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Benefits from a renewable energy Village electrification system

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A B S T R A C T

More than 100 years after Edison's life changing discovery, 1.6–2 billion people around the globe still live without light, in dark and smoke filled homes. The remote and impoverished Himalayan villages of upper Humla, in north-west Nepal, belong to some of the 2.4 billion people who still depend on the use of traditional biomass for their daily energy services such as cooking, heating and light. These activities on open fireplaces have a direct chronic impact on the health and extremely low life expectancy of the women and children along with devastating deforestation.

There is a strong relationship between prosperity and access to electricity. The more remote and isolated communities in Nepal generally live in great poverty. Eighty percent of Nepal's 28.5 million people live in rural areas, with around half of these so remote, that neither a road, nor the national grid is ever likely to reach them.

While Nepal has no fossil fuel resources, it is a country that is rich in renewable energy resources such as hydropower and solar energy. These abundant and locally available renewable energy resources can be tapped into with appropriate locally developed technologies. Generating and storing electrical energy derived from these rich local energy resources can provide for appropriate and sustainable lighting, which brings potential health, education, social and economic benefits to the people who have previously lived in homes with excessive indoor air pollution.

This paper describes the living conditions of some villages in upper Humla, and the possible benefits of a simple village electrification system that provides basic lighting for the homes and the consequent improvements in the living conditions of the villagers.

1. Introduction

Almost all of the 1.6–2 billion people who live without access to electricity [7,16,22], and rely for their daily energy services such as cooking, heating and light on traditional biomass, live in the developing world. Today, over 100 years after Edison's visionary statement that: "we will make electricity so cheap that only the rich will burn candles" [16], this is only true for the industrialised countries. More people today do not enjoy the luxury of having light in their homes in the developing world than the world's population in Edison's time.

There is a clear relationship between poverty and access to electricity [7,22]. Poverty levels increase the more remote and inaccessible the communities are, while costs for electrification increase due to transport and maintenance costs.

Nepal's population is estimated to be 28.5 million (at the end of 2006), out of which about 80% live in rural areas. About 10 million of these people live in such remote locations (5–18 days walk) that neither a road nor the national electricity grid will reach them, for decades to come. Conditions in Nepal confirm the IEA's statement that lack of electricity and heavy reliance on traditional biomass are hallmarks of poverty in developing countries [7]. Families in the remote Himalayan areas use precious trees for firewood on open fireplaces for cooking, room heating and lighting. These activities consume 20–40 kg of firewood a day [28], and this has a direct chronic impact on the health of women and children in particular, due to the enormous indoor smoke pollution [10]. These cause respiratory diseases, asthma, blindness and heart disease [7], resulting in the extremely low life expectancy for women and the high death rate of children under five years of age in Nepal [7,11].

Nepal has an annual population growth of 2.27%. Thus it is not surprising that the environment too shows clear signs of the widespread massive overuse of biomass. The once picturesque, biodiverse forests and valleys have been stripped of their resources to provide for the necessities of life. The alarming deforestation results in a scarcity of local firewood, and thus forces the people, mainly the women and children, to spend up to 7 h every second day gathering fuel wood from further afield [24].

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During the year 2003–2004 Nepal's national average per capita electricity consumption was 68.5 kWh/year [13]. The national average GDP was 1000–1370 US$ [25], though in Humla it was only 72 US$ [12], with 42% of the people living below the poverty line [27]. This defines Nepal as one of the poorest and most needy countries in the world today.

Nepal has no fossil fuel resources, but plenty of renewable energy resources such as water and sunlight and in some valleys suitable potential to utilise the local wind energy on a small scale. With an annual average water runoff of 225 billion m^3 from over 6000 rivers, Nepal's theoretical potential hydropower capacity is estimated to be around 83,000 MW. The technically and economically feasible hydro potential is estimated to be around 43,000 MW. Until July 2005 only 546 MW [20], or 1.3% of the feasible hydropower potential had been exploited. The average capacity factor of only 47% [9] indicates that only half of the installed hydropower capacity was available. In addition, long dry periods, from October to March, force the authorities to introduce yearly load shadings in the main urban areas.

Humla is the most northern district of the Karnali Zone, which is part of Nepal's western regional development area. This Zone is isolated from the mainstream of the wider development in Nepal due to its remoteness, and because it is also the only Zone with no link or connection to a road. In fact only a 16-day walk from the nearest road head brings you to Humla's district center Simikot. The alternative is a 1 h flight with a 25 year old Twin Otter aircraft from Nepalgunj, in the very south of Nepal at the border to India, to Simikot, landing on a rough earthen and gravel landing strip. According to the UN's Human Development report, the Karnali Zone, with an HDI of 0.244 is the least developed area in Nepal. The whole Zone is known for its permanent food shortage, environmental degradation, low productivity, annual disease epidemics among people and livestock, harsh and unforgiving climate, famines, weak educational system, negligible employment opportunities, the staggering degree of inhumanity in the treatment of women (gender inequalities), and growing migration in a desperate search for work to feed the families. These present the dire outer frame of the Humla peoples' living conditions, steeped in poverty and suffering throughout their lives in the 21st century.

2. An elementary village electrification system

The Humla communities belong to the 1.6–2 billion people worldwide without grid connections. That will remain like that for several generations to come, because Humla is just too remote and too difficult to access. It lies 16 days walk from the next grid connection, in the most difficult terrain, with high, snow covered peaks, thick forests, wild rivers and a harsh climate, with freezing winters, stormy springs and the annual monsoon rain. In these circumstances just to think of the shear cost of a grid connection is prohibitive. Thus the most appropriate solution is embedded power generation, through the utilisation of the locally available renewable energy resources. The remoteness makes it obvious that non-renewable fuels (such as petrol or diesel for a generator) are not affordable, having almost quadrupled in price by the time they reach Humla, due to the transport costs. Thus it is the available renewable energy resources, such as the streams and the sun, which are feasible and sustainable resources for power generation.

When we think of the availability of power, we mostly think of the availability of electricity by the flick of a switch at any time, and for almost any kind of application, independent of the power demand. This is in part because we either live in a developed country, or in an urban place in a developing country where the power grid is a reality. In the case of Humla this will probably never be the case, as embedded power generation demands considerable financial investment and careful long-term planning. That is why for a remote and impoverished end user community, which never had the experience of power access in the form of electricity, the first step into that new realm of experience is often an elementary village electrification system. This is a simple power generation system for a few, low power consuming, long-lasting lights (Fig. 2), utilising the locally available renewable energy resource.

In recent years RAPS (Remote Area Power Supply) systems have become a very suitable and appropriate power generation approach for remote communities. A RAPS system (Figs. 3, 4) is a power generation system that is clearly defined in its scope, capability and life expectation. It utilises either a single or several renewable energy resources – the latter case is called a hybrid system. Because a RAPS system is clearly defined for its entire life expectancy, distinct assumptions form the foundation of the design. To define these in the initial stage of a project is by no means an easy task, as they will form the "outer frame" and limits of the RAPS system, and are not easily changed afterwards. Thus some of the important "software" (social, cultural and environmental [31]) and technical hardware issues that need to be defined beforehand, and numerically and qualitatively discussed by all stakeholders, in particular by the end user community are:

- User identified energy service needs over the life cycle of the power generation system, including realistic power demand adjustments dependant on the development of, and population changes in, the community.
- Population growth rate of the end user community over the past two decades.
- Identifying the power consuming applications, and the hours used per day.
- For how many days, without the renewable energy resource available, do the energy services need to be provided?
- Community ownership and the financial commitment the end users are able/willing to invest for the initial cost, as well as for their ongoing generation and recurrent costs (training, maintenance and repair).
- Locally available materials, equipment and services to build and maintain the RAPS system.
- Availability of national or international subsidies/funds for financial support.

Fig. 1. Indoor air pollution through open fire place cooking, heating and lighting in Humla homes. These are major reasons for the chronic respiratory diseases, premature death and low life expectancy of women and children (Picture: Alex Zahnd).

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Fig. 2. 1 Watt WLED light, with 26 lm/W and a life expectancy of up to 100,000 h (Picture: Alex Zahnd).

Thus in the following, an elementary village electrification system in the context of a Humla village, is a power generation system, generating small amounts of energy through a RAPS system. It converts the available local renewable energy resource into a defined energy service. This generated energy is used only to provide basic and minimal indoor lighting services through low power consuming lights. The lamps used are white LED (WLED) lamps, consuming just 1 W per light, providing just enough light to see each other, socialise and to do the daily indoor tasks such as cooking, cleaning and reading (Fig. 2). It represents a power generation system which is the first step away from the traditional energy pattern ("jharro", the resin soaked pine wood stick, shown in Fig. 5) to a cleaner and more convenient energy service.

While LED diodes have been available for nearly half a century, and thus have become part of our daily life, white LED diodes (WLED) are still rather new, as this technology is still in its infancy. The first good quality WLED diodes have only come on the market in the second half of the 1990s. In 1998 the principal author developed and installed, in partnership with LUTW (Light Up The World) [14], the first elementary rural village electrification scheme in Jumla, Nepal. A pico-hydropower plant, generating 150 W, provided 30 homes each with three WLED lights. That project ran successfully for three and a half years until one neighboring villager, who did not have light in his home, broke the generator out of jealous spite.

LUTW operates in various countries such as Sri Lanka, India and the Dominican Republic. Fundation Naturale in the Galapagos Islands, as well as the principal author in Jumla and Humla, Nepal, have installed PV powered lighting systems in several villages and single homes. Mostly they consist of three WLED lights each consuming 1 W (with initially nine, and from 2007 on, 12 high quality Nichia NPSW510BS white light emitting diodes per lamp (Figs. 2, 7) manufactured in Nepal by PPN [18]). They are powered either from a 5–20 W solar PV module, a relevant battery bank (with up to five days independence from the sun) and a charge- and discharge-

Fig. 3. RAPS Solar PV System for the remote and impoverished mountain village of Chauganphaya in Humla, Nepal [29]. A centrally built 300 W PV array, with a two-axis self-tracking frame, developed and manufactured in Nepal, generates power for three WLED lights in 63 homes, for 6–7 h a day. All transmission cables are buried underground and able to carry a three times increased load demand over the RAPS system's cycle life of 20 years. Three local people have been trained to install, operate and maintain the system, and each household pays 15 NRp/month (~0.22 US$) for the light service (Picture: Alex Zahnd).

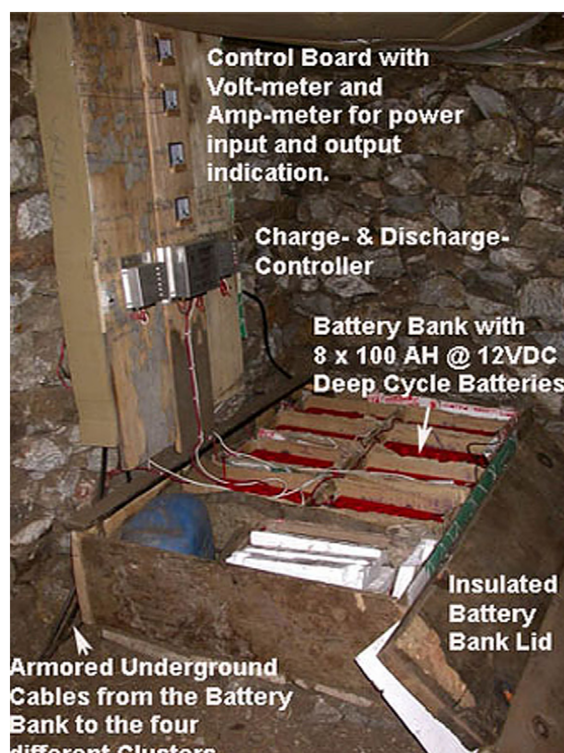

Fig. 4. Battery Bank in the power house, designed to be replaced once in the RAPS system's life cycle. It is insulated in a locally made wooden box, calculated to provide up to 5 days light services without sunshine, with a maximum battery bank DoD (depth of discharge) of 35% (Picture: Alex Zahnd).

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Fig. 5. "Jharro" the only means to generate light in the home. Strong black smoke, soot and a very dim light is the output (Picture: Alex Zahnd).

controller for a cluster of one to four homes, or from a 75 W solar PV system with relevant infrastructure, for a cluster with 15–18 homes connected.

3. Possible benefits of an elementary village electrification system

Worldwide, the average household of four people uses about 300 kWh per year just for lighting purposes [19]. Nepal's average total electricity consumption per capita is 68.5 kWh/year, which is less than one fourth of this amount. People value lighting very highly, as it brings enormous improvements and benefits to their lives [26]. Thus it is important that we remember under what conditions millions of people still live (Figs. 1, 5) and we recall the initial benefits that minimal indoor lighting through an elementary village electrification system can bring (Figs. 6, 7). The minimal lighting energy service, in the context of an average Humla family, consists of three 1 W WLED lights per home. The following six areas benefit directly from indoor lighting.

3.1. Health

To have two WLED lights in the main room, where most of the daily activities and social gatherings take place, and one WLED light in a second room (often the bed and storage room), means that the people do not need to burn "jharro", which has been thus far the only means to generate light (Fig. 5). The WLED light output is several times brighter [1] with a clean indoor environment, while the black soot from the burning "jharro" covers the walls and wood ceilings, with an even worse effect on the human respiratory system (51% of baby boys and 45% of baby girls suffer under acute respiratory infections [4]). Further, the smokeless metal stove (Fig. 6), an intrinsic part of all RIDS-Nepal holistic community development (HCD) projects in Humla, is installed alongside every village lighting project. Once installed, and in proper use, no more hazardous CO, and PM_{10} indoor air pollution occurs through open fire place cooking, heating and lighting (compare Figs. 1, 5 with Figs. 6, 7).

3.2. Education

Various surveys, such as those conducted in Nicaragua and India [22], illustrated clearly, that access to indoor lighting has a direct influence on the education level in the community. Electric light in the homes enables adults and children to conduct study and

Fig. 6. Smokeless metal stove for clean indoor air (Picture: Alex Zahnd).

informal education classes after their daytime work. With a literacy rate for Humla women of just 4.8% [12], this will have a profound long-term impact in regard to raised awareness, self-confidence, independence and increased income generation opportunities (Fig. 7).

3.3. Social life

Reading has thus far not been part of the culture of the Humla people. Exchanging and sharing news, elders teaching the younger generation, has all taken place as part of the social family gatherings in the evenings around the open, smoky fire, with often the neighbors present. With a minimal domestic lighting service and a smokeless metal stove, these social activities are much more enjoyable, besides strengthening the social structure of the community. Now their eyes do not burn any more from the soot of the

Fig. 7. Even a small light in the home allows non-formal education classes and study times (Picture: Alex Zahnd).

"jharro" or the open fire place, nor do they have a permanent cough from the smoked-filled rooms. These improved conditions lead to increased social gatherings, bringing forth more self-initiated community development activities, which strengthen and build up the community in a more independent way (Fig. 6).

3.4. Income generation

With only three to four months per year available for growing food in their own fields, considerable income must be generated through other means, in order to survive for the other eight to nine months of the year. Often the men leave the villages to travel to Tibet/China and India, to trade and to find work. The harsh climate, dangerous routes and long trips make this an unreliable and risky business. Further, the high risk of infectious diseases (such as HIV) in Nepal's neighboring countries, bring considerable danger. Light in the homes, minimal as it is, still allows them to start small income generating activities during the evening hours. Thus knitting, bamboo weaving and other handicraft skills allow women and men at home, with their families, to boost their income and skills.

3.5. Physical conditions

In the past, in order to have a dim light, "jharro" had to be "produced". To produce it, the local people cut a pine tree's bark and top layer wood, so that the tree had to start producing resin, in order to "cure" the inflicted "wound". After a week, when the tree has produced so much resin that the "wound" can heal, people come and cut out that layer plus the next deeper layer (Fig. 7). This part is so soaked with resin that it burns very well, like a torch, generating a dim light with lots of soot (Fig. 5). Over time, the tree will die slowly as it tries to cover up the "wound" inflicted on it again and again, deeper and deeper, until it is unable to produce any more protective resin.

3.6. Environment

It is obvious (Fig. 8) that the production of "jharro" is very destructive to the already heavily overused forests, which are also exploited for firewood. This leads to massive deforestation in the Himalayas. Further, the inefficient and incomplete combustion process in an open fire place and the "jharro" burning create comparatively high CO, PM_{10}, $PM_{2.5}$ and CO_2 values, producing dangerous indoor air pollution conditions with considerable greenhouse gas emissions.

If a community has reliable access to basic lighting services it can have a major impact in a short time. With an average family consumption of ~5.5 kWh per year for lights (three WLED lights, each consuming 1 W, for 5 h a day), or 55 times less than the world's average family consumption, an enormous difference in the lives of millions of poor and remote communities can be achieved. Therefore, we have to abandon the "100 W per household" approach, which was previously the benchmark for a minimal village electrification system in Nepal [3] and elsewhere, based on inefficient, short life incandescent bulbs. That approach demands a micro-hydropower plant of considerable size (5–20 kW) for an average village of 30–170 households. The shear size and cost and remoteness of such a project also limits the possible villages to be electrified. Already Craine [3] suggests that 30 W/household would be sufficient, if 3 × 10 W high quality CFL lights are used. While this is a step in the right direction, the elementary village electrification system approach, described in this paper, takes another giant step by reducing the requirement further by a factor of 10, to 3 W/household. Thus basic lighting services, provided with reliable and field approved technologies, such as a solar PV village system and WLED lights (Figs. 2, 3, 4), with a mere 3 W of power consumption per household (or maximum 20 Wh energy consumption a day), have now become a reality for previously unreached and "forgotten" communities in Nepal.

Fig. 8. "Jharro" production kills the trees slowly (Picture: Alex Zahnd).

4. Experience from implemented projects in Nepal

In order to bring light into the homes of the 1.6–2 billion people still living in dark homes in developing countries, rural village electrification will play a central role. Traditional medium to large-scale electrification schemes will not be able to address the urgent needs for basic energy services such as light, due to their shear project size, costs and dependence on external technical and financial support. What is needed is a much more modest approach, which is able to "carry" sustainable, affordable and teachable technologies into the homes of the remotest and poorest communities.

There are ample successful project examples from all over the world, clearly showing that rural electrification can be done successfully and sustainably. What is described here though is an order of magnitude smaller than what is the "common" trend.

From the author's eight years experience with WLED lights powered mostly by solar PV systems, with approximately 600 homes electrified in the remotest mountain areas of north-west Nepal, in Jumla and Humla, the following observations can be made:

- The local community has to initiate the request for the implementation of an HCD project in their village, which includes an elementary village electrification project for lighting.
- First a house by house base-line survey has to be carried out [6], in order to have the local people contemplate upon and identify their own living conditions.
- The local community has to be introduced to the WLED technology and lighting services it can provide through practical

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examples of operational systems, before the project is designed.

- The local community's financial capability to participate in the initial project costs as well as in the operating and maintaining of the project over its life cycle, has to be agreed upon and signed, before the project is designed.
- A written and signed (by thumb print) agreement by all stakeholders, on the kind of voluntary participation, initial cost participation, monthly fees, initial training for installation, operation and maintenance, has to be in place.
- The definition of the project scope and design occurs in close partnership and consultation with the local community, thus increasing the ownership responsibility.
- Along with the elementary lighting project, a minimum of three other HCD project components, a smokeless metal stove, a pit latrine and clean drinking water from village taps, have to be implemented alongside each other. Even better is to include also NFE (non-formal education for adults and out-of-school children), greenhouses and solar driers [30].
- A carefully defined and faithfully executed follow-up program (over 10 years) has to be in place and adhered to, once the initially installed HCD programs are implemented.
- The follow-up program should also include a data monitoring and recording program, as well as periodic village surveys, to record factual and anecdotal experience of the changes occurring over time. It is often difficult to convince sponsors to fund this important aspect of the project.

5. Preliminary field results

It is an intrinsic part of each new RIDS-Nepal (Rural Integrated Development Service [21]) HCD village project in Humla, that a context related base-line survey is carried out, which aims to get a detailed and "close-up" picture of the community's living conditions and circumstances. These are identified by the people themselves through individual interviews with each household's family members. In a 65-question survey, developed by RIDS-Nepal and *The ISIS Foundation*, social, cultural, economic, health and development status are discussed with each family in detail, so that all members of the family can identify and express their own conditions and opinions. It also tries to reveal the level of awareness regarding their own development status and the level of awareness and knowledge of their own needs.

Asking the questions in the right way, in order to remain respectful but clear, is a task which has to be learned and understood. Often the real answers have to be read "between" the lines and filtered with an in-depth understanding of the prevailing local culture, traditions and customs. This intensive, time consuming and often emotional work, is carried out by our trained RIDS-Nepal project staff. They are also the main technicians and RIDS-Nepal HCD project implementers of the surveyed villages. They too provide the initial training for the local people to install, operate and maintain the village based projects. The established friendship and understanding of the local conditions and life are of crucial importance and great help in the HCD project design and execution in close partnership with the local people.

After ~~one or~~ two years of the implementation of the various components of an HCD project, a follow-up survey, with slightly different questions, is carried out by the RIDS-Nepal staff, in each household of the village. That provides information and data regarding all aspects of the local people's life in regard to the changes that occurred due to the implementation of the HCD project. How have the various project components (minimal light inside the home, smokeless stove, pit latrine, clean drinking water, etc.) changed the life and living conditions of the people over the course of ~~one to~~ two years? How have the local people coped with the changes and how do they perceive the changes? These data enable a clear feedback for all project stakeholders, in particular for the designer and implementers on whether the intended changes have actually occurred and if not, why not.

Some evidence of impacts and perceived changes, identified by the end users are:

- *Improved health conditions*: clean indoor air, no cough, no eye burning, less small children get burned by the open fire place and improved breathing.
- *Increased indoor cleanliness*: generally cleaner indoor conditions (with the WLED lights inside the home some of the previous unnoticed soot and long-term dirt on the walls was finally recognized and removed by the house owner).
- *Improved personal hygiene*: with the hot water from the stainless steel tank attached to the smokeless metal stove people wash their hands and faces regularly.
- *Commencement of literacy courses*: since the installation of the WLED lights inside the homes several mothers and out-of-school children (mostly girls who have never been to school before) meet for organized NFE classes as part of the RIDS-Nepal HCD project, using specially-designed HCD related teaching materials.
- *Increased home studies*: children who have attended school previously are now able to do 2–3 h per day of additional reading and home work (Fig. 7). The local school teachers have recognized a clear improvement in academic performance of the students with access to lights in the evening in their homes.
- *Increased social gatherings*: in the homes with WLED lights and smokeless stoves, people tend to stay up later in the evening, discussing and socialising in a warmer, cleaner and better illuminated environment.

6. Conclusions

This paper aimed to bring some of the most forgotten communities, the people living in the remote high altitude Himalayan mountain regions of Humla, Nepal, back on our agenda, in particular in regard to the millennium development goal (MDG) number one [23] which aims to:

- Reduce by half the proportion of people living on less than a dollar (US$) a day.
- Reduce by half the proportion of people who suffer from hunger.

Literature, practical and anecdotal experiences show that improved access to energy services is one of the main steps to the fulfillment of this MDG. People do not want energy resources as such but rather the energy services they can provide through the exploitation and conversion of available renewable energy resources. Almost universally, the local communities, with no access to modern energy services, identify lighting, cooking, heating and clean drinking water as their main needs for improved living conditions. In particular lighting, for brighter illuminance and cleaner indoor air conditions, for reading/studying and socialising, is the one which ranks most of the time at the top of the wish list of people without access to electric light.

In the view of the poorest of the poor, living in remote mountain communities, electricity, even for minimal lighting services, is one of the most desired energy services. It often marks a first milestone on the path of a community's development towards an improved living standard. But, as the EnPoGe report also recognises:

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"Rural electrification is generally the costliest and structurally the most loss-making activity for power utilities. It mostly brings in micro-consumers, which worsens the load factor, and [puts] politically sensitive pressure on tariffs" [15].

This does not provide a good starting point to consider the electrification of the remotest and economically weak communities, living in some of the most hostile and inaccessible areas of the world. The worldwide trend to privatise utilities, to have electricity generation, transmission and distribution under the direct influence of the free market, aiming for maximum profits and ever increasing market shares, favours the fulfillment of the "wants" of the rich rather than the "needs" of the poor.

Against this background rural electrification schemes stand no chance unless new approaches are developed and put into action. The approach of an "Elementary Village Electrification System", as explained in this paper, has been developed and implemented in various villages in the remote north-western district of Humla in Nepal, against the background of deep rooted poverty and apparent hopelessness. The willingness to change the status quo, is the first important decision to be taken, if we want to strive to reach the MDG number one.

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[2,5,8,17].

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