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Energy-efficient Innovative Lighting and Energy Supply Solutions in Developing Countries

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Abstract – *The vast majority of the rural population in the developing countries is out of reach of electricity and hence has to depend on the traditional fuels to fulfil the daily energy needs. Providing grid electricity to the rural areas of many developing countries is a very difficult task due to the geographical complexity and lack of financial resources. The paper explains the use of different renewable energy sources in combination with efficient lighting technology as a realistic option to provide clean lighting services to developing countries. The application of Light Emitting Diodes and renewable energy sources has been a sustainable solution to the basic lighting needs of rural people. The paper also presents a comparison of costs between available renewable energy technologies.*

***Keywords**: Renewable Energy, Rural Lighting, Energy Efficiency, Light Up The World*

I. Introduction

After Edison's futuristic statement over 100 years ago –"We will make electricity so cheap that only the rich will burn candles"[1] – the wishful dream of cheap, abundant electricity has not come true for more than 1.6 billion people around the globe, more people than the entire world's population in Edison's time. Only about 24% of the people living in sub-Saharan Africa had access to electricity in 2000 [2]. Electrical networks in most of the developing countries are limited mainly to the urban areas. In the rural areas of sub-Saharan countries, only 2% - 5% of the population is supplied with electrical networks. The grid connectivity is somewhat higher in countries such as Brazil, Bangladesh, India, Morocco, and South Africa, with 20% - 30% of rural population having access to electrical networks [3]. Rest of the people, who do not have access to the electric supply, use biomass and petroleum fuels for lighting. Fuel based lighting is not only inefficient and expensive compared to electric lighting, but is also a severe cause of respiratory and cardiac health problems [2], [4]-[5].

The electrification rate in the developing countries has been continuously increasing during the past few decades. The urban electrification rate is higher than the rural one. The world urban electrification rate was estimated to be 91.2 % while the rural was 56.9 % in 2000 [2]. Although the electrification rate is increasing, the number of households without electricity is also growing due to the population growth. Between 1970 and 1990, 18 million people in sub-Saharan Africa were newly supplied with electricity, but the total population growth at the same time was 118 million [6]. Similarly in South Asia, due to high population growth, the number of people without electricity grew by more than 100 million during the same period. Extending the electricity networks to rural areas of developing countries is very expensive due to the geographical remoteness, lack of basic infrastructures, and low population density. Hence, the remote and rural parts of the many developing countries are not expected to be accessed by electric networks in near future.

The use of renewable energy systems to produce electricity is becoming a viable option in fulfilling the basic energy needs of rural villages. There are a range of innovative and sustainable technology solutions which can meet the energy needs in developing countries [7]-[9]. The technologies involving wind power, solar power, and small-scale hydropower exploit the local resources, operate on small scale and have an advantage of meeting the needs of widely dispersed rural communities. The efficient use of electrical energy is very important issue in these situations because of the low level of power production capacity from these technologies and also due to the associated costs.

Light Emitting Diodes (LEDs) are rapidly evolving light sources. Increasing luminous efficacy, long life-time, and low power requirements make them suitable to be used for lighting in the rural villages. Cost analysis of LED based lighting systems driven with renewable energy sources in different parts of developing countries have shown them to be cost effective in comparison with the existing options [5], [10]-[11]. The Light Up the World (LUTW) organization is one of the pioneer to apply LEDs for lighting in rural villages, and it has already lit up more than 14000 homes around the world [12]. This article analyses different aspects of the activities of LUTW to provide basic lighting in developing countries. Energy supply systems used by LUTW to drive the LEDs for rural lighting are also discussed in the article. Economic analyses of different alternatives are also made to find the best solution for rural lighting in the developing countries.

II. Case Study: Light Up the World Activities in Developing Countries

Light Up the World (LUTW) is a non-profit organization devoted to the development of renewable energy based innovative lighting technologies for the developing countries. Founded in Nepal in 1997 by Canadian Prof. Dr. Dave Irvine-Halliday, LUTW is the first humanitarian organization to utilize white LEDs in order to replace fuel based lighting in developing countries [12]. The goal of the organization is to bring safe, healthy, reliable, environmentally friendly and affordable home lighting to more than one quarter of the world's population that lives without access to electricity [13]. LUTW has become the platform for the adoption of solid state lighting technology in the most remote and needy parts of the world. To date, LUTW has lit up more than 14000 homes in 42 countries, improving the life of more than 100000 people [12].

II.1. LEDs for Illumination

Light emitting diodes are solid state lighting devices that convert electricity directly into light. LEDs were developed more than 40 years ago but were limited only to emit coloured light. The possibility of using LEDs for illumination became a reality after Shuji Nakamura from the Nichia Corporation developed the high brightness blue LED in the mid 1990s [14]. After this invention it was possible to produce LEDs emitting white light. The two most common methods to generate white light with LEDs are: 1) the use of blue LEDs with a yellow phosphor, and 2) the mixing of two or more coloured LEDs in appropriate proportions.

Technical advances have greatly enhanced the performance of LEDs in the past years. According to Agilent Technologies, the lumens per package value of red LEDs has been increasing 30 times per decade whereas the price is decreasing 10 times per decade [15]. Some of the current white LEDs have luminous efficacy up to 70 lm/W [16], which is more than four times greater than that of incandescent lamp. The luminous efficacy of prototype white LEDs have reached up to 150 lm/W [17]. Although the theoretical maximum for luminous efficacy of white light is 400 lm/W, half of that value is estimated to be feasible with LEDs [15]. The optoelectronics industry development association (OIDA) roadmap has a target to achieve the value 200 lm/W by 2020 [18]. The other important advantages of LED light sources making them suitable for rural lighting are their lifetimes measured in tens of thousands of hours, ruggedness, compact size, and low operating voltage.

II.2. Providing Basic Lighting Needs

Currently many homes in rural areas of developing countries without access to electricity are illuminated by the use of biomass or petroleum fuel, which cause health problems due to the smoke produced. On the other hand, the homes in the developing countries have very low income. The designed electric lighting systems have to be affordable, simple, and reliable. The aim of the basic lighting services is to provide a safe visual environment for movement, to enable people to see each another and to do daily indoor tasks such as cooking, cleaning, socializing and school homework. This is the first step on the path charted from a traditional lighting (use of biomass and petroleum for lighting) to cleaner, convenient, and modern lighting. Keeping these things in mind, LUTW is not trying to light up the homes to a North American level of illumination, but only light up those areas of the home where it is essentially needed [19]. The illumination level is chosen to provide minimal but sufficient lighting in an affordable and sustainable way.

II.3. Lighting Systems for Villages

The activities of LUTW started in 2000 from its birth place by lighting four rural Nepali villages Thulo Pokhara, Raje Danda, Thalpi, and Norung. Each light source used in the villages with the power consumption of less than one watt consisted of six or nine white LEDs (driven at 20 mA current). The light sources were powered by electricity generated from pedal generator, pico hydro, and solar photo voltaic systems (Table I).

TABLE I
DESCRIPTION OF LUTW FIRST PROJECTS [19]

	Thulo Pokhara	Raje Danda	Thalpi	Norung
Power source	Pedal Generator	Pedal Generator	Pico Hydro	Solar PV
Number of homes	23 (plus Gompa and school)	31	28	45
LEDs per light source	6 (homes) 9 (others)	6	6 and 9	9

LUTW donated all the equipment needed in Thulo Pokhara and Raje Danda projects. The Norung project was implemented by LUTW partner Luxtreks, a Canadian NGO (non-governmental organization) helping rural areas which have poor or non-existent lighting. For the Thalpi village only lighting systems had to be provided, as there was already an experimental 200 W Pico Hydro generation system. The power from the Pico Hydro was used to provide lighting to two houses fitted with incandescent lamps. All the 30 homes in the Thalpi village were illuminated when replacing these lamps with LUTW designed LED sources, each home provided with two LED light sources.

LUTW was the first to provide solid state lighting to medical operating theatre in Asia [12]. As part of LUTW Indian lighting project in 2001, LED light sources were installed in the medical operating theatre in Bagdogra. LED light sources in the Indian villages are powered with the mix of pedal generators, diesel generators and the local electrical network.

LUTW has also worked as a disaster relief organization by providing 2000 solar power LED lighting systems to Tsunami refugee camps in Sri Lanka. Before the Tsunami disaster, several Sri Lankan villages had already been benefited from the LED lighting systems provided by LUTW. By today, LUTW has provided light to many developing countries in Asia, Middle East, Africa, and Latin America.

LUTW operates on a sustainable business model. It promotes the creation of locally owned and operated micro enterprises in each country. It purchases the assembled equipment and services from the local companies. The LUTW assisted local companies ensure the continuation of installation, maintenance and support services after the project completion. Pico Power Nepal (PPN), a Nepali manufacturing company is an example of such an enterprise [20]. PPN receives diodes at reduced cost from LUTW and locally develops lighting systems and sells them at affordable prices to the rural villagers. In addition to providing light to the very poorest, LUTW is also promoting job creation and guaranteeing the sustainability of the project.

II.4. Energy Supply Solutions

The LUTW rural lighting projects have utilized a number of different energy supply systems to power the LED light sources. These energy systems include pedal generators, pico hydro, and solar photovoltaic systems. The selection of the system depends on the availability of the local resources, local geographical situation, costs, and sustainability of the system.

The first village lighting project of LUTW utilized pedal power to charge a battery by using a pedal generator (PG). The pedal generator was chosen as it could be operated at any time of day when required, it was economic, easy to maintain, and could be manufactured in the place where it is used [19]. The PG consists of a DC motor used as a generator, a locally manufactured flywheel, a voltage regulator, a digital multi-metre, and a poly-fibre belt. The PG system is installed at one home serving eight to twelve other homes. The battery of each home can be recharged with the PG by only about 30 minutes of gentle pedalling. The size of the battery is chosen so that it is enough to fulfil the daily lighting needs of each home, which is roughly between four and five hours per night.

The application of very small scale hydroelectric generation (pico hydro) has great potential to power the villages in many rural areas. If electricity is produced from the estimated 200,000 traditional water mills existing in rural India, Nepal and Bhutan, large number of villages in these regions can be illuminated by utilizing efficient lighting technologies [21]. Pico hydro is taken as a sustainable and viable option to provide power to rural areas. It exploits local resources and operates on a small scale using flexible and modular equipment manufactured locally. Local manufacturing enables appropriate designs for local settings and reduces the capital costs of the equipment. The installation and maintenance costs are low and the technology used is simple. In LUTW pico hydro systems, different kinds of generators are used depending on the availability. The turbines driven by flow of water rotate the machine to generate the AC voltage, which is converted to DC to drive the LEDs.

Most of the LUTW lighting projects use solar photovoltaic (PV) arrays to produce electricity. The solar PV system consists of a solar panel, a lead acid battery and a battery charging circuit. Depending on the local needs and circumstances, three different approaches have been used in solar PV system: a centralized solar system, a distributed solar system, and an individual solar system. A centralized system is used in villages where the homes are closely located and widely distributed. Solar panels in a centralized system are installed in the centre of the village together with battery bank and charging circuit. In case the homes are far apart, each home can have its own small battery which can be daily charged in the central charging unit. In a distributed solar system, a large village is divided into approximately equal sectors and each sector has its own centralized solar system. An Individual solar system is suitable for scattered homes in the villages. In this case each home having its own small panel of approximately 5 W, and its own small battery forms an individual solar home system.

III. Life Cycle Cost Analysis of Energy Supply Systems

A simple life cycle cost analysis is used to compare the costs of different energy supply systems used for lighting in the rural Nepali villages. The costs of generating capacity are calculated for pico hydro and

PV solar systems over their entire lifetime by taking into consideration the characteristics of each individual case.

Initially, the intention of the study was to calculate the costs of pedal power systems as well. The pedal power system installations in Nepali villages were the first projects of LUTW (started 7to 8 years ago); hence no recent data for their costs is available. On the other hand, a cost comparison of the pedal systems with the others would not be meaningful as the pedal systems did not last to their expected life due to the mishandling of the systems (used by kids as toys for playing, too low discharging of battery, wrong connection while charging the battery with pedal generator). Although the normal lifetime of a battery used in a pedal system was two years, most of the batteries were out of order after six months of operation.

III.1. Pico Hydro System

The cost calculation is made for the pico power system with generating capacity of 1.1 kW installed in the most remote village in western Nepal. The system is used to provide lighting for 70 homes. The high cost of equipment compared to that in the other parts of Nepal is due to the transportation costs. All the equipment have first to be carried by airplane and then by Yak or porter to reach the installation site. Some part of the construction work was carried out voluntarily by the villagers. The local labour costs are estimated in calculating the cost of the construction work. The cost components of the pico hydro system include the cost for the equipment, dam, canal, power house, and installation work (Table 2). The costs are given in Nepali Rupees (NRs).

TABLE II
CHARACTERISTICS OF THE PICO HYDRO SYSTEM

Generating capacity	1.1 kW
Cost of generation equipment (generator, turbine, accessories)	NRs 200000
Cost of transformer	NRs 70000
Cost of construction work (power house, dam, canal, etc.)	NRs 150000
Cost of installation	NRs 100000
Estimated lifetime of generation equipment	10 years
Estimated lifetime of transformer	10 years

III.2. Solar Photovoltaic System

The PV systems used in the villages consist of a PV panel, a battery, and a battery charging unit. The system with a generating capacity of 75 W and battery of capacity 75 Ah is considered for the calculation. Depending on the geographical location and distances between the houses, this kind of system is used to illuminate up to 15 homes.

TABLE III
CHARACTERISTICS OF THE SOLAR PV SYSTEM

Generating capacity	75W
Cost of solar photovoltaic module	NRs 30000
Cost of battery (75 Ah)	NRs 6000
Cost of charge controller	NRs 2000
Estimated lifetime of photovoltaic module	25 years
Estimated lifetime of charge controller	8 years
Estimated lifetime of battery	6 years

The components of the PV system, their cost and the estimated life time of each component is summarised in table III. The calculated life cycle cost is converted to the life cycle cost per kilowatt of generating capacity.

III.3. Results and discussion

A 20 year life cycle cost (LCC) analysis period is used for each system. Using a discount rate of 4 %, discount factors are calculated for each cost occurring year and the costs are converted into present value. The life cycle costs are then converted into cost per kilowatt of generating capacity to enable the comparison of the two systems. The results of the calculations are presented in table IV.

TABLE IV
CALCULATION OF LIFE CYCLE COST (LCC) OF
PICO HYDRO AND SOLAR PV SYSTEMS

Year	Base Year cost	Discount factor	Present value
Pico Hydro System			
0	NRs 520000	1	NRs 520000
11	NRs 370000	0.65	NRs 240500
LCC			**NRs 760500**
LCC of per kW generating capacity pico hydro system			*NRs 691364*
Solar PV System			
Year	Base Year cost	Discount factor	Present value
0	NRs 38000	1	NRs 38000
7	NRs 6000	0.76	NRs 4560
9	NRs 2000	0.703	NRs 1406
13	NRs 6000	0.601	NRs 3606
17	NRs 2000	0.513	NRs 1026
19	NRs 6000	0.475	NRs 2850
LCC			**NRs 51448**
LCC of per kW generating capacity solar PV system			*NRs 685973*

The LCC calculation over 20 year service life does not show any significant difference in costs per kW generating capacity between the solar PV and pico hydro. However, the cost calculations depend greatly on the assumptions made and the cost varies depending on the systems and condition and context of the villages.

The maintenance and operation costs were not considered in the LCC analysis. There are no operating costs associated with solar PV system. The maintenance costs of a PV system are low including the costs for periodic inspection and cleaning of the solar panels, battery, and circuits. On the other hand, pico hydro system needs trained manpower for the operation and maintenance. Special training has to be given to the local people for operation and minor maintenance work. In cases of major maintenance needed, the situation becomes more complicated because of transportation problems. The operation and maintenance costs for pico hydro systems can be partly collected by making use of its power in daytime for other purposes, e.g. grinding grain and pumping water.

An energy supply system for rural village electrification has to be cheap, easy to maintain, and sustainable. Energy technologies that require low maintenance are suited for the remote areas due to unavailability of skilled labour. Although the costs of pedal power are very low and it could work if handled properly, it is found to be very unreliable for the rural people with low technical knowledge. Solar PV system is found to be a more reliable and appropriate technology for small loads and remote rural areas.

IV. Conclusion

Connecting the rural and remote areas of developing countries with electric networks is a challenging task and it is not expected to occur in the near future. The application of locally available renewable energy resources and efficient lighting technologies is the best way to provide safe and clean lighting to the villages. It will improve the quality of life in the rural villages while reducing the environmental emissions. The availability of electric lighting will contribute to improve the health, education, and income generation of the rural environments.

In choosing the appropriate renewable energy technology for rural lighting, the reliability and sustainability of the technology in local context are important issues for the successful implementation. Solar photovoltaic systems are economically competitive and are suited for the widely scattered rural areas.

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