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Appropriate Distributed Generation Technology for Electrifying the Village

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Abstract

This paper examines the condition under which distributed generation (DG) technology make a genuine contribution to electrify the remote village. To study the circumstance for DG technology and village electrification, three indicators – affordability, institutional capacity and replicability - are drawn with ‘appropriate technology’.

With the role of energy and electricity to make progress for human, the urgency and justification for village electrification with DG technology is highlighted. In the off-grid remote villages, electrification with distributed generation (DG) with renewable energy technology would be viable option. To examine the appropriateness of DG technology in the village context, three village electrification cases are chosen from Nepal, India and Sri Lanka. In each cases, DG with the solar PV, biomass gasifier and hybrid solar & wind technology are studied to find answer those technologies are appropriate in the village context with three indicators.

This paper concludes that the appropriate technology in the circumstances is determined by the ability to afford the technology, the work of institution and resources to replicate the technology system, or integrated effect of three indicators. To make DG technology for village electrification more appropriate, the constant monitoring and evaluation is necessary in the flexible circumstances.

Abbreviations

AC	Alternate Current
CFL	Compact Fluorescent Lamp
DC	Direct Current
DG	Distributed Generation
FAO	Food and Agriculture Organisation of United Nations
GDP	Gross Domestic Product
GW	Gigawatt
HDI	Human Development Index
IEA	International Energy Agency
IRR	Internal Rate of Return
KWh	Kilowatt Hours
MNES	Ministry of Non-conventional Energy Sources
MW	Megawatt
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
RET	Renewable Energy Technologies
SAR	South Asia Region
SHS	Solar Home System
SLR	Sri Lanka Rupee (SRL 100= US 1 dollar)
SSHP	Small Scale Hydro Power
UNDP	United Nations Development Organisation
UNEP	United Nations Environment Programme
US	United States
WLED	White Light Emitting Diodes
WRI	World Resources Institute

Abstract
Abbreviation

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Chapter 1 Introduction

1.1 Introduction

Village is the spatial and functional concept which collectively comprises of the whole feature of society. As a village is the fundamental component of society, its social, economic and environmental status should be addressed significantly to achieve holistic development of society. But, in reality, many villages have frequently been excluded from the governmental development efforts due to the various constraints from geographical disadvantage to the economic issues.

Electrification is one of the major indicators to evaluate to what extent a village currently falls behind in the pathway to development. However, many of villages in rural areas particularly in developing countries have not been connected to the grid electricity for a long time. In this respect, concentration on providing electricity to the poor villages with strong humanitarian argument is justified.

In the traditional image of electrification, there are large power plants and high-voltage of long transmission and distribution lines. And this form of electrification has been still prevailing and favored by utilities and, implicitly or explicitly, by policy makers(Zerriffi 2007). With the conventional electrification system, electrifying villages in rural areas is generally more expensive because they are remote and scattered and their consumption is low in comparison with the urban areas. Therefore, the un-served poor villages by the electricity grid have not either been focused or are the last place to be provided with electricity.

Such constraints of providing electricity duet to socio-economic conditions in remote villages could be challenged by distributed power generation not solely depending on the centralized power generation with extending grid network and distribution. Particularly, distributed power generation with use of locally available renewable sources like solar, wind, biomass could be environmentally sustainable and beneficial to end-users and also key to solve village electricity problem. For example, 18,000 villages of India have been identified where electricity generation through renewable resources will be more appropriate (MNES 2002-03).

Distributed generation has several advantages over grid-based village electrification. The most important advantage is that heavy dependence on fossil fuel will be reduced with use of renewable resources and consequently, emission of greenhouse gases will be controlled. Transmission and distribution costs can be downgraded. And distributed generation will lead to employment to local people because distributed generation system is run by participation of local people.

1.2 Energy, electricity and sustainable development

The role that energy plays in sustainable development can be argued mainly with three pillars of sustainability – social, economic and environmental aspect. In its social aspect, energy and electricity are principle pre-requisites for basic human needs by contributing to poverty eradication, empowerment of socially marginalized people, gender equity, natural resources conservation, better quality of education and health improvement. Energy is necessary for economic growth. In particular, in the case of rural area, the role of energy in economic aspect is mainly concerned with energy consumption of agriculture and rural industries. For instance, according to FAO, there is close relation between quantity and quality of food production and quantity and quality of energy used. The use of energy in non-agro industries such as boiling sugar cane, tobacco and copra drying is substantial (WRI/FAO 1999).

Conventional energy use like fossil fuel significantly stresses environment by emitting greenhouse gases and exploiting natural resources (Najam and Cleveland 2003). For example, the wood and charcoal consumption in Africa cause deforestation of 2 million hectares with soil degradation, vegetation distinction, animal species and local climate change (Benchikh 2001). Meanwhile, there is other opinion that economic and social development through using either fossil fuel or alternative energy can contribute to the improvement of the environment. If only non-fossil fuel would be used for economic development, there is no environmental stress arising from energy use and the economic development can also be supportive for protecting environment.

Electricity as commodity is indispensable to support the three pillars of sustainable development – economic growth, social development and improvement of environment. Access to electricity can contributes to industry development and income generation; promote social progress through advanced education, better quality of health treatment, increased gender quality, and other social welfare(Zerriffi 2007); and improve environmental condition by removing less efficient way of energy conversion.

But electricity needs to be more accessible, reliable and affordable for the people suffering from energy poverty, because the world is divided in access to the basic energy and electricity needs. About 1.6 billion people are living without electricity. And another 2 billion people have access to electricity just to unreliable extent(IEA 2002).

Energy has an impact on UN’s Human Development Index in the aspects of equity, empowerment and environmental soundness. Energy impact on HDI can be varied according to its application in end-user and tasks it performs. And the positive contribution of electricity to Human Development Index has the most dramatic change for the first kilowatt-hour(de France 2002). It reflects the poorest are most likely to benefit from the little amount of electricity.

1.3 Research question

Improved form of energy is vital factor for holistic development of a region. The growth of developing countries will be significantly guided by energy environment. Given the important role of energy and electricity in social, economic and environmental improvement and distributed power generation as an alternative to supply electricity to the geographically disadvantaged villages, this paper studied three village electrification cases with the different kinds of technologies of developing countries and asked those chosen electrification system is feasible in the village context. In other words, the question is not focused on distributed generation technology per se, but on the surrounding of the village which makes the distributed generation technology more feasible in the consideration with the characteristics each technology has. The feasibility of distributed generation technology is examined specifically through village electrification of Humla in Nepal, Hosahalli in India and Pokunutenna in Sri Lanka.

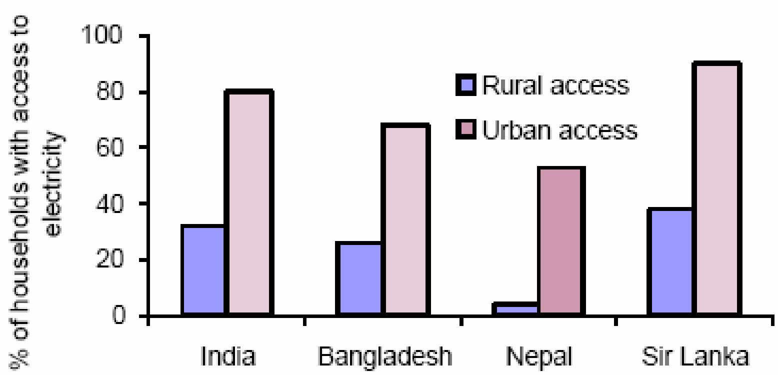
This paper attempts to find whether a distributed generation technology is feasible in the village with reference to the sustainable development resulting from electricity provision. So, criteria to assess the feasibility are drawn from inter-relation with the technology and its surrounding.

Figure 1. DG technologies and surrounding: inter-related approach

1.4 Methodology

Many cases of distributed generation conducted in the village level have existed around the world. In this paper, 3 cases of village electrification are chosen from Nepal, India and Sri Lanka of South Asia Region. Three case studies were selected in the consideration of (rural) energy status of these countries. Level of access to energy in this region varies widely from 5 % in Afghanistan to 65 % in Sri Lanka. In Sri Lanka, the disparity between rural and urban is very high. Non-viable power utilities and a large fiscal burden by them are problematic in India. Nepal is one of the poorest countries in the world. The average energy consumption per capita is 15GJ per year. Biomass is primary energy source, 77 percent of which is firewood. Around 85 percent of Nepal population lives in the rural area(Nepal 2007). All of case villages are geographically disadvantaged and attempted to use the distributed power generation with different renewable sources from each other.

Figure 2. Energy access in South Asian Countries



Data for study were collected through secondary sources. And all national level data were collected from the relevant organizations and the information about each case was gathered through many relevant articles describing village electrification process and other sources in the internet. These data on village electrification were analyzed in the perspective of technology feasibility and are presented along with observation and conclusions.

1.5 Structure of research paper

This paper has the following structure. Chapter 2 presents the definition of distributed generation with the factor of technology, ownership and operation mode. And it continues to discuss how distributed generation relates with on-grid and off-grid system. Following part addresses its advantages over the conventional energy system if the distributed generation uses renewable sources. With general advantage of distributed generation with renewable energy technology, it moves on the explanation of the major renewable energy technologies either currently being used or under further development. And the concept to assess feasibility of distributed generation with renewable energy technology in the village context is framed.

From Chapter 3 up to Chapter 5, three village electrification cases of Nepal, India and Sri Lanka through DG with RET are followed. Each chapter consists of the general living condition including geographic condition and the current energy use, the feature of village electrification system and benefits in social, economic and environmental aspect from village electrification. And the village electrification is analyzed with indicators to assess the feasibility of the chosen DG with RET. In Chapter 6, this paper forms the conclusion with the general findings.

Chapter 2 Distributed generation

2.1 Definition of DG

Defining distributed generation can be varied according to which characteristics it uses. First, it can be defined which sources and technology it uses. Small modular power generating technologies such as diesel engine and natural gas, as well as renewable sources of hydro, solar, wind in the range of 1 kW to 50 MW might be the most familiar DG technologies. Ownership is also used to define DG system. While a definition using the ownership characteristic means the unit must be owned by end-user, there exists a number of possible institutional forms such as utility co-ownership or energy service company ownership. The operational mode is also often used to define DG whether power generation is dispatchable or scheduled. Sources and technology, ownership and the operational mode result in narrow definition of distributed generation. With the discussion of all three of these characteristics the definition Ackerman et al suggest is that distributed generation only means generation located within the whole distributed generation network or customer side of the meter of both off-grid and on-grid application (Ackermann, Andersson et al. 2001).

The grid connection is also a major factor to define distributed generation in the context of village electrification. DG technology may or may not be connected to the electric grid. But connecting certain village or community to the grid may pose technological, regulatory and commercial problems. Therefore in the village electrification, distributed generation has to be necessarily grid independent. But DG unit typically below 10 MW capacity can be connected to the low-voltage local distribution network. DG with local mini-grid improves electricity supply by diminishing the load on the local systems through on-site generation and by improving the voltage at the end of village distribution system (Chaurey, Ranganathan et al. 2004).

This paper adopts more flexible definition conforming to the cases of village electrification. Distributed generation is understood like that the power is locally generated and consumed and this definition includes various technologies from solar home systems to diesel engine and allows flexibility in operation modes and institutional arrangements(Zerriffi). These DG technologies can be operated completely off-grid or as just some part of local mini-grid. Given the definition above, this paper focuses on the distributed generation to meet the demand of the village populations in rural areas.

The DG technology is likely to be favored with the view that it can correspond to peak load shortage, losses from transmission and distribution and rural electrification of remote and inaccessible areas.

2.2 Distributed generation and Renewable energy technology

Distributed generations mainly use renewable energy technologies and diesel generators. But environmental concern and fuel independence are advantages of RETs over diesel generators. So, DG with RETs have gained enormous support in provision of electricity in off-grid regions of developing countries. The next part describes successful cases of each technology like solar PV, hydropower, biomass gasifier and wind turbines to give understanding of basic principle.

2.2.1 Small hydro power (SHP)

Small scale hydro power is to convert kinetic energy of flowing water into mechanical power with the use of transmission mechanism like turbine. A generation capacity of up to 25 MW is categorized in small. Major constraints of large hydro power relates with social and environmental problems like large hydroelectric dams and power plants. But, SSHP can avoid those constraints. Harnessing water resource is the basic important work to make SSHP function best by constructing small dam or diverting water flow to store water. Small water resource is mostly available in hilly areas in which extending grid is difficult and relatively expensive. So, SHP is well suited for power generation near end-user without transmission and distribution lines.

2.2.2 Solar photovoltaic

Solar PV systems are solar cells. Solar cells are small, square-shaped panel semi-conductors manufactured in thin film layers from silicon. These are the fundamental unit of solar photovoltaic which converts sun light into direct current (DC) electricity. Connected several cells form string and then, laminated into a module to increase power output. It also can be converted into alternative current (AC) electricity with inverter. The power generated from solar PV can be stored into batteries for use at night. Solar PV technology is particularly appropriate to provide basic service like lighting, safe water and power for income generation. Solar energy mini grid for village electrification and solar home systems (SHS) for indoor lighting, street lighting and solar pumps are the main systems used in developing countries.

SHS are widely used in rural area to provide the basic electricity needs for lighting. It consists of a PV module, deep discharge lead acid battery, charge controller, 1-3 CFLs (compact fluorescent lamps) and DC power point for appliances like radios and tape recorders. Generated energy by module is stored in the battery and can be used when needed. Facility cost is up to capacity and quality of system from 150-500 US dollar. About 1.2 millions of SHSs provide electricity in rural households in the developing countries. Especially in India, China, Mexico, Kenya, South Africa, Indonesia, Bangladesh have widely accepted SHSs, which is facilitated by national governments and private initiatives(IEA 2002).

In remote and off-grid places, as roads are not equipped, maintenance and management of system get easily failed. And high initial cost is the major hurdle for the poor households in developing countries. Appropriate financing system for rural poor households and maintenance are the biggest challenge for spreading SHSs.

2.2.3 Biomass gasifier

Biomass gasifier technology is that biomass is burned in the gasifier, a chemical reactor, to convert it into gaseous fuel known as producer gas. Firewood and agricultural residues such as bagasse, crop stalks, rice husk, coconut shells and animal dung are used. The direct combustion of biomass is not efficient and causes air pollution. But, if biomass is combusted at high temperature and with low oxygen supply, biomass is converted into producer gas. Producer gas consists of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. It has a low calorific value of 1,000-1,200 Kcal/Nm^3 compared to natural gas or liquefied petroleum gas but has high efficiency without emitting smoke. After cleaning, the producer gas can be used to operate IC engine(Ravindranath, Somashekar et al. 2004).

Since the last two decades, biomass gasification technology has been developed intensively and it can be applied for various purposes such as thermal use (cooking, steam generation, drying etc), motive power in IC engines for water pumping and electricity generation.

Biomass gasification gives economic advantages to locations where biomass is available at lower price and industries use fuel wood and has also shown successful application for village electrification. Electricity from this system provide village with basic service like lighting, drinking water and further service related to income generation activities like irrigation and flouring milling service.

2.2.4 Wind turbines

The basic principle of wind energy technology is to converting kinetic energy of moving air masses with the wind turbine blades into mechanical or electricity. The power generated from wind turbine is directly related to the wind speed. Therefore, good wind speed is important to decide feasibility of any wind energy project. It is more competitive in the comparison with solar PV, biomass based power system and diesel generators, but expensive than other micro hydro systems.

2.2.5 Small diesel-power generators

As conventional technology, diesel generator is widely used technology in the remote areas. The fact that it is reliable and quickly installed is the main advantage of diesel generator. Electricity from diesel generator is directly fed into the existing grid or consumed to solve power shortage and frequent blackouts. And diesel generators are possible in various capacity ranges from just few watts and upto megawatt.

Although it has shown field success and potential for decentralized electricity in rural areas, diesel generator causes environmental effect because diesel burning emits high amount of $CO_{2,}$ engine makes noise and frequently contaminates soil and groundwater.

2.2.6 Microturbine

Mircoturbines are very small turbine containing one moving part and use either air or oil for lubrication. Currently, the capacity of unit rages from about 25 kW to 75 kW and microturbine unit costs 1,000 to 1,500 US dollar per kW and cost to make electricity appears between 7.5 and 10 US cent(DOE 2000).

So far, the barrier of technology was efficiency. It drops rapidly to 10 to 15 percent when loaded at half. But, efficiency improvement carried out sees promising future of technology and commercial operation. Once efficiency is improved, the technology can be used for off-grid applications.

2.3 Conceptual framework

A various forms of DG technology have been applied to provide electricity and to achieve further development of the villages in the remote area. Once the distributed generation with renewable energy technology is adopted, it is important to focus on how the chosen DG technology produces electricity and meet the power needs of populations in the village.

The way the DG technology functions and output they create can be varied in accordance with the social, economic and environmental context surrounding the technology system. And potential benefits resulted from DG technology may be achieved only through the process that harnesses the social and financial context of village life(Biswas, Bryce et al. 2001). Therefore, this paper studies the village electrification cases with the inter-related approach between the chosen DG technology and the village life. In terms of the inter-related approach, the DG technology affects the village development by providing electricity and in turn, the village influences on the appropriateness of technology. In other words, the function of a technology is best understood in the consideration of the circumstances where a technology has been placed. Then, what are the indicators that make the chosen DG technology more appropriate in the village?

Schumacher discussed the concept of ‘appropriate technology’ in his book, *Small is Beautiful*, suggesting that essential part of appropriate technology as simple, small scale, low cost and non-violence and people should completely control the technology(Schumacher 1989). As seen his statement, the capabilities of entity which employs technology to solve the problems are highlighted in deciding what appropriate technology is for human. And it can be stated that the capabilities of entity are mainly concerned in social and economic aspect. In this view, the indicators concerning social and economic capabilities for assessment of the appropriateness of DG technology in the village can be obtained. With Schumacher's 'appropriate technology' criteria, this paper has obtained three indictors – affordability, institutional capacity and replicability.

2.3.1 Affordability

It means the capacity of the target users to afford the acquisition and maintenance of DG technology. Affordability to acquire DG system is related with economic ability of villagers. In most of DG systems application, the cost is mainly recognized as one of the main barriers for its use(Mala, Schl?pfer et al. 2008).

Affordability to maintain DG technology means social and economic capability after the DG system is established in the village. It offers reasonable basis for villagers to comprehend the technological process and technology can be sustained at the village level. DG power generation system should be able to operate beyond the initial funding period. Therefore necessary arrangements for maintenance like local skills, monitoring, on-site services and spare parts supply are required to sustain villagers' satisfaction with DG technology and to completely control the whole DG system. The lack of comprehension of DG technology has led to failures in the international efforts wasting individual or group resources(Wicklein 2001)

2.3.2. Institutional capacity

DG system is only available through ¡°decentralized planning and implementation, holistic development, integrated promotion of rural energy technologies, multiple use of natural resource and energy, coordination and synergetic collaboration¡±(Koirala 2007). And village organization can be foundation for all these works. Therefore, capacity of village organization is critical for the appropriate DG technology. Organization development is the institutional platform in the village electrification for the villagers to come together. In the village electrification process, the role of village organization is to

- encourage local people, both males and females,
- make people aware about the importance of social capital to initiate development work through self-help approach,
- raise awareness among village members about the adverse consequences of the unsustainable use of energy systems,
- mobilizes village resources and skills to undertake DG systems
- enhance skill and capability to manage and utilize energy resources for various socio-economic activities
- promotes self-governance

2.3.3 Replicability

Replicability is an indicator to ask whether the particular DG technology can be used to provide electricity to the village((Zerriffi). It includes available materials and resources for DG technology to operate in the village. Many renewable energy projects just come to an end as monumental event or can be replicated on the different scale according to resources the village have. Evaluation of the level of replicability of DG technology would be decided by the comprehensive consideration of other two affordability and institutional capacity.

Figure 3. Conceptual Framework: Indicator to evaluate appropriate DG technology

Chapter 3 Case 1: Nepal

3.1 Nepal context

Nepal mainly consists of hills and mountains. A number of villages of Nepal are found at the remote and high altitude. According to the estimation of the end of 2006, Nepal’s population is to be 28.5 million **Error! Reference source not found.**. About 10 million of populations live in the remote mountain areas where the fundamental infrastructure couldn’t reach them. So, in these areas, energy requirement is low for consumptive use of energy like cooking and heating because of scattered settlement patterns and insufficient development of either road or national grid.

Condition of Nepal is in line with the statement of IEA that lack access to electricity and dependence on traditional biomass lead to poverty in developing countries. The national average electricity consumption per capita was under 70 kWh per year in 2003-2004(Alex, Kimber et al.) Since Nepal has so poor fossil fuel, they have to import widely used fuel resources such as kerosene, diesel, petroleum, LPG and coal from India. The cost for importing fossil fuels is burden for this one of poorest countries and Nepalese.

Himalayan households that can’t afford to buy expensive fossil fuel in the remote villages use precious trees for cooking, heating and lighting. For these purposes, 20-40 kg of firewood is consumed per day and smoke from firewood burning pollutes the indoor of house and directly affects health of women and children, in particular. This causes respiratory diseases, blindness and heart problem (IEA 2002).

Annual population growth in Nepal is 2.27 percent which can give clear sign of over-exploitation of natural biomass and deforestation to provide necessities of life. Monitoring data shows that forests are annually decreasing by 1.7 %(Koirala 2007). Consequently, deforestation results in lack of firewood and forces people to go far away spending up to seven hour every second day to gather fuel wood **Error! Reference source not found.**.

But, Nepal is rich in renewable energy resources like water and sunlight and some hills and mountain areas are suitable to utilize the local wind energy on a small scale. And Nepal’s hydro power capacity is estimated to be 83,000 MW with running off water of 225 billion m^3 from over 6,000 rivers.

3.2 Village electrification in Humla with PV

Given these characteristics of energy status and the fact that mountain areas are very scale-sensitive due to their fragile nature, distributed generation through renewable energy technology is more suitable in mountain areas. In particular, Nepal has annual 300 sunny days and lies in the 30^o North ideal solar belt(Alex, Kimber et al.). Solar irradiation measurement on tracking frame for solar PV module during 2004-2005 showed that Humla had the highest value of 9.9kWh/m^2 per day on a sunny day in November(Alex, Kimber et al.)

In Simikot, Humla, there has been a solar PV system installed by French government development project in 1989. Since the late 90s, the system has provided only DC power, because inverters for AC power failed due to poor maintenance, lack of spare parts and skilled people. Currently, only 1-2 hours of indoor lighting a day with incandescent bulbs is provided(Alex, Kimber et al.)

3.2.1 Living condition

Humla is the part of Nepal's northwestern area of Nepal. Humla is isolated from the national development due to its remoteness with no access to a road or grid system. It takes 16 days of walking from the nearest road to reach Humla's district center Simikot. UN's Human Development report shows that Humla area (the Karnali Zone) is the least developed area in Nepal with an HDI of 0.244. Humla has suffered from permanent food shortage, environmental degradation, poor productivity, annual epidemics among people and livestock, weak education system, inhumanity toward women and growing migration to search for work to feed families.

3.2.2 Feature of village electrification system through RAPS

Humla doesn't have connection to the on-grid. The fewer grid extension to the rural areas is experiencing frequent overloading, low reliability, high line looses and power theft(Alex, Kimber et al.) And there is prediction that this situation will not be improved just in a few years. That's because Humla is in the most difficult terrain with high, snow-covered peaks, thick forests, wild rivers and harsh climates. Geographic disadvantages increase cost of the grid extension. Humla has no previous experience to have power access in the form of electricity.

Elementary village electrification was designed by corresponding to what the users demand in energy service. They answered what the most important energy service in the remote village is light. It has been undertaken by RIDS (Rural Integrated Development Service)-Nepal village project in Humla since 2004, adopting embedded power generation by utilizing locally available renewable energy resources like streams and sunlight. This is power generation project generating small amount of energy through RAPS (Remote Area Power Supply) system. A RAPS can be defined as power generation system within or near to the village using locally available renewable energy sources that are either single or hybrid system of several renewable energy resources like combination of renewable resources with a diesel or petrol generators, battery charge control system, battery storage and inverter. What determine the kind and size of the RAPS system are locally available energy resources, community's average energy demand and their affordable paying budget(Alex, Kimber et al.).

To provide solution for lighting in the Humla, power generation and light power consumption started to be improved. As what people demanded is lighting, less power needed to be generated. In several villages and single homes of Humla, lighting system through PV (photovoltaic) has been installed. This lighting system mainly consists of three WLED lights which are powered 5-20 W_R solar PV module, a relevant battery bank and charge/discharge controller for a cluster of one to four homes, or from a 75 W_R solar PV systems for a cluster of 15-18 homes. WLED lamps which consume just 1 W per lamp are used and WLED provides sufficient light to see each other and to do daily task in the house. Before using WLED of 1 W for lighting, they used 'jharro' which is a pinewood stick soaked with resin.

3.2.3 Benefits

Social benefits

Villagers in Humla adopted WLED lights for indoor lighting, instead of burning 'jharro' which has been previously used to generate light. With WLED lighting, people have much brighter light with cleaner air in the house and avoid black soot from burning 'jharro' and reduce negative impact on human's respiratory system[1](4). Advanced form of lighting has impact on the improvement of health of villagers in Humla. Electrical light pulls up the level of education by enabling children and adult to study after work of daytime and from the view of long-term, it can raise the literacy rate, self-confidence and independence of villagers. And light service makes

[1] 51 % of baby boys and 45 % of baby girls have respiratory disease.

social life like news exchange conversation and story telling more enjoyable and therefore, unity of village can be strengthened.

Economic benefits

Small activities to generate income are available with provision of minimal electrical light in the house after dark. Knitting, weaving bamboo and making handicraft are conducted among family members during evening time. Electrical lighting can boost income by increasing their skill and expanding labor time.

Environmental impact

In the past, to produce ‘jharro’, pine tree’s bark and top layer of wood had been cut. Then, the tree made resin to cure wound itself. After the tree was healed producing resin, people cut out the healed layer and deeper part. This is so soaked with resin that burns very well. With the heavily repeated activities being wound and healing with protective resin, the wood will slowly die until it can’t produce resin any more. Exploitation of forests causes deforestation in Humla area and Himalayas.

3.3 Analysis on feasibility of the DG technology

3.3.1 Affordability

Lighting technology used in Humla is WLED lighting system. Before WLED, incandescent bulbs are installed in most homes. While the expected life time of 1 W WLED light is between 50,000-100,000 hours according to the manufactures, an incandescent bulb has life span of 750-1,000 hours. Incandescent bulb is easy breakable and difficult to get a new bulb in the remote areas. The village cluster solar PV systems in Humla have the trained local operators. Each day power provision from the cluster power house is undertaken by the local operators. The capacity to maintain the solar PV system and WLED lighting system can be evaluated as feasible - local skill can be improved through the cluster solar PV systems; the well-trained local operators provide on-site service near the village; WLELD lamps are also easy to maintain for the villagers in comparison to the existing incandescent bulbs.

The capacity to acquire solar PV system and WLED lighting system in Humla is heavily dependent on the external funding resource. Most of the households of rural villages like Humla will not have economic power to buy WLED lighting system. So, from the long-term perspective, end-users need to participate through financial contribution even though donor agency mainly provides funding for the system to sustain the energy and lighting system. And local community’s financial capability to participate in the initial stage of the project cost as well as in the operation and maintenance of the project has to be ensured.

3.3.2. Institutional capability

Humla adopted village cluster solar PV system. Up to 15 houses in proximity to each other are interconnected through armored underground cables in a cluster. The house in the geographically middle is the cluster’s power house with solar PV module of 75 W_R on the rooftop. And in the house, charge-discharge controller and suitable size of well-insulated battery bank are installed. The WLED lighting system consists of three 1 W WLED lamps per house. Thus around 45 WLED lamps are connected to 15 houses of cluster. The village cluster solar PV system has been installed as part of holistic village development in Humla since January of 2005. To manage cluster power house system, local operators get trained. They provide power twice from the cluster power house to each connected house for totally up to 6 hours, 2-3 hours in the morning and 3-4 hours in the evening. Village cluster system gets the whole village motivated for the elementary village electrification because it brings dynamic, skills and work force to the project. And each person of the village who participates in can have the sense of ownership of the power systems.

3.3.3 Replicability

Technical expertise is limited in the remote village and transporting cost for carrying equipments is very high for most of the geographically disadvantaged areas. These problems raise question what makes DG technology affordable. Elementary village electrification in Humla have identified what villagers really need to have the basic lighting system and therefore, aimed to provide more advanced type of light with village electrification through solar PV. As a WLED (white light emitting diode) light applied in the Humla case needs only 1 W per lamp, a smaller system was needed to generate less power for the light. Smaller systems are easier to install, operate, maintain and repair in the case of defect. The manufacturers say the expected life time of WLED is between 50,000-100,000 hours. For minimal lighting purpose, WLED lamps are the most suitable solution to meet the village peoples' demand.

For solar PV system, it is important to use locally available materials and resources in the village. In this sense of replicability, using and installing as much as possible locally manufactured equipment for solar PV system. It can make additional benefit besides provision of good basic lighting system by strengthening local industry more independently.

Chapter 4 Case 2: India

4.1 India Context

Electricity generation has considerably developed since it gained independence from British colonial rulers in 1947. Generation capacity has increased many times through conventional way of large coal-fired power plants and big dams. As economy develops, demand for electricity continues to exceed amount of supply and it results in lack of energy all over the country. The annual increasing rate of energy consumption in India is 4 percent (Bank 2000). And almost 40 percent of power is lost in the process of transmission and distribution. With energy shortage issue, the major challenge India face is that 80,000 villages have to be electrified and about 77 million households lack access to electricity.

The total capacity of installation of India amounted to 109 GW in 2003 and 5 percent of which is shared by renewable. Renewable sources have the potential to provide large opportunities for the power generation in India. For example, as the fifth largest country in wind energy capacity around the world, wind produces nearly half the total renewable power(Reddy, Uitto et al. 2006).

	Potential (MW)	**Achievement (MW)**
Wind	45000	1702
Small hydro	15000	1463
Biomass power	19500	468
Solar PV	20/KM2	25 MWe

Table 1. Energy potential and achievement of Renewable sources (MNES 2002-03)

Renewable energy can solve the problem of electricity in off-grid areas. Indian government has taken an effort to develop distributed technologies. The national electricity policy proposed village electrification by creating rural electrification distribution backbone (REDB) with at least of one sub-station in every cluster of few villages**Error! Reference source not found.**. In village or community, renewable resources have been used in the form of distributed generation without being connected to grid. As, grid extension needs technical and regulatory matters to be arranged, distributed generation in village context has to be necessarily independent from grid. Under distributed power generation with locally available renewable sources, electricity local people demand is met from power station installed in the villages, which is based on renewable sources – biomass, solar, wind and mini hydro. Electricity generated in the village is distributed to industries, households and public facilities through a village level distribution network. People in the village run the whole system by themselves without any intervention of the electricity utilities of government or other agencies.

4.2 Village electrification in Hosahalli with biomass gasifier

4.2.1 Biomass-based power in India

Major available options for distributed power generation are biomass, solar and mini hydro. Annually, about 200 million tones of firewood and the equivalent amount of residues from agriculture are burnt in India with very low efficiency in end-use. There is wide range of gasifiers with capacities varying from 20 to 500 kW for electrical application in India and research and development to develop and refine various biomass power generation are underway. TERI (The Energy and Resource Institute) designed a gasifier system suitable to gasify firewood as well as briquettes made out of agro-residues and industrial waste. And they are developing low-cost membrane filters using biomass ash and technologies for treatment of wastewater from biomass system. Combustion of biomass with the controlled air supply generates producer gas constituting H_2 (20%), CO (20%) and CH_4 (1-2%). The producer gas can be used as fuel to operate internal combustion engine for mechanical and electrical applications. Among biomass resources, woody biomass grown in waste-lands is considered to have the largest potential for rural electricity needs in most areas of India.

4.2.2 Feature of village electrification system

At Hosahalli villages of Tumkur district, 20 kW of distributed power generation through biomass gasifier system was established in 1997. Hosahalli was not electrified and didn't have any pumps or a flourmill at the moment of initiating biomass gasifier system. Kerosene was previous resource for lighting and farmers occasionally hired diesel engine to pump water for irrigation before adopting biomass gasification. After discussion was held within village communities, energy forests were formed in 1988 and gasifier-based generation was installed in Hosahalli in 1998(Ravindranath, Somashekar et al. 2004).

Description of Hosahalli	
Year of establishment	1988
Number of households	35
Population	218
Energy plantation raised (ha)	4
Installed capacity (kW_e)	20
Installed end-use capacity	
Lighting	4.0
Drinking water	2.6
Flour mill	5.6
Irrigation pump	18.5
Installed end-use capacity(TOTAL)	30.7

Table 2. Feature of biomass gasification

This system was operational for over 90 percent of the days during 1998-2003 in Hosahalli. The annual total electricity generated varied from 12 to 22 MWh. The system was occasionally replaced by diesel system, if gasifiers cannot function. This duel fuel system needs the use of diesel to start up operation and to support auxiliaries. Under the conditions of high diesel substitution, major portion of energy is from the producer gas, while energy from diesel is small.

To make distributed generation system more viable, maximizing capacity of utilization is important. Therefore, generating demand for power with various activities needs to be made. Irrigation water pumping is one of the potential activities to make income and generate load to farmers. The cost of irrigation including water and power accounted for 10-20 percent of gross income and the rate charged per irrigation is based on the current rate charged for diesel power pumping.

And this case adopted a fee for service in consultation with the village community. They convinced villagers to accept service fee system for the sustainable finance by providing people with all of information about inputs and costs. The village community and the scientific experts jointly decided the tariff. Fee for lighting was R_S 5/bulb-point/month, R_S 10/household/month for water supply through the pipe. In deciding fee of service, what should be considered is that affordability of households. In addition, all of the households have to benefit from lighting and water supply and irrigation service should be profitable to all farmers equitably. .

The cost per kW is based on fuel and operation and maintenance cost. Plant load factor mainly contributes to fuel cost and operation and maintenance cost consists of engine maintenance, gasifier maintenance and operator's monthly salary. The operation in Hosahalli is carried out by using diesel engine as dual fuel system. Development of producer gas based engine system decreases use of diesel and further eliminates it. Therefore, switching to gas-alone mode from dual fuel system could reduce the cost of electricity by about 25 percent.

4.2.3 Benefits

Social benefits

Each household could have reliable and safe water with provision of electricity from DG biomass gasification. It took away women's labor burden of carrying water from water pond and quantity of consumed water has increased. Safe and enough quantity of water could improve health of women and children. Electricity for lighting also could change the livelihoods of women and children, in particular. Women used to walk a long distance to neighboring places to work, but they don't need to do since flourmill has been installed in the Hosahalli village.

Economic benefits

Electricity from DG with biomass based gasifier could generate income activity and employment and increased crop production. Farmers started growing labor-intensive cash crops with advanced irrigation capacity. Through the whole process of biomass gasifier system, employment has increased and income activities were created in the establishing energy forest, harvesting, transportation, wood-fuel chips and preparation and operation.

Environmental impact

Energy forests established to prepare input for biomass gasifier play the role to conserve soil and water in the land. Biomass produces lesser or no ash production compared to coal fuel and finally emits much less sulphur. Diesel, kerosene and coal fuel combustion emit CO_2 and other greenhouse gases. The distributed generation through biomass-based gasifier substitutes diesel, kerosene and coal fuel and contributes to the reduction in the greenhouse gases emission. And as forestry is widely known for mitigating climate change, energy forestry can also sequester carbon in soil and trees.

4.3 Analysis on feasibility of biomass gasifier

4.3.1 Affordability

For the biomass gasifier system in the Hosahalli, CST (Center for Sutainable Technologiesy) obtained funds to implement the system in the village. And this case adopted a fee for service to make finance sustainable. The local operators have the responsibility to collect the service fee with the help of the village community.

Year	**Domestic+Flour mill bill amount**	**Amount collected**	**Percentage recovery**	**Irrigation bill amount**	**Amount collected**	**Percentage recovery**
1998	9465	6051	64	-	-	-
1999	9570	5564	58	-	-	-
2000	9790	3622	37	-	-	-
2001	11655	10965	94	10560	8640	82
2002	10475	10388	99	17720	13480	76
Total	59270	40440		40940	32240	
			68			79

Table 3. Tariff collection in Hosahalli for provided services

The payment for domestic and flour mill is nearly close to 100 %. It is very rare in India for any services provided by utilities to have the complete recovery rate(Ravindranath, Somashekar et al. 2004). Recovery for the irrigation is also high in the range of 76 to 82 %. According to the tariff collection data, approach to fix the tariff on the service is likely to be affordable to the village. And the rate charged per irrigation, based on the current charge for diesel-based pumping is R_S 40/h, which is affordable to farmers.

But, the human resource to operate the system was very limited in the case. Only one trained operator was employed due to financial constraints. To run the system effectively, a number of operators need to be trained in the village. In line with recognition for enough operation resources, local youth are trained to operate minor maintenance of the system.

4.3.2. Institutional capability

In Hosahalli village case, the village community contributed to the effective biomass gasification system. In order to sustain the entire energy system, community participation and meetings were held. The village community gave explanation of biomass gasifier technology and benefits of the project to the villagers and defined the roles and responsibilities of individual. And the village committee was developed for the purpose of management. They decided operation of system, supervised the operator, protected the energy forest to supply firewood regularly and ensured payment for the provided services.

4.3.3 Replicability

Wood chips are the major input sources for biomass gasifier system. In particular, cutting and drying energy wood is a problem during rainy season. Planting and harvesting wood in the energy forestry and cutting to the suitable size of pieces need appropriate labor capacities in the village. Therefore during peak crop season, there is lack of wood chips due to limited labor. When cut and dried wood chips are not available, power generation system is operated on diesel engine system. But it’s frequent that diesel is not accessible to the gasifier system operators.

To mitigate input constraints in biomass gasifier system, some measures need to be developed. First, storage facility for wood chips should be created in response with the rainy season during which wood chips are not available. And additional mechanical system for cutting and drying wood is needed to solve lack of labor during peak crop season by using exhaust gas of engine.

Generally, the level of replicability of biomass gasification is high, because this system can be installed and operated in any village where biomass is available. The potential of the broad application is the unique characteristic of the biomass gasification. The operation time can be varied from 1 to 24 hour a day with the amount of load.

Chapter 5 Case 3: Sri Lanka

5.1 Sri Lanka context

The household electrification rate has increased from 62.4 % in 2001 to 76.7 % in 2005. At present, around 79 % of the households in the Sri Lanka are electrified. The current electricity capacity of Sri Lanka is around at 1,835 MW. But this is too low to meet the demand for power especially in considering that demand for power is annually increasing at 8-9 % rate. Large hydro facilities account for 60 % of power generation. However, now most of large hydro potential is coming to an end. Large short of energy has already started. Only 60 % of the total 18 million populations have access to on-grid electricity and over half of the rural households have remained to be electrified in the least economically prosperous and the most remote area.

State-owned electricity utility, the Ceylon Electricity Board (CEB) has been trying to build a 900 MW coal-fired power plant. That's because all additional generation capacity is established on commercial and least-cost basis. But besides negative environmental impact, growing dependency on imported fossil fuel will threaten Sri Lanka as it has no fossil fuel resources in its land. In this situation, Sri Lanka urgently needs alternative energy pathways by which to meet the energy demand of people(Seneviratne and Rossel 2004).

5.2 Village electrification through hybrid solar and wind power

5.2.1 Living condition

Pokunutenna village is situated at the border of the northeast corner of the Uda Walawe National Park and about 3 km away from the main road. People in Pokunutenna mainly cultivate rice and chena depending on the irrigation from the rain-fed reservoir or tank in the village. Around thirty households are spread over 2km^2 area and average income of a household would be around SLR 18,000 equivalent to 180 US dollar. People have used kerosene bottle lamps or lanterns for lighting(Ganesh Doluweera).

5.2.2 Feature of village electrification system

The system consists of a set of solar panels and wind generator as supplement facility. Generated power is stored in sealed deep rechargeable discharge batteries through a charge controller. Like any solar energy system, inverter converts the stored DC power into AC power. Then AC power is distributed through underground mini grid network within village to separate clusters of houses and street lamps.

In each cluster, there is a power distribution box to provide maximum 50 W to each household. In order to activate the village and to grant ownership to the village, official and a general committee was elected and village co-operative society was formed. Officials and the general committee govern its operation with the basis of constitution.

5.2.3 Benefits

Social benefits

Risky factors in using a bottled kerosene lamp have reduced while the quality of light has improved quality of livelihood, allowing children to read at night and driving out the threat of wild animals. Health and safety has been improved as elephant attacks and snakebites. Explosive populations of elephants keep putting pressure on forest land and raiding crop in Sri Lanka. To tackle the conflict with elephants, the field station for detecting elephants was set up in Pokunutenna. In this project, various detecting tools were used with the provision of electricity from hybrid solar and wind power system.

The village structure could be strengthened ever through co-operative way of work in the village electrification process. The villagers got importantly recognized in management and operation of the village electrification system and made opportunity to have their own voice.

Economic benefits

Small scale of power generating systems with renewable resources creates micro-enterprises in the village. The internal rate of return (IRR) of a typical solar power station system is 13 %, based on that 40% of the initial investment is government subsidy and monthly tariff is SLR 400 per house. For example, for the rechargeable flash battery charging micro-enterprise, IRR can be derived to the village societies through the micro-enterprise and respective societies fund such micro-enterprises.

Environmental impact

Pokunutenna is a typical buffer zone village in Sri Lanka, adjacent to conservation areas or within biodiversity abundant areas. Sustainable environment of these buffer zone villages is critical for global level of sustainability. A buffer zone like Pokunutenna village bordering national park and protected areas has benefit in the conservation effort through electrifying village with renewable resources.

5.3 Analysis on Feasibility of hybrid solar and wind power

5.3.1 Affordability

To install the hybrid system of solar and wind power station and distribution Pokunutenna, SRL 40,000 equivalent to 400 US dollar is required per household. From the national point of view, installing the hybrid system is much less than subsiding the utility to extend national grid, estimated to cost 800 US dollar per household while village itself are not be able to afford to invest to the hybrid system. Pokunutenna's village electrification system is maintained by the monthly tariff. Current monthly tariff of SLR 75 per household is collected to make fund and the local bank manages the fund. It could be used to make the future common good and manage the core system(Seneviratne and Rossel 2004).

On the average rural households of Sri Lanka have spent around SRL 400 (4 US dollar) per month to get kerosene and disposable flash battery. This budget could be used to invest to distributed energy generation system. In addition, individual expenses for operating like replacement of bulbs could be made by the respective households within the village.

Small-scale micro enterprises created with expansion of the system can provide paid employment in the system operating job within the village. With these operating persons, village can acquire more stable and sustaining operating skill. In addition, the battery-charging center, an example of micro-enterprises in the system has already been set up and it makes maintenance of the system more feasible(Allerdice and Rogers 2000).

5.3.2. Institutional capacity

Village co-operative power generation in Pokunutenna is undertaken by the coordination and the synergetic collaboration in the village. This formed the village co-operative society in the Pokunutenna area. The village co-operative society, as an institutional platform, governed the operation of hybrid power generation system. It consists of the elected officials and general committee with a constitution and law for governance of the system operation. Village co-operative society gives the ownership of the system to the villagers and consequently, it enhances skill and capability of the villagers to manage and utilize energy resources for various socio-economic activities.

5.3.3 Replicability

In this case, as seen economic benefit section, potential to replicate and expand hybrid solar and wind power stations could be relevant with the formation of small-scale micro enterprises. The advantage of micro enterprises is that they would address what villager need and provide service according to the specified needs. In the village-based renewable energy system, micro enterprise support plays the role business incubator services and promotion of productive use(Allerdice and Rogers 2000)

Chapter 6 Conclusion

Electrifying the village in the remote area with the conventional grid extension has been limited by facing economic and geographical constraints. Energy and electricity are the most principle elements to sustain daily lives. They have the close relation with social, economic and environmental development. At least developed countries, just a few watts of electricity use would show the dramatic change in the HDI. In consideration with the role of energy and electricity in sustainable development, it should be urgently taken to get the un-electrified to have electricity.

Distributed generation with renewable energy technology would be viable option in many ways. According to the definition of this paper, distributed generation is that the power is locally generated and locally consumed. It doesn't need to be connected to the grid system. And distributed generation is usually conducted with the locally available renewable energy technology like solar PV, biomass gasifier, wind etc. However, the distributed generation technology clearly has the varied outcome in the different village context. And conditions under which distributed generation technology make genuine contribution in the village electrification are examined with three indicators – affordability, institutional capacity and replicability.

6.1 General findings

Affordability

- Acquisition of the DG technology is not determined by the external funding and the national subsidy. The capability to obtain the system should be resulted from the villagers' sustainable budget.
- Maintenance of the DG technology system beyond the initial achievement is critical factor to provide the village with the long-term benefits.
- By adopting the fee for service approach, the village can keep providing finance to sustain DG technology system, not solely depending on the external funding or subsidy. But what is important is that the service fee should be determined the economic condition of the village.

Institutional capacity

- Village organization does play a key role to operate DG technology system. Organization development can be more facilitated if the people were to be given the better quality of education and to find self-confidence with the social benefits from access to electricity.
- DG technology works best with the involvement of the villagers.

Replicability

- The level of replicability is determined jointly by both affordability and institutional capacity of the village
- Village electrification with DG technology can grow the local micro-enterprises dealing with the renewable energy technology. With the formation of micro-enterprises, village level electrification would be replicated. And interactively, village society supports micro-enterprises in their area.

And other findings related with village electrification is below

- DG technology system and power generation for village electrification should be completely based on the demand of end-users, their paying ability and available energy source in the village.
- Elementary village electrification is fundamental process as a step stone for moving toward higher level of development
- It is important for all of households and farmers in the village to have the benefits through electricity generated from DG technology without making marginalized area.

- In the village electrification of the poor rural area, DG technology should boost the income generation of residents either directly or indirectly.
- As DG technology system can be considered as more viable by maximizing the capacity of DG technology system, creating demand of end-users for power is needed.
- DG technology sometimes needs the additional mechanical system to complement input supply. Like the DG technology, these complement mechanical systems are run by exhaust gas of DG technology system.

6.2 Conclusion and next step

Getting access to electricity with distributed technology brings in social, economic benefit and environment improvement and those benefits also affect the function of distributed technology by constructing the better village condition to sustain the energy system. The better condition under which the chosen distributed generation technology can be an appropriate technology is examined with three indicators – affordability, institutional capacity and replicability. Through those indicators, village electrification projects with distributed generation technologies under the planning stage and on-going can be examined more objectively and realistically.

What determine the appropriate technology in the circumstances are the ability to afford the technology, the work of institution and resources to replicate the technology system, or integrated effect of three indicators. In this sense, there is no definite ‘appropriate technology’ under the variable condition. Therefore, to make DG technology for village electrification more appropriate, the constant monitoring and evaluation is necessary in the flexible circumstances. There is no question that the DG technologies always work in a proper way. To find deficit and widen the potential of DG technology, it is important to ask about appropriateness of technology applying the above indicators.

References

Ackermann, T., G. Andersson, et al. (2001). "Distributed generation: a definition." Electric Power Systems Research **57**(3): 195-204.

Alex, Z., H. Kimber, et al. "Renewable Energy Village Power Systems for Remote and Impoverished Himalayan Villages in Nepal."

Allerdice, A. and J. Rogers (2000). "Renewable Energy for Micro-enterprise." 2000.

Bank, W. (2000). "World Development Indicators, Development Data Center, Washington, DC.".

Benchikh, O. (2001). "Global renewable energy education and training programme (GREET Programme)." Desalination **141**(2): 209-221.

Biswas, W., P. Bryce, et al. (2001). "Model for empowering rural poor through renewable energy technologies in Bangladesh." Environmental Science and Policy **4**(6): 333-344.

Chaurey, A., M. Ranganathan, et al. (2004). "Electricity access for geographically disadvantaged rural communities?technology and policy insights." Energy Policy **32**(15): 1693-1705.

de France, E. (2002). "Electricity for all: Targets, timetables and instruments." EDF/DPRI.

DOE (2000). "Microturbine Systems, Programme Plan for Fiscal Year 2000-2006, US Department of Agency, March 2000."

Ganesh Doluweera, S. F., Laith Seneviratne "Can Community Solutions Help? Experiences in Developing a "Toolbox"."

IEA (2002). "International Energy Agency, World Energy Outlook, Energy and Poverty, 2002."

Koirala, B. (2007). "A Community Based Micro Hydro: A Promising Technology for Rural Development in Nepal."

Mala, K., A. Schl?pfer, et al. (2008). "Better or worse? The role of solar photovoltaic (PV) systems in sustainable development: Case studies of remote atoll communities in Kiribati." Renewable Energy.

MNES (2002-03). Ministry of Non-conventional Energy Sources, Government of India.

Najam, A. and C. Cleveland (2003). "Energy and Sustainable Development at Global Environmental Summits: An Evolving Agenda." Environment, Development and Sustainability **5**(1): 117-138.

Nepal, G. o. (2007). "National Planning Commission."

Ravindranath, N., H. Somashekar, et al. (2004). "Sustainable biomass power for rural India: case study of biomass gasifier for village electrification." Current Science **87**(7): 932-941.

Reddy, V., J. Uitto, et al. (2006). "Achieving global environmental benefits through local development of clean energy? The case of small hilly hydel in India." Energy Policy **34**(18): 4069-4080.

Schumacher, E. (1989). Small is Beautiful: Economics as If People Mattered, HarperPerennial.

Seneviratne, L. and G. Rossel (2004). "Lighting up a village Community RE generating systems for the developing world." Refocus **5**(1): 26-28.

Sharma, D. (2007). "Transforming rural lives through decentralized green power." Futures **39**(5): 583-596.

Welfare, C. (2006). "www." from www.childwelfarescheme.org/about/nepal/facts.

Wicklein, R. (2001). Appropriate Technology for Sustainable Living, Glencoe McGraw-Hill.

WRI/FAO (1999). " The Challenge of Rural Energy Poverty in Developing Countries, World Resource Institute/FAO, October 1999."

Zerriffi, H. "Making Small Work: Business Models for Electrifying the World."

Zerriffi, H. (2007). "Making Small Work: Business Models for Electrifying the World." PESD Working Paper #63.