lighting over the course of a day to spend socially with each other and to dedicate to cultural practices. As a result, an outcome of SSL may be more frequent practice of cultural activities and/or the strengthening of social ties.

b) Laggard Impact

Impact on Growth: An increase in disposable income will undoubtedly lead to a general increase in demand for goods and services in the community. If supply bottlenecks are present for certain goods or services, then a higher supply of money in the economy, in the form of newly established disposable income, will lead to inflationary pressures for those items. It is argued, however, that some inflation is necessary for economic growth to occur because it signals to entrepreneurs that there are opportunities for profit, which influence them to enter the market. If there are no structural features of the economy that would inhibit this activity, prices are likely to increase in the short term, but should then stabilize over the medium term as more supply networks are established.

As businesses begin to increase their savings by switching from fuel based lighting to SSL, their retained profits will increase, an outcome which may enable them to invest in more capital equipment. Investments in capital equipment are likely to increase the economic productivity of businesses. Increased economy activity that results from new markets being established in a community is also likely to have a positive impact on employment opportunities.

Impact on the Financial Sector and Taxation: The financial system in a community has the ability to allocate resources between savers and borrowers more efficiency in a community. The impact of SSL depends on the maturity of the financial sector in the community and the financial products that are offered. If the formal financial sector is relatively well functioning, then households may be more inclined to deposit their savings into bank accounts, leading to a greater pool of capital available to the banks. As more disposable income is available to people, there is an opportunity for the municipal government to collect more revenue from residents. The potential affects of SSL on the financial sector and taxation are diverse and are not explored in detail in this paper.

Perverse Outcomes: As was mentioned above, as the first households are able to pay off their loans for the SSL systems, there are inflationary pressures for the most highly demanded goods and services. If the supply bottlenecks are many or the response by entrepreneurs in the community to price signals is slow, then higher prices may persist into the medium to long term. If this takes place then the primary benefit of increased savings for households will be eroded by lower purchasing power. Price increases will have an even more pronounced negative impact for families that made a decision to not purchase the SSL system.

A perverse outcome for the environment as a result of introducing LED lighting systems is that as households save more money from reduced kerosene consumption, they may choose to spend more money on food, and in effect, more of their income on kerosene for cooking if it is typically used for this purpose. In addition, as it is assumed that SSL will result in people in the home staying awake for longer hours than before, it is possible that they may consume other goods that have a negative affect on the environment. For instance, in communities with colder weather, households may choose to cut down more trees for firewood so they can stay warm while they are awake.

While cultural enrichment may be a positive outcome of SSL, as light is a transformational change in the community, it may alter cultural institutions in a community in a way that may be viewed as detrimental as well to the society or cultural practices.

4.2 Macroeconomic Impact

SSL has the potential to transform the social and economic structures not only at the household and community levels, but also at the national level. The macroeconomic impact of SSL focuses on changes to a country's balance of payments, which are the sum of monetary transactions between a country and the rest of the world. As most, if not all, of the components of the SSL systems will be imported goods, their initial purchase will drive up demand for foreign exchange. This will add pressure for the price of the foreign exchange used to purchases systems to increase relative to the domestic currency in the short term. In a free-floating exchange rate regime, this may stimulate some depreciation of the local currency, however, as many developing countries actively manage exchange rate movements, the decision to manipulate the rate would be political and not necessary based on supply and demand forces. If no move is made, then the outcome may be a premium charged for foreign exchange in the kerb markets. However, because the cost of the system for the household is in many cases equivalent to the cost of importing kerosene over a 1-2 year period, the demand for foreign exchange would increase only initially and demand conditions for foreign exchange would ease and likely swing in favor of the domestic currency once the systems have been repaid. The final outcome for both net importing and exporting countries are likely to be similar: a general appreciation of the domestic currency in the medium to long term.

Another positive outcome of currency appreciation is the favourable affect that it can have on companies, individuals and government bodies that hold debt held in foreign currencies. Relative appreciation enables these agents to pay off loans with a lower amount of currency than would otherwise be needed if currencies were trading at fixed levels. Foreign debt in many countries that have a limited electrical grid network are burdensome and account for a significant portion of the government's annual expenditures. If governments are able to reduce foreign debt levels, they are likely to have more resources for other priority investments such as infrastructure, education and health care.

At the aggregate level, inflation can be caused by various factors in an economy. If inflation is linked to a volatile exchange rate and low foreign exchange reserves, then replacing fuel based products for lighting with solar powered LED systems could reduce national inflation and stimulate a number of other service sectors in the economy.

In countries where the government provides subsidies for kerosene, SSL has the potential to significantly alter government expenditure. As households gain access to SSL systems for lighting, their demand for kerosene will decrease. If subsidies are no longer necessary for at least a portion of the population, the government will save a considerable amount of financial resources, which can then be allocated to some of the other priority areas as mentioned above. At the microeconomic level, the cost savings in a country where kerosene is highly subsidized will be lower than in those where the subsidy is lower or nonexistent. Where subsidies are high, the macroeconomic impact will be more significant than the microeconomic impact.

Perverse Outcomes: Appreciation of the domestic currency can have a variety of economic affects. It is also important to consider the velocity at which a currency appreciates as the rate of change is more likely to affect economic outcomes than currency appreciation on its own. One perverse outcome is that if currency appreciation happens too quickly, companies may not be able to adapt and take advantage of the benefits of the change in exchange rates, and as a result, may experience greater difficulty competing with companies in other countries as their products become relatively more expensive.

4.3 The Political Economic Considerations

As Mills estimated, the global household-sector use of fuel based lighting is responsible for annual energy consumption of 96 billion litres of kerosene[3]. This is equivalent to 1.7 million barrels of oil per day. With these numbers in mind, it is clear that the market for kerosene is mature and well-functioning. It has an established value chain, collection systems, and supported by distribution network for lighting infrastructure (i.e. lanterns) that has available technical support, access to spare parts, and repair services. The kerosene market is highly profitable and supports a large network of businesses, institutions, and small scale entrepreneurial middlemen who add a small margin to each litre of fuel that they sell to consumers throughout the world. With so many vested interests in the continuation of the delivery of this product, it is understandable that the case for SSL as a substitute to kerosene must be overwhelming.

Considering this affect, if those involved in kerosene sales hold strategic power on any community or municipal government, programs introducing the use of solar powered LED lighting systems, no matter how beneficial they may be, may be outright rejected or at a minimum stalled. In the case of kerosene, however, as it is also used by many households for other purposes such as cooking, merchants involved in the sale of kerosene may not object to the new technology outright as it will not completely eliminate the sale of the fuel. It is also important to consider that as the introduction of SSL is a gradual process, the threat to anchored industries may go relatively unnoticed at least in the short term.

As mentioned earlier in the paper, the market for kerosene is in many cases artificially leveraged by government subsidies where they have been put in place to meet a variety of objectives. However, once in place, kerosene becomes accepted as a basic good and the subsidy to purchase it becomes too politically destructive to remove. As a result, many governments are handicapped by their subsidy commitments. In cases where a government is no longer able or willing to support a subsidy, increasing prices are often met with resistance, riots, and political upheaval. Accordingly, the ability of countries to move beyond kerosene as a fuel for lighting provides great promise for the governments to improve social conditions in a country as more resources are available for allocation to priority areas. It holds the potential to enhance political stability as well.

While households who have obtained SSL systems and are no longer relying on kerosene for lighting in the home, business agents involved in the sale of kerosene (and other lighting sources) will experience lower income as a result of lower demand for their product.

It is also important to consider that the penetration of SSL into the community will depend on the development of services that facilitate the acquisition and maintenance of SSL systems. Therefore, the impact ultimately depends on the ability of solar LED systems to establish or converge with existing distribution networks.

5. CONTRIBUTIONS TO MILLENNIUM DEVELOPMENT GOALS (MDGS)

Through promotion of SSL technology LUTW is addressing serious socio-economic and environmental problems in the developing world and beyond. The reported benefits of SSL technology being used as a development tool in the developing countries include improved living conditions, enhanced safety and health, improved physical environment, ability to read and study after sunset and operate cottage industries by night. Given the potential impact of SSL technology on the wellbeing of the poor, there is no question that SSL is an important tool in achieving the Millennium Development Goals (MDGs).

Goal 1: Eradicate extreme poverty and hunger: SSL technology helps to break the entrenched cycle of poverty by providing significantly improved levels of lighting in homes. By replacing expensive and inefficient kerosene and other non-electric light sources used in developing countries SSL provides an increase in family disposable annual income. Lighting in the home has also proven to stimulate home enterprise, which can enhance the income earning potential of families (Fig. 7(a)). Both outcomes reduce the likelihood that a family would go hungry and suffer extreme poverty.

Goal 2: Achieve universal primary education: LUTW's primary reason for lighting up homes and villages is to promote literacy and education since illiteracy is one of the root causes of poverty. In many regions of the world, children must work and cannot study during the day. In the evenings they will read by kerosene lamps and candles which are inefficient (only a few lumens) and unsafe lighting sources. The light from kerosene lamps is so dim that children can only see their schoolbooks if they are almost on top of the flame, directly inhaling even more of the toxic fumes [6].

SSL lighting provides more than enough light for a child to read and write by (Fig. 7(b)). It is also safe and healthy lighting with no heat fracture of the lamp body and spillage of kerosene that result in countless injuries. SSL is essential if children are going to be able to reach their true academic potential, with all the social and economic opportunities that offers. Furthermore, many studies have found strong correlation between female literacy and fertility rates. As education among women improves, fertility rates tend to drop. Therefore, providing opportunities for learning among women in a safe and healthy environment can be viewed as one of the ways to stabilize the population growth.

Goal 3: Promote gender equality and empower women: The San Jose Technology Museum has recognized LUTW with the Knight Ridder Equality award for its work in advancing and advocating the use of SSL for providing a small solution to large problems of inequality. In many developing countries, women carry the bulk of the productive, reproductive and community organization roles but have limited political power and social status. Adding to their responsibility, for example, Nepalese women spend several hours a day scouring the landscape for scarce firewood. Others trek for 2-7 days to reach the nearest kerosene depot only to find that no fuel is available or it is too expensive[16]. LUTW works to address the issues of gender inequality by using solid state lighting as a community development tool. Women can create microenterprises run in the evenings and earn their own income. SSL and micro entrepreneurship go hand in hand and women can easily learn to manufacture, sell and install SSL systems. Rural community based solar powered battery charging stations for SSL can be owned and operated by women, thus empowering them. Together with partners LUTW encourages and trains women to take active and often leading roles in the project planning and implementation (Fig. 8).

Goal 4: Reduce child mortality: LUTW provides safe, reliable and long lasting SSL lighting which reduces air pollution in the home while enhancing safety and improving health conditions. It has been reported that in each village where kerosene lamps were replaced with LUTW the air quality in homes dramatically improved (Fig. 4(b)). Improvement in indoor air quality is directly linked to better health conditions and reduction in mortality among children due to kerosene use. Being a primary lighting fuel, kerosene causes heavy local and indoor air pollution resulting in illnesses and death (Fig. 4(a)). Acute respiratory infections such as influenza and pneumonia kill nearly 2 million children in developing nations each year. Also, kerosene and candles are responsible for countless fire catastrophes every year. In India alone, 2.5 million people (350,000 of them children) suffer severe burns each year, primarily due to overturned kerosene lamps. Each year, many homes burn to the ground when a lamp is toppled[6].

Furthermore, having light in a hospital significantly improves the hospital care for sick children and adults. Hospitals and clinics which currently do not have access to electric lighting might now be able to afford it. Having light for birthing dramatically improves the chances of a safe and healthy birth. Better medical care enabled by SSL lighting helps save the lives of children. Dentistry is safer and can be done on the road so much easier and often. Remote clinics can have affordable, reliable and rugged lighting. An example of this is the LUTW project, in partnership with the Goddard family, to provide a sustainable lighting solution for the rural first aid posts across Papua New Guinea in order for health care workers to be better equipped to deliver health services to many isolated villages in the country. There are more than 1000 functioning first aid posts across Papua New Guinea that are at the 'front line' of health care in many isolated villages, where more than 80% of the country's population lives. Due to the country's close proximity to the equator, darkness covers the land for 12 hours a day. Without proper lighting, there are significant limitations in treating the sick including children and mothers.

Goal 5: Improve maternal health: Each year more than half a million women die during pregnancy or childbirth. Many more suffer serious injury or disability[17]. As noted above, having safe and reliable light in the hospitals and remote clinics helps provide improved health care after sick mothers as well as have safer pregnancy and birth experience (Fig. 9(a)). Furthermore, kerosene replacement with SSL results in increased disposable income which allows mothers to better look after their own and their families' health and nutrition.

Goal 6: Combat HIV/AIDS, malaria and other diseases: Improved air quality allows the achievement of considerable heath benefits. For example in rural Humla in Nepal where SSL was installed, it was estimated that due to the decreased instances of chronic respiratory diseases, life expectancy would increase by 10 years, from the present 54 to 64 years. Hence the Human Development Index (HDI), a measure of human welfare, would improve significantly [18]. Villagers have mentioned that there are less mosquitoes and geckos in their homes when SSL is used instead of kerosene lighting.

Goal 7: Ensure environmental sustainability: Dry-cell batteries contribute a significant amount of toxic heavy metals into the local environment. LUTW's ultra efficient SSL run off rechargeable sealed batteries that last much longer and result in fewer battery disposals. The installation of SSL also reduces the demand for firewood thus mitigating deforestation and desertification. According to the United Nations the primary cause of habitat destruction and run-off water pollution is the denudation of the landscape by the rural poor in a desperate search for scarce firewood. By various estimates from the Schumacher Institute and other development organizations, 60%-90% of firewood and fuel use is for lighting purposes.

LUTW is also very active in remote ecologically sensitive areas, and an example of that is the project in the biologically diverse Knuckles Range, a proposed UNESCO world heritage site and a national nature reserve in Sri Lanka. The costs associated with the grid extension and the environmental constraints prohibit connection of the inhabitants to the electrical grid. Together with partners, LUTW has illuminated 300 houses in 8 villages in the Knuckles Range using SSL[7]. Furthermore, fuel based lighting in the developing world is a source of 244 Million tons of carbon dioxide emissions to the atmosphere each year, or 58% of the CO2 emissions from global residential electric lighting[19]. SSL powered by renewable energy replaces fuel-based lighting thus reducing greenhouse gas emissions responsible for climate change. LUTW estimates that by replacing kerosene lamps with modern SSL technology it reduces approximately 150 kgCO_2 per household per year. Using SSL for 300 million homes at the BOP would result in a reduction of approximately 52 million tonnes of CO_2 per year[6]. Without question SSL can make a significant positive contribution to climate change.

Goal 8: Develop a Global Partnership for Development LUTW is active in transferring technology and knowledge that can help people at the BOP to climb the economic ladder. The organization creates opportunities for local, national and international business development. Through microenterprise development LUTW helps increase local employment and ensure sustainability of the lighting projects and Pico Power Nepal (PPN) noted earlier is a successful example of this strategy (Fig. 9(b)). PPN operates as an independent social enterprise that enhances income for the family operators and presently provides full-time employment for three technicians. Community members benefit as they can purchase lighting systems and receive installation and warranty services at a price that typically has a payback period of much less than 2 years when compared to substandard and unhealthy fuel sources such as kerosene. Furthermore, replacing fuel based lighting with SSL technology reduces reliance on imported energy which helps decrease associated debts and free up funds for important national programs.

6. CONCLUSIONS

SSL is a technology that is transforming the social and economic lives of people throughout the world. The developing world is a perfect marketplace for SSL for various reasons. Used as a development tool SSL significantly improves living conditions of the poor, enhances their safety and health, improves literacy, protects the environment and creates opportunities for income generation and enterprise development. Reviewing the various social and economic impacts that may result from the introduction of SSL, even when considering the potential perverse outcomes, it is clear that the outcomes for the household and the community are positive. Furthermore, as many governments do not have access to the large amount of capital required to invest in the extension of the grid networks to cover all populated areas of their countries, less costly sources of energy that are de-centralized are ideal for reducing energy inequality. With the very low power requirement, SSL along with renewable energy sources is arguably the most appropriate lighting solution available to countries in these situations: enabling them to leapfrog less efficient types of energy distribution. The potential to eliminate the need for governments to subsidize kerosene for lighting is another favourable aspect of the introduction of SSL, since freeing up government resources for other priority expenditures is likely to have a very positive affect on the development objectives of countries. Although the actual impact will be different in different communities, generally the impacts of SSL for many communities are consistent with what can be considered as the world's development objectives, as articulated in the MDGs. SSL can help with the attainment of all eight Millennium Development Goals and help to improve the HDI of the developing countries.

Stuart Hart, the co-author of "*The Fortune at the Bottom of the Pyramid*", says the prime example of a win-win-win solution is the LUTW solar powered SSL system: *"This is a perfect example of leapfrogging to next-generation technology and these LEDs can indeed ease the four-way collision between Poverty, Population Growth, Economic Expansion and Environmental Limits."*

He also says that the BOP is the key to commercializing tomorrow's inherently clean technology, most of which is disruptive, because people at the base of the pyramid are so often poorly served, exploited and they pay a lot of money for bad services. There is a huge opportunity to create new technologies for them.

LUTW's RE based SSL initiatives do in effect provide a catalyst for a very comprehensive and positive bottom up and top down impact on the global market.

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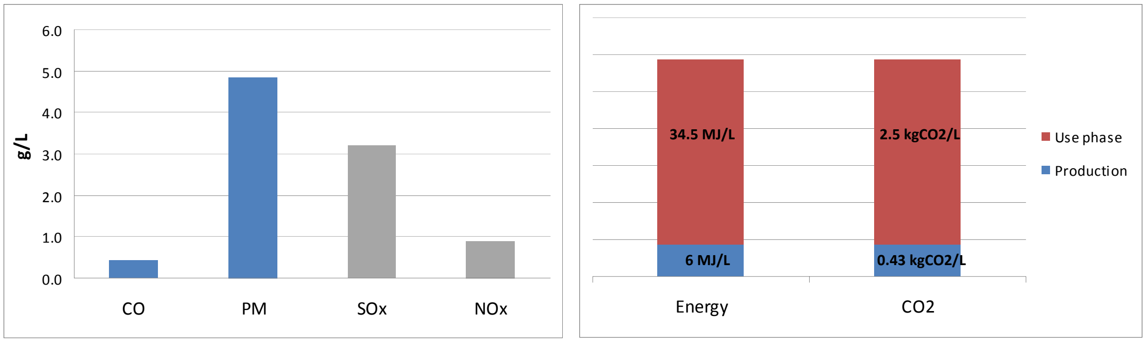
(a)

(b)

Figure 1 – (a) A typical kerosene lamp in India; (b) A woman in Papua New Guinea with a kerosene lantern

Figure 2 – LUTW home lighting system



(a) (b)

Figure 3 – (a) Air pollutants emissions from a kerosene lamp (CO and PM emission rates are calculated using experimental data from [8, 9]; SOx and NOx rates are estimated by authors). (b) Energy requirements and CO_2 emission of kerosene lighting (Calculated using the life cycle emission data obtained from Global Emission Model for Integrated Systems (GEMIS 4.4; available at: http://www.oeko.de/service/gemis/en/index.htm) data base.

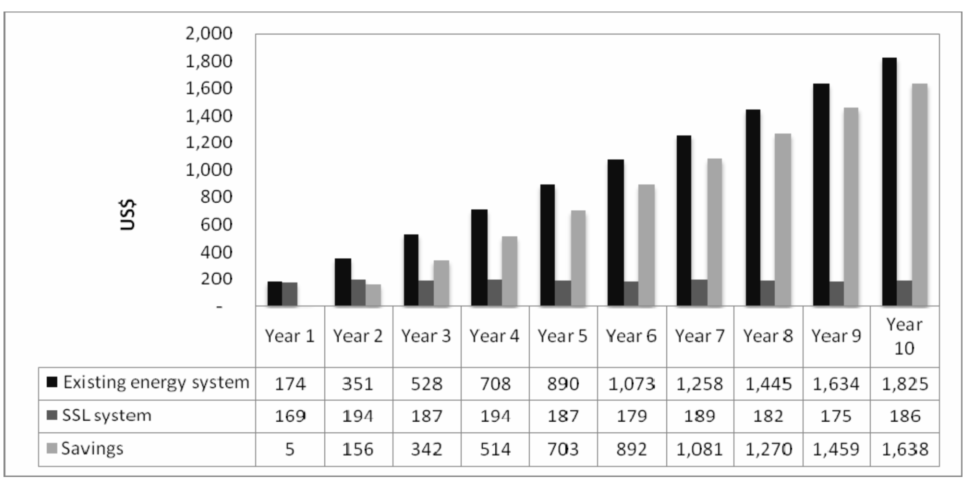
(a) (b)

Figure 4 – Impact of fuel-based Lighting and SSL on indoor air quality in developing countries. (a) Before SSL introduction; (b) After SSL introduction, (Jumla, Nepal, 2001)

Figure 5 – Solid state street lighting system project in UNHCR refugee camp, Damak, Nepal (2007)

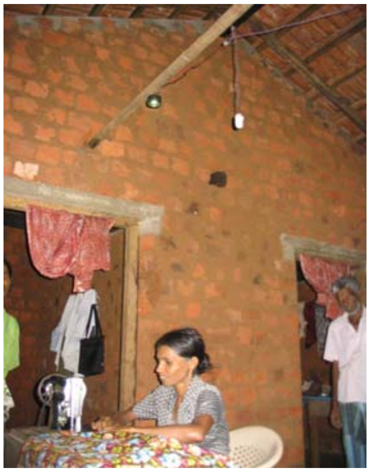
Country	Annual Lighting Expenditure (US $)
Afghanistan	$240
Costa Rica	$200
Ecuador	$200
Ghana	$120
Malawi	$120
Pakistan	$140
South Africa	$130

Figure 6(a) – Annual lighting expenditures (US $) for various LUTW countries

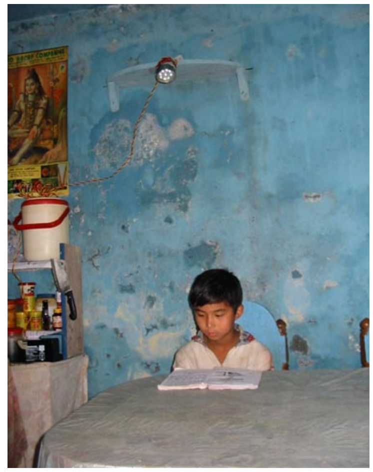


	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Existing energy system	174	351	528	708	890	1,073	1,258	1,445	1,634	1,825
SSL system	169	194	187	194	187	179	189	182	175	186
Savings	5	156	342	514	703	892	1,081	1,270	1,459	1,638

Figure 6(b) – Shanty town household - cumulative expenditures (US$) of existing fuel based lighting system, the SSL system, and cumulative saving if SSL is purchased through micro credit.



(a)



(b)

Figure 7 – (a) A woman sewing under LUTW LED Light, Dambuwe, Sri Lanka, 2004; (b) A boy studying by the SSL light in India, 2001

Figure 8 – Training for women in the Humla Project, Nepal (Photo courtesy of Alex Zahnd).

(a)

(b)

Figure 9 – (a) SSL Lighting in the Operating Room in a hospital in West Bengal, India (2001). (b) Pico Power Nepal – A successful SSL business, Kathmandu, Nepal.