Case Study of a Solar Photovoltaic Elementary Lighting System for a Poor and Remote Mountain Village in Nepal

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

Signature: ..…Alexander Zahnd …..

Place: Kathmandu, Nepal Date: 31st October 2004

ABSTRACT

Nepal is situated in the lap of the Himalayas and landlocked between China to the north, and India to the south. The country is known for its natural beauty, and as the land of the highest mountains in the world. 88 % of Nepal's population live in remote and difficult to access mountain areas. It is one of the only countries in the world with a lower female life expectancy rate than the male. While in the cities it has become "normal" to have access to energy services, 85% of Nepal's rural communities are deprived of even the most basic energy services. 99% of the 2 billion people in the world that are without access to electricity, live in developing countries. Nepal is one of these countries, and four out of five live in rural areas. Furthermore, over 90% of the population of Nepal belongs to the 2.4 billion people relying on traditional biomass such as firewood, agricultural residues and dung, for their day to day cooking, heating and lighting purposes.

The village of Chauganphaya, in the northwestern district of Humla, belongs to the poorest villages of Nepal. Here, as elsewhere in Nepal, the forests are gradually being stripped bare, to meet the minimum energy needs of cooking, heating and lighting for the village folk. Unfortunately this is being done without any sustainable reforestation efforts. Furthermore, cooking and heating indoors on open fire places has had a direct chronic impact on the health of village folk, resulting in the low life expectancy for women, and the high death rate of children under 5.

This thesis goes into detail about various lighting technologies available for the remote mountain communities and suggests that the WLED lights are a real option for elementary rural electrification. This conclusion has been drawn on the basis of an electrification project undertaken in the above mentioned village of

Chauganphaya. Efforts made through a solar PV village electrification project with low wattage WLED technology, were successful, in that all 63 homes of the village of Chauganphaya are now able to have three lights each in their homes. This was made possible with each light consuming only 1 Watt and with a locally developed and manufactured 2-axis self-tracking frame for the four 75-Watt solar PV modules. The Powerhouse with the self-tracking frame, battery bank and its charging and discharging units are centrally located in the village. The whole village has been divided into four clusters, with 15-18 homes per cluster. The central powerhouse is connected to the main house of each of the clusters by means of an underground power line distribution network through armored cables. Likewise, each house in a cluster is connected to the main cluster home by means of an underground armored cable. In this way the power distribution is approximately equal and in the case of one cluster distribution line facing a problem, the other homes in that cluster are not effected and will still have power.

This rural electrification project was not undertaken in a vacuum but as one part of a wider holistic grass root community development project. In the initial stage, a detailed survey, with questions specifically designed for this community was conducted, in order to assess the living conditions of the people. In the next stage, with the help of the outcome of the survey, four integrated projects were developed to improve the living conditions of the people. These projects aim to address the most urgent needs of the people as identified by themselves. Following is a gist of these projects:

- The rural electrification project with low wattage WLED technology.
- Each family from the Chauganphaya village has been able to purchase an improved smokeless metal stove at a subsidized rate. This has been specially designed to accommodate their cooking and eating habits, based on locally

available foods. It also heats their rooms for most of the year, and has provisions for boiling water.

- In order to be able to purchase such a stove at a subsidised rate, each household had to build a pit latrine, after undergoing a simple training in building such a latrine.
- The whole village community participated in the repair, and rebuilding of their village drinking water system, with the result that there are several tap stands to be found in the village.

The survey undertaken before any of these projects were carried out will be repeated once a year, to assess the actual impact these projects have, on a long-term basis.

Developing and carrying out these projects in the challenging environment we find ourselves in, with the ongoing political unrest and the continuing war between the Government troops and the rebels, and the ever present caste system has been an enormous task. Nonetheless, at the time of writing this, the electrification project should have been fully installed and operational. There are some minor improvements still needed, such as, the unexpected voltage drop in one cluster due to extended underground cable installation. Mitigation of that is planned as early as the political situation allows it.

The thesis goes into details about various lighting technologies for remote mountain communities, arguing that WLED lights are a real option for this purpose. In order to design a solar PV system according to the local conditions, it is crucial to understand the available solar energy resource. As no solar irradiation data for Chauganphaya or Humla are available, a study was undertaken to gather data from the NASA web site, and to generate solar irradiation data through the

METEONORM software tool. As both these methods rely only on satellite data, a solar radiation monitoring and data recording system was designed, built and installed in the KU HARS in Simikot. Since May 2004, the daily solar radiation is being recorded on a horizontal, a 30° south inclined, and on a 2-axis self-tracking solar PV frame.

The Simikot HARS and Chauganphaya solar PV systems are designed with a back of the envelope, as well as with a professional solar PV system design software tool, called PVSyst3.31. All the different equipment used in both PV systems are looked at in detail in this thesis. In comparison to the HARS and the Chauganphaya village PV systems, the Tangin village SHS project, installed by a private company through the Government solar PV subsidy program, serves as a comparative case study.

Sustainability and appropriateness are crucial factors, which have to be considered in any rural community development project. What is appropriate technology and how one can strive towards more sustainable projects, is looked at on the basis of the experience of the Chauganphaya village project.

"What can be Learned" tries to highlight the most important lessons learned form this project, up to the present stage. The thesis concludes, that the installed solar PV village system in Chauganphaya is an appropriate way to enable the poorest of the poor to bring light into their dark homes. It also reiterates the fact that additional to the lights, the smokeless metal stove, the pit latrine, and access to clean and pure drinking water, are important integrated parts of an appropriate holistic community development endeavour. It is expected that their synergetic effect will multiply the final impact upon the improved living conditions of the local community as opposed to their individual benefits.

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Muni Upadhaya Raj, the owner of Pico Power Nepal (PPN), who relentlessly worked on the implementation of all new ideas I put forward for the improvement of the WLED lights, the 2-axis self-tracking solar PV frame, the solar charge and discharge controller, electronic fuse system, lightning protection system, underground and house wiring cables etc., till a satisfactory level of quality and sustainability was reached.

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Preface

From 1996 – end of 2000 the writer has lived and worked in Jumla, one of the most remote, impoverished and underdeveloped mountain areas of western Nepal, developing and leading an extensive holistic grass root village community development project. More and more projects included the application of renewable energy technologies (RETs), in particular solar photovoltaic home systems, for elementary electrification for light. The designed and installed solar PV systems have undergone constant development, testing and follow-up, in order to become more appropriate and sustainable for the communities' context.

Since 2001, the writer has been working with the KU-RDC (Kathmandu University - Research, Development and Consultancy) Unit. As part of RDC's consultancy work various projects in the area of applied RETs, such as solar PV systems for whole villages in the remote and impoverished district of Humla have started with the local communities, and in collaboration with local INGOs/NGOs.

It is paramount to these projects to constantly improve the RETs applied, in order to better serve the poor and remotely located mountain communities in more appropriate and sustainable ways. At the same time it is important to continue the ongoing research in these fields of expertise as a University. In this way newly gained knowledge is put into practice through prototype testing. This provides a good foundation for the wider dissemination of practical applications in the local communities, addressing their enormous development needs in more holistic and sustainable ways.

Objective

The objective of this dissertation is the investigation of the design and design process, implementation and the social impact and technical lessons learned of an elementary solar photovoltaic lighting system in a remote and impoverished mountain village in Nepal.

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ABBREVIATIONS AND ACRONYMS

AC / DC	Alternating current / Direct Current
AEPC	Alternative Energy Promotion Centre (under the Nepali Government)
Ah	Amp-hour
AM	Air Mass
AMP	Amperes
A.P.C.S.	Analog Process Control Services ltd in NSW Australia
BOS	Balance of System
BTU	British Thermal Unit (1 BTU = 1,06 kJ, or 0.293 Wh)
°C	Degrees Celcius
CEM	Channel Extension Module
CFL	Compact Fluorescent Lamp
DANIDA	Danish International Development Agency
DDC	District Development Committee
DoD	Depth of Discharge
DT605	dataTaker 605
EPA	Environmental Protection Agency (a USA Government Agency)
ESAP	Energy Sector Assistance Project (run by DANIDA and AEPC)
GDP	Gross Domestic Product
HARS	High Altitude Research Station
HDI	Human Development Index
HMG	His Majesty Government of Nepal
IEA	International Energy Agency
ISPS	Institutional Solar PV Systems
KLDP	Karnali Local Development Program, Jumla, Nepal
KU	Kathmandu University
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
LOL	Loss of Load
l/s	Litres per second
LED/WLED	Light-Emitting Diode / White Light Emitting Diode
LUTW	Light Up The World, Calgary, Canada
m	Meter
MHP	Micro Hydropower Plant/Project
MJ	Mega Joule (1 MJ = 0.278 kWh)
MOLD	Ministry of Local Development
MOST	Ministry of Science and Technology

MOVCD	Metal Organic Chemical Vapor Deposition
MPP	Maximum Power Point
MTBF	Mean Time Between Failures
MW	Mega Watt (1 MW = 1,000 kW, or 10^6 W)
MWh	Megawatt hour (1 MWh = 3.6 GJ)
NEA	Nepal Electricity Authority (Government-owned), Kathmandu
NGO	Non-Governmental organization
NOTC	Nominal Operation Collector Temperature
NM	Nano Meter (1 nm = 10^{-9} meters)
NPV	Net Present Value
NREL	National Renewable Energy Laboratories, USA
OECD	Organisations for Economic Cooperation and Development
O&M	Operation and Maintenance
PPN	Pico Power Nepal
PSH	Peak Sun Hours
PV	Photovoltaic
PVSOL	Solar Photovoltaic System design software (Germany)
PVSyst3.31	Solar Photovoltaic System design software version 3.31 (Switzerland)
RAPS	Remote Area Power Supply
RDC	Research Development & Consultancy
RET	Renewable Energy Technology
RETScreen	Renewable Energy Technology Screening software (Canada)
RTD	Resistance Temperature Detector
SHS	Solar Home System
STC	Standard Testing Conditions
TWh	Tera Watt Hour (1 TWh = 1,000 GWh, or 10^{12} Wh)
UN	United Nations
US	United States of America
UV	Ultra Violet
V	Volts
VAT	Value Added Tax
VDC	Village Development Committee
W	Watt
Wh	Watt-hour
WECS	Water and Energy Commission Secretariat
WLG	Wisdom Light Group
Wp	Watt peak power output

US$1 = 70 NRp (Nepali rupees) / AU$1 = 50 NRp

1. Inspiration for the Dissertation

This dissertation is an integrated part of an ongoing applied KU-RDC research project, the Chauganphaya village solar photovoltaic (PV) system, running from June 2003 – into 2005.

The following points inspired the dissertation:

- To understand the conditions of the village through a detailed survey before the project started.
- What an appropriate lighting technology for the context could be.
- To design and install a solar radiation monitoring and data recording station in the HARS office in Humla.
- Monitoring, recording and interpreting actual solar irradiation data for Humla.
- Changes that were brought about in the community/families after the first 8 months of experience with light in their homes.
- Evaluation of the installed solar village PV system after 8 months in use.
- Crucial issues for such a PV system project with regard to sustainability and appropriateness.
- Lessons that can be learned from the solar village PV system project.

2. Introduction to Nepal

Nepal (see Figure 2-1) is situated in the lap of the Himalayas and landlocked between China to the north, and India to the south, between 26° 22' N to 30° 27' N latitudes, and 80° 4' E to 88° 12' E longitudes (Figure 2.1). Three diverse and extreme physiographic regions divide Nepal. The Himalayan mountain range to the north, with Mt Everest (8,848 m), the highest peak in the world, the hills and mountains in the central part, and the flat, almost at sea level, Terai in the south. Mainly two distinct people groups, the Aryans and the Mongolians, make up a population of 26.5 million. Nepal has a GDP of 243 US$ (in 2000)[1], and with 88 % of its population living in remote, difficult to access mountain areas. Nepal is one of the only countries in the world with a lower female life expectancy rate of 36 – 44 in remote mountain areas, and 58.6 years in urban vicinities. Men live longer, 40 - 48 years on an average in remote areas[2], and 59.4 years in urban settings. The high fertility rate (4.39 children born/women), indicates the high population growth rate of 2.26 % in urban areas and 2.5 % - 2.7 % in remote mountain areas.

Figure 2-1: Nepal Map (from www.maps.com)

3. Energy and Poverty in general and in Chauganphaya Humla

Cities "shine" in the nights and can be seen from far away. Access to energy services has become "normal" and it is so taken for granted, to the extent that we do not think of anything if we flick the light switch. On the other hand, in the remote, difficult to access areas of the world, many people are deprived even of the basic energy services. Does access to energy have a direct link to the impoverished conditions of the communities to whom energy services are not available? This section tries to highlight the issues related to this question.

3.1. Introduction

More than 99% of the identified 1.64 – 2 billion[3] people without access to electricity live in developing countries, and four out of five live in rural areas (see Figure 3-1)[4]

While today an estimated 2.4 billion people rely on traditional biomass such as firewood, agricultural residues and dung for their daily cooking and heating purposes, this figure will increase to 2.6. billion by 2030[5]. The International Energy Agency (IEA) in its World Energy Outlook 2002 book makes a harsh, though clear statement regarding the relationship between poverty and electricity access, by saying:

> "Lack of electricity and heavy reliance on traditional biomass are hallmarks of poverty in developing countries. Lack of electricity exacerbates poverty and contributes to its perpetuation, as it precludes most industrial activities and the jobs they create."[6].

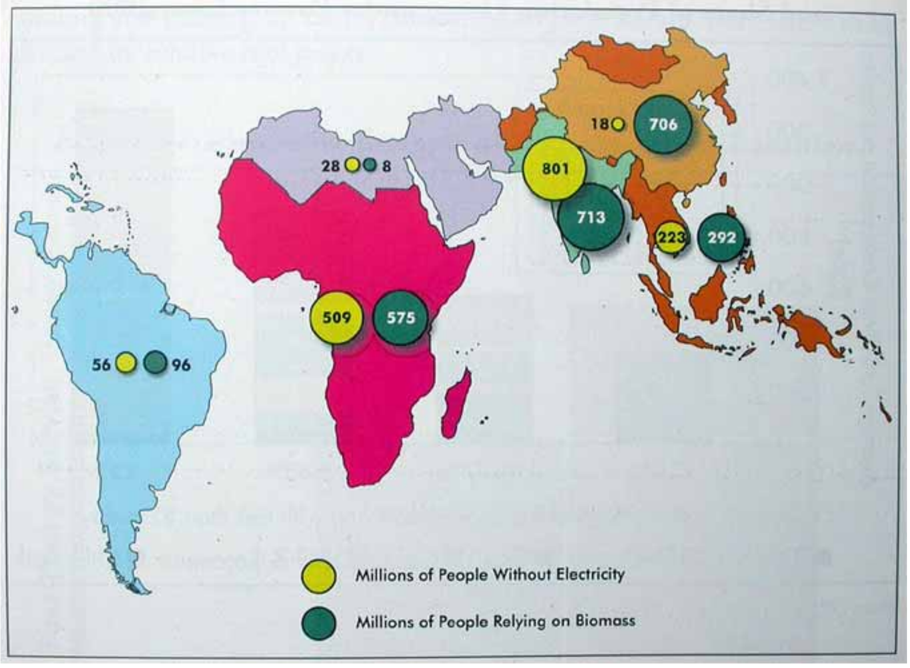


Figure 3-1: Distribution of the estimated 1.635 billion people without access to electricity, and the estimated 2.39 billion people relying on biomass[7].

To what extent can that statement be supported and how does it fit the context of Nepal's poorest who live in the remotest mountain communities? The first part of this section aims to look very briefly at some of the recently published literature with regard to the relationship between energy and poverty. The second part aims at more specific details on the impoverished mountain communities in the Nepal Himalayas, with a particular emphasis on the people living in the Chauganphaya village in Humla. In this village, beside other development project parameters, such as smokeless metal stoves, pit latrines and drinking water access for every household, a rural elementary electrification system was installed (see Chapter 12 for details).

3.2. Energy and Poverty with a more global Perspective

Energy and poverty issues have found wide public interest during the last decades, as many Governments have been pushed to start understanding and address issues such as the vast imbalance of energy consumption per capita around the globe. Many articles, workshops and even more seminars, with an international audience have been held to discuss issues responsible for the prevailing condition. Usually there is no shortage of resolutions and suggestions to change the status quo, though what actually has been achieved at the grass root level, to change this huge discrepancy on a global scale, is rather disappointing. And if the IEA is correct with their estimated figures for the year 2030, as mentioned above, it is not likely that the actual number of people who are fully dependent on traditional biomass to fulfill their daily energy demands, will come down by 2030, even though the actual percentage will be slightly lower due to the overall population growth of the world.

Most of the papers, focusing on energy and poverty in developing countries, agree that the extensive use of biomass for cooking and heating in traditional and inefficient ways (mostly in open fire places), with none, or very limited, access to modern energy resources (such as electricity and kerosene) are hallmarks of poverty[8] [9] [10] [11]. They also agree, that women carry a disproportionately greater burden in terms of poverty, energy access, and the availability of energy services in the developing world. Further it can be clearly extracted, that improved access to energy services will enhance the life of the poor in "countless ways"[12]. Thus access to energy services is one of the major underlying components linked to the achievement of grand scale poverty alleviation.

3.2.1. Energy, Poverty and Gender

Studies on poverty have recognised that the reasons and processes by which people fall into poverty are different for men and women[13]. Men in their young and middle age often migrate into more urban areas to find jobs to earn cash, while women are left behind for reproduction, household responsibilities and food production. The time spent on these responsibilities is often disproportionate when compared to their male counterparts in urban employment. Further the women do all these jobs on an unpaid (i.e. in the form of cash payment) basis, again as compared to their husbands, who are able to bring home cash money if they have found jobs in the city. Besides this, among disadvantaged people groups, the traditional inheritance patterns do not favour women, thus implying that the possibility for women to inherit property and earned wealth (such as house and land) is often restricted and limited. This is more so because these transactions are usually mediated through male kin. Men are also more likely to be the decision makers on behalf of the whole household, especially on issues related to the family's economic and progress.[14].

The poorer a household, the greater the time, physical effort, and health burdens put upon women and young girls. The absence of simple, appropriate technologies, such as a more fuel efficient smokeless stove, not only demand more time for firewood collection, but also diminish women's capacity to undertake other productive activities. The disproportionately high health impacts on women, young girls and children who are exposed to these hazardous conditions day-by-day, are further consequences of the unjust division of labour between men and women. Such gender inequalities that are based on, and deeply rooted in the social and cultural customs, mean that women on the whole have less access to productivity enhancing resources, such as labour, credit facilities, information and training[15].

These prevailing conditions make it necessary to actively involve women in the decision making process for any planned energy projects, as otherwise once more they are the ones less likely to benefit, even though they are at the center of the household's energy production and consumption. To involve them means to empower them and to enable them to improve their own working and living conditions, and by doing so, automatically improve the conditions of the whole family.

3.2.2. Energy Services and Poverty

As shown above, energy related issues are often different for men and women, due to their division (and definition) of labour, and that is often well reflected in their relationship to the utilised technology.

The benefits derived from improved and easier to access services are often not clear cut but rather complex. They range from direct benefits of contributing to increased production and reducing sweat work in the immediate and short term (such as through a smokeless stove which consumes only half the daily firewood), to the contribution that energy can make to health, education and living standards, on the long term (such as through light in the homes, or pumping of water for irrigation). There are also more intangible benefits such as increased security (e.g. through street lights, or back up water storage through pumping stations, increasing the food security), or a sense of inclusion in the more modern society, e.g. through the access to improved communication facilities.

In general, in a given society men and women may have different perspectives and priorities on what kind and quality of energy services are needed, but they have also common interests, particularly in relation to long-term, sustainable life improvement strategies.

The replacement of traditional sources of energy (such as firewood or cow dung), with commercial fuels (such as kerosene and electricity) is known as the energy transition[16]. The history of the more developed countries has shown, that the balance between the various sources of primary energy has changed for all countries as and when their economies developed. For example this energy transition has taken Europe from wind and water, to coal and steam, through oil and gas, and now again to the renewable energy resources such as wind, and solar. As people acquire more material goods and possessions, they move up the energy ladder, i.e. from traditional biomass to fossil fuel commercial traded, energy resources, to more efficient or convenient energy sources, while at the same time moving up to end-use technologies that better suit their needs[17]. Even though not exactly equally prioritised by men and women, some of the major interests in improved energy services among the poorer communities and families include:

- Basic light services in the home.
- Smokeless cooking stoves.
- Heating.
- Agriculture (irrigation).
- Industry (more entrepreneurships and working places established).
- Communication.
- Transport.

It is important that one remains realistic in the euphoria of possibilities of increasing the energy services for the marginalised and poor. Too often, especially with planners and policymakers, the word energy is interpreted and seen as synonymous with the word electricity. It is therefore important to, firstly define energy services according to their output, and secondly in the way they are generated, meaning the technologies applied to provide them. Providing a remotely located poor community with a relatively small amount of electricity (Wh/day rather than kWh/day) through a village based solar PV system or solar home systems (SHS) may improve their lives phenomenally, as a simple thing as light inside their homes brings several basic changes, impacting health, education and social life. But it will not meet all their energy needs such as to cook their daily food, and heat their rooms during the winter. Figure 3-1 shows that in many areas where people do have access to electricity they still are dependent on the use of biomass, usually for cooking and heating. It has to be mentioned here, that all modern renewable energy technologies share a particular characteristic that in many cases limits their use and application by the poorer communities. They (with a particular focus on solar photovoltaic, micro hydro power and wind power) incur comparably high initial capital costs, even though the recurrent costs are very low. This is in comparison to the fossil fuel based services, such as electricity generated by a diesel generator set, which is readily available in all sizes, from less than 1 kW to several MW[18]. Thus the poorer the people in need of improved energy services, the less likely they are to invest through their own means, in a renewable energy technology based energy generation plant. This means large numbers of people and communities suffer from a vicious circle of energy poverty, meaning they are energy poor because they do not have the means to buy improved energy services, even if they have access to them, or are in close proximity to an energy/electricity supply (see Figure 3-2 and Figure 3-3). Increased access to cash becomes crucial both for poverty reduction and in order to acquire improved energy services. Improved energy services at the household level often demand an improved use of the traditional energy resource (e.g. through purchasing a smokeless stove) or switching to an energy resource demanding a conversion technology (e.g. solar PV), which costs money.

There are no easy answers or readily available solutions at hand to address all the various issues related to the improvement of energy services for the poor and disadvantaged. Furthermore, the supply of improved energy services to the poor and remotely located communities is by its very nature not a very profitable business for private investors. If energy service improvement projects are initiated, as described in the following three scenarios, there are realistic and modest profits to be earned by a business, particularly if the relevant economic, legal, social and physical infrastructures are in place. In the context of this chapter, three possible ways to break out of the vicious cycle of energy poverty are suggested:

1. *Through income generation:* It is indeed possible to escape the cycle of energy and poverty if through the improved energy services additional income, in the form of cash, can be generated. That can be achieved through the establishment of a new industry, increased output, enhanced production activities (new product lines added), or improved quality in the product.
2. *Through joint projects, with various stakeholders:* The stakeholder community is comprised of the local community (whose participation starts right at the initial project beginning), the sponsors, the project designer and local governing authorities. The sponsors provide the funds for the initial capital costs to get the project up and going, the local authority provides the legal support, and the local community participates in designing, the project, implementing it, and once the project is successfully realised, takes over the running and maintenance expenses.
3. *Through grants, subsidies and loans:* A project can be initiated and set up through various grants, subsidies and loans, taken on behalf of the local community. Once the energy services are accessible, the local people have to gain an income from the improved services, in order to pay back the various debts over the defined period of time. That option though is very much dependent on the level of grants and loans available, and the conditions to pay back.

In the case of the Chauganphaya elementary village electrification (see chapter 12), only option 2 is viable, as the main aim of this project is to enable the people just to have lights in their homes (thus is called elementary village electrification as it is the first time in the village's history that electric lighting has been made available). The project was not planned to have any electricity consuming income generation schemes launched, but to provide just lighting service, as a first step towards the alleviation of poverty, and improvement in the quality of life in the homes (as seen in Figures 4-6 and 4-7) [19].

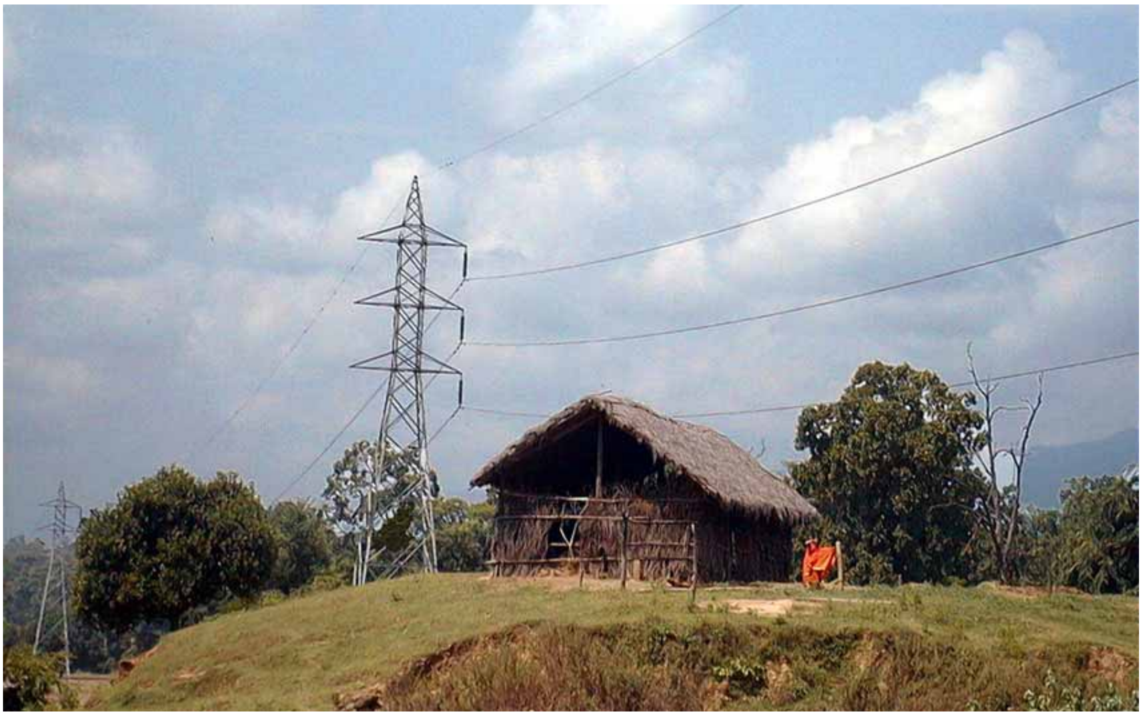


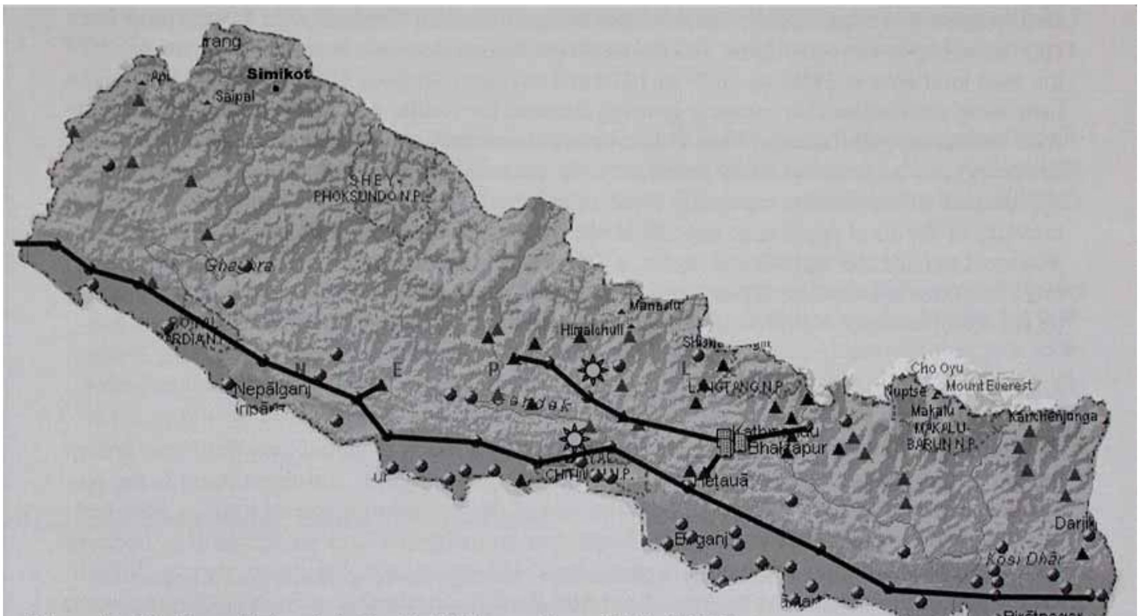
Figure 3-2: Grid Electricity Transmission lines but with still no Power in the Home

Though electricity is in close proximity (providing even land to put up the electricity poles as can be seen in Figure 3-2), the homes of this village in western Nepal have no access to it. It shows that while the overall planning for the electrification of Nepal is taking place, it is done only on a large scale, and mainly only for cities of considerable size, population and easy accessibility. Thus the grid electrification happens predominantly in the flat low altitude areas, and not in the more remote, medium to small size villages (even if they are also in the flat, low altitude parts of Nepal, as can be seen in Figure 3-2). That raises important points for discussions such as:

- Appropriate national planning and budgeting.
- Unjust political decisions to the disadvantage of the poor and marginalised,

which can lead to increased political instability in the country, if and when the disadvantaged communities raise and make their voices heard.

- Utilisation of designated foreign aid in regard to electrification.
- Applicability of the strategy of poverty alleviation (under which electrification is a major point).
- Empowerment and Dis-empowerment of people and communities.
- Sustainable and appropriate development.



Nepal's National Electricity Grid (based on NEA 1998)

Figure 3-3: Nepal's National Electricity Grid in 1998

Figure 3-3 shows that the easy to access areas in the low altitude, flatter southern parts of Nepal, with big cities, more thriving businesses have a far higher priority than the more difficult-to-access remote and impoverished hill and mountain regions in the northern parts of the country. To some extent it is understandable and logical, that the easier transmission lines are built first to reach as many people as possible. But on the other hand, huge annual financial foreign aid and support for the electrification of the poor and marginalized communities living in the mid-hills and northern higher altitude regions seems to flow into the country under the strategy of poverty alleviation.

3.2.3. Financing Models for Energy Service Projects

While Government subsidies, grants and loans for projects is a vast topic in itself, especially when looked at in more detail, and therefore cannot be dealt with fully in this paper, it is nevertheless something that has to be addressed, however briefly. One must recognise, that in addition to the poverty of rural communities, their remoteness, sparse population and often unsuccessful history of repayment of loans, make Government schemes for subsidies and grants even more complicated than they often already are. These schemes are a necessity if a country wants to improve the possibility of access to energy services for the underprivileged communities as part of a wider poverty reduction strategy (as in the case in Nepal). But the more a Government tries to secure the subsidies and grants to be paid back, the more the overhead structure and costs will be. Further, some subsidies or grants have done more harm than good by destroying the existing local markets and benefiting people who are already rich and thus have access to mass imports, rather than concentrating on, and developing of, the local capacities, skills and entrepreneurship. Thus in the limited context of this chapter all that can be said is that any subsidy, or grant programme for improved energy services for the poor and disadvantaged people groups, can not just be copied from others. However successful they may have been in other programmes. It has to be looked at in its own cultural, social and economic setting, in order to enable appropriate, sustainable energy access improvement programmes, which leave the community with their dignity intact, rather than enslave them further to harsh and unfair economic ties. The aim must be to lead these communities from their vicious cycle of energy poverty (no energy access – low productivity – low cash – no money to buy improved energy supplies or conversion equipment) to a virtuous circle[20]. In that increased access to improved energy services lead to increased productivity, thus bringing forth increased sales and profit in the form of cash. This results in increased income, enabling them to buy improved energy supplies or energy conversion equipment[21].

3.3. The Humla and Chauganphaya Village Situation

3.3.1. Humla District

Nepal is split up into 14 Zones or greater regions called "Anchals", which are further divided into 75 districts. The Karnali Anchal is geographically linked with Tibet to the north, and it covers the five districts of Dolpa, Jumla, Kalikot, Mugu and Humla. It is the only region without access to a road, or a road head. That means that any place in the Karnali zone can only be reached by foot, or first by plane to one of the three mountain airports and then by foot for anything from one to seven days walk to the intended place. With only 260,528 people[22], spread over 21,351 km^2, or 15% of Nepal's total land area, the Karnali zone is sparsely populated.

Socially and economically, the Karnali region is the most backward area of Nepal[23]. This is reflected in the low human development index levels (HDI) of the districts, which rank between 0.147 and 0.244, according to the UN rating. The Humla district ranks at the 67th place of all districts in Nepal with regard to its development, with the other four Karnali districts ranking between 69th and 75th. Humla's population in 2001 counted 40,595, with a yearly population growth of 2.1%, spread over an area of 5,655 km^2. Humla's adult literacy is 18%, though the women's literacy rate is a mere 4.8%, with an overall average of 0.88 years of schooling, and a per capita yearly income of NRp 5,057 (or US$ 70).

Humla's average life expectancy is 54 years, which is high compared to its neighboring district Mugu at only 36 years[24]. The reason for this could be the different food and drinking habits, and the lower population density of the people of Humla. The Karnali region in general, and Humla in particular, is known as a permanent food shortage area, and the extreme poverty, hunger, diseases and social backwardness have crippled this whole area, despite the availability of considerable natural resources, such as water, plenty of sunshine, and medical herbs. The majority of homes throughout the Karnali zone still light their homes in the evenings with torches made from splints of resin-impregnated local pine wood trees, called "jharro".

Thousands of men, from their late youth on (16 years onwards), migrate for six months out of the year to India, to escape the food shortage, and in the hope of finding some short term manual work for cash income. The impact such migration has had on this poor rural areas is seen by the condition of the population left behind, the majority of whom are the elderly, women of child bearing age and young children. The state of their fields, the food they eat and the hygienic conditions inside and around the home, are clear signs of overloaded work responsibilities, which the women bear on their own in the absence of their husbands and sons, resulting in utter impoverishment. It is just impossible for one woman, pregnant nine months each year for half of her life, to provide the necessary field work to feed all the hungry mouths of her family of growing children, and often her extended family as well. Further, gender discrimination is huge, as explained by the *Governance in the Karnali Exploratory Study*[25], in a summary of the problems identified regarding gender discrimination and women:

> "Girls are not given a name at birth, women are compelled to stay in cowsheds while delivering babies and menstruating, and are deprived of nutritious food after giving birth. Sexual exploitation of women, the social attitude that women should work more than men, lack of awareness about diseases and women rights."[26]

3.3.2. Chauganphaya Village

Chauganphaya very much reflects the average living conditions of the Humla district explained in the previous sub section. Chauganphaya village is a one-day walk north of Simikot, the capital of Humla, slightly off the main route to Tibet. With 63 homes and a total population of 368, Chauganphaya is a medium sized village. The people of Chauganphaya belong to the Dalit (untouchable, lowest caste), Chetri and Thakuri people groups. The Chetris are part of the warrior caste, while the Thakuris belong to the King's casts, according to the Hindu caste system.

Why Chauganphaya? Chauganphaya village was chosen, because at the time of the initial survey and visit to all of the villages in that area (in May - June 2003), Chauganphaya was perceived as one of the poorest.

- Only one of the 63 homes had at that time a smokeless metal stove, though poorly manufactured and not in proper use.
- Only three of the homes had pit latrines, and even those did not look like they were frequently used. The bulk of the people used the near-by fields, walking paths, and riverbeds as open latrines.
- Though there was a village drinking water system installed about eight years ago by the Government (exact date unknown), it had not provided any drinking water for over five years, as it was damaged and in poor condition. There were neither the funds for repair and maintenance, nor anyone trained to carry out these tasks.

- Through personal interviews with families in the village, it was found that the families of Chauganphaya have food to eat from their own fields for about 4 - 6 months per year. The rest of the year they either learned how to be hungry, or, if they managed to get some cash income through gathering and selling firewood in the local bazaar in Simikot, were able to buy some food to feed their families through the winter months.
- Often during the interviews it was found out, that women gave birth to 6 - 10 children, but had only 2 - 3 remaining alive beyond the age of 5.

Part of the energy and poverty study was to assess what energy resources the Chauganphaya community currently used, and which renewable energy resources are actually available to them. It was found out that an average family of four to six people consumes about 20 – 40 kg firewood a day, and that no one really was in a position to afford to buy kerosene for wick lamps or cooking. Limited amounts of kerosene are available in the bazaar in Simikot (one-days walk away), but at exorbitant prices, as it has to be flown in by airplane. After a survey of the available renewable energy resources which the people of Chauganphaya village have access to, it became clear that the most appropriate way to provide elementary village electrification for light was through utilizing the abundant solar energy resource with a solar PV village system. This became clear as the local stream does not carry enough water throughout the year, and the wind, with less than 3 m/s average annual wind speed, is not suitable, and other non-renewable energy sources did not seem an option, due to high prices, remoteness and sustainability.

4. Electrification in Nepal

4.1. World Wide Electricity Scenario at a Glance

The population of the world is assumed to grow by about 37 % from 6 billion in 2000 to 8.2 billion in 2030, and most of this increase will take place in the urban areas of developing countries[27]. More than 99% of the identified 1.64 – 2 billion[28] people without access to electricity today live in developing countries, and four out of five of these live in rural areas[29]. Today, 100 years after Edison's seemingly forward-looking statement, which said "we will make electricity so cheap that only the rich will burn candles" [30] has been only true for the industrialized countries. Who anticipated that today more people have no light in their homes in the developing world than the world's population in Edison's time?

In the year 2000 the world's power stations generated around 15,000 TWh of electricity, roughly 2,500 kWh for each of the world's 6 billion people. 60 per cent of this was for the benefit of 800 million people in OECD countries. In contrast, 80% of the world's people in developing countries will consume an average of 900 kWh per person, or just about one tenth. And 1.6 billion, twice as many as in all of the OECD countries, will have no access to electricity supply at all[31]. Nepal, with an annual per capita electricity consumption in 2001 of 66.7 kWh provides an even more extreme contrast. Considering that only 3.97 million people consume electricity, as 85% have no access to electricity, that figure rises to 444 kWh per annual capita. Even that, completely neglecting the poorest and marginalized 85% without access to electricity, is way below the average consumption rate of other developing countries.

There is a clear relationship between poverty and access to electricity[32] (as was discussed in Chapter 3), and the more remote the communities live, the higher the level of poverty. At the same time the more remote and inaccessible a community is, the higher the increase in cost for electrification projects. This is due to increased transport, building, support and maintenance costs.

4.2. Nepal's Energy Scenario at a Glance

88% of Nepal's 26.5 million people live in the rural areas, and about half of these, or approx. 11 – 12 million people, live in such remote areas that neither a road, nor the national electricity grid reaches them, and it is unlikely that this will change for decades to come. These families have no choice but to cut down precious trees for firewood needed for cooking, room heating and light. Heating and cooking indoors on open fire places have a direct chronic impact on their health, resulting in the extremely low life expectancy for women, and the high death rate of young children under five[33]. Deforestation has reached alarming conditions. The once picturesque, bio-diverse rich forests and valleys are stripped of their resources in unsustainable ways, to satisfy the minimum energy service needs.

Nepal has no reserves of oil or gas. There are only small, insignificant coal reserves. Commercial energy consumption in Nepal is made up of hydroelectricity, coal and small amounts of oil products. Non-commercial energy sources, such as wood, animal wastes and crop residues, account for the most significant share of the country's total energy consumption. In remote mountain areas, people rely 95% - 100% on firewood for their daily minimum energy services (cooking, heating and light). Nepal meets its growing demands of oil consumption and coal, through imports from India[34] [35]. This shows the utter dependence of Nepal on foreign fossil resource imports, making it vulnerable to rapid and high price fluctuations, all effected by its political relationships with foreign countries.

Nepal's per capita energy consumption is one of the lowest in the world, with a mere annual per capita energy consumption of 618 kWh or 2230 MJ (2.109 Mbtu[36]). The average growth rate per capita energy consumption from 1990 to 2000 was just under 10%[37], which is one of the highest in the world.

4.3. Electricity through Hydro Power in Nepal

Nepal installed its first hydro power plant, the Pharping plant with 500 kW in 1911. Today, Nepal's installed electric generating capacity (end of 2003) is 590 MW, of which 90% or 533 MW, is from hydroelectric power plants, and the remaining 57 MW is from 3 diesel generator mini-grids. Only a small share (1.26 %) of Nepal's technical and economically feasible potential hydroelectric power capacity (estimated with a total potential of 83,290 MW[38], though with an estimated 42,133 MW to be technical and economical feasible[39]) is currently exploited. That enables only 15 % of Nepal's households, mainly in urban areas, to have electricity. Nepal's grid electricity losses are estimated to be 28%[40], which is due to transmission losses, distribution losses and mainly due to unauthorized connections (power theft). Hydro projects currently under planning and construction in Nepal should nearly double the country's total generating capacity within the next few years, but Nepal's unstable political conditions over the last eight years do not allow for any specific or reliable forecasting[41]. In total, 29 new hydro power plants (with rated power generation > 10 MW) are planned. But only two are currently under construction and are to be joined to the grid in the foreseeable next three years[42].

4.4. Remote Area Power Supply

Nepal is still at its beginning stage of providing electricity to its people. Nepal's unique geographical and topographical conditions make this task even more difficult and time consuming. These circumstances demand new approaches and technologies, as the traditional electrification system through the grid, is neither viable, nor a realistic option for the 85% of Nepal's population living in difficult and hard to access remote mountain areas.

Renewable energies, including micro-hydro, biomass, and solar energy, are gaining popularity in Nepal, particularly in the remote regions of the country. Therefore, one new viable option is the generation of electricity within, or near to a community, with locally available energy resources. Generating power locally, can be achieved through a Remote Area Power Supply (RAPS) system. A RAPS system can be defined as a power generation system, generating electricity for remote and rural homes and communities. RAPS systems are small scale (usually <50kW) self-contained units, providing electricity independent of the main electricity grid or mini grid network. RAPS systems range from small petrol generators, able to power appliances directly, to more complex installations using either renewable energy, only, or in combination with a diesel or petrol generator.

A RAPS system that has a combination of energy sources, such as a wind generator, solar panels, petrol or diesel generator, battery charge control system, battery storage and inverter, is termed a hybrid RAPS system. For the remote mountain areas of Nepal a RAPS system will usually mean power generated from renewable energy resources such as solar energy, utilised through solar PV panels or wind generators. Any petrol-powered back-up generator is not a feasible solution for the remote and impoverished mountain communities, as the mere transport cost for fossil fuels (carried by porters for days or weeks) is unrealistic. Thus this option will not be given any consideration. For those times when the renewable energy resource is not available for prolonged periods of time, the way to ensure an appropriate back-up system to provide the demanded energy is to design a battery bank, that is able to provide the needed energy for a realistic span of time.

A RAPS system is defined to a particular area, without being connected to the grid, operating independently as a mini-grid. RAPS systems are often designed with 20 years life expectancy, and it is good engineering practice to include in the life cycle cost all the needed operation, maintenance, repair and spare parts cost. This provides a realist energy unit (kWh) price that each consumer has to pay, in order to keep the RAPS system operational. The locally available energy resources, the community's average daily energy service demands (including a realistic future load demand growth) and their affordable budget will determine the size of the RAPS system.

Nepal is poor in fossil fuel resources, but what Nepal is rich in, are renewable energy resources. Especially water, flowing down the steep Himalayan mountains from uncountable streams and rivers, sun shine, too with an average of 300 sunshine days a year[43], and average daily solar irradiation values of 4.5 – 5.5 kWh/m^2 [44]. These resources can be utilised locally through appropriate renewable energy technologies such as micro-hydro (5 kW – 100 kW) and pico-hydro (0.1 kW – 5 kW) power plants, or solar photovoltaic modules and arrays, to generate the desired electrical power to meet basic energy demands. RAPS systems provide a realistic and appropriate solution for the vast majority of Nepal's population still without access to electricity within their foreseeable lifetime. A RAPS system can be clearly defined to a community's needs and means, utilizing the locally available renewable energy resources. A further important consideration is, that often it is the community that owns RAPS systems. In many cases the community has participated actively in the initial planning stage in the building and installation of the RAPS system. Local people are trained on the job in all practical steps, which assures a high degree of willingness to maintain and repair the RAPS system, since a strong ownership feeling has been created throughout the process of implementing the projects. In this way, a RAPS system can provide electricity demands for even the most remote communities in appropriate and sustainable ways for years to come.

4.5. Electricity through Solar Photovoltaic in Nepal

4.5.1. Central Solar PV Array Systems

In the mid 80's the French Government offered the Nepali Government to build and install three 50 kW solar PV systems for the three remote district centers, Tatopani in Mayagdi district, Simikot in Humla district and Gamghadi in Mugu district, all in the mid-western region of Nepal. They were intended to serve the local Government, INGOs/NGOs and near-by local villages with AC power in a mini-grid connection. In October 1989 all three systems were installed and handed over to the local Government authorities. All three centrally installed solar PV systems were built with the same design (with 1,250 40Watt PhotoWatt PW P-402 modules) by the French solar PV company PhotoWatt, contracted by the French Government. The Tatopani mini-grid solar PV system failed within a few years due to the lack of trained people to maintain it and due to the unavailability of spare parts. Thus it was dismantled in the 90's. The Gamghadi system stopped providing any energy services by October 2002 (after a whole generation of people grew up with the benefit of light in their home), after having provided only DC (due to the failure of both, the 5 kW and 50 kW inverters) for the last eight years. The last of the three 50 kW array mini-grid systems, in Simikot, Humla, has still been providing DC electricity direct from the battery bank for 1 – 2 ½ hours per day in the evenings, for the last seven years (also due to the failure of, and inability to repair both, the 5 kW and 50 kW inverters). But the condition of the battery bank, the solar PV modules and the distribution grid does not look promising, and it is unlikely that it can go on for many more years. However, after 14 years of operation in such a harsh and remote mountain area, the Simikot solar PV system project can be called a success. The following issues, if addressed, could prolong the operational period and life expectancy of these remote located solar PV mini-grid systems. They are:[45]

- No training was provided to any of the solar PV mini-grid operators.
- Thus the needed maintenance was not done according to a scheduled maintenance plan, nor could any potential damage be recognised in time to prevent load losses.
- No appropriate annual budget for proper maintenance or repair was set aside from the beginning by the governing authorities.
- No periodic check-up or follow-up was carried out by a professional solar PV engineer or the company that installed it.
- The local context (remote and difficult to access) was not taken into account for the running of the solar PV system. For example the distilled water for the huge battery bank had to be flown in by airplane, which makes the cost per litre prohibitive. Instead, the distilled water could have been produced locally, including collected rain water (in suitable plastic basin). Neither were there any spare parts stored such as fuses or spare light bulbs, for those times when for weeks at a time, no planes can reach these places.
- No log book is kept which shows the status of the solar PV system, as well as indicating possible forthcoming maintenance needs, such as cleaning of the panels or topping up of the battery bank.
- There is no proper payment system for periodical payments, based on calculated life cycle cost for the energy services provided.

- There are no switches installed in any of the consumer houses for the lights. When electricity is provided all the lights are on, independent of the occupancy of the room.
- All the lights installed are 40 – 60 Watt incandescent light bulbs. This light technology is inefficient, providing a mere ~5% of the rated power consumption as visible light.

The following Figures are from the 50 kW Simikot solar PV array system.

Figure 4-1: Simikot Humla 50 kW PV Array
4 rows of eight sets of four times ten 40 Watt PhotoWatt PW P-402 polycrystalline PV modules make up the 50 kW rated output power. The array is at 29.967º latitude North, and 81.817º longitude East. In the back to the left side of the PV array is the battery bank and power house located, with the dysfunctional AC inverters.

Figure 4-2: Simikot Humla 50 kW PV Array south view
A fish-eye view at sunrise looking straight south. The solar PV arrays are installed at a fixed angle of 33º south, guaranteeing a slightly higher power output during the 4 winter months from November to February.

Figure 4-3: Bombed Simikot PV Array
The civil war between the Maoists and the Government troops has again and again taken its toll on important infrastructure installations. A pressure cooker bomb blast, laid by the Maoists underneath the Simikot solar array, destroyed 40 solar PV modules totally.

Figure 4-4: PV Module close-up
Many PV modules show signs of aging, possibly due to power collection imbalance and moisture creeping into the encapsulation.

4.5.2. Solar Home System Programme in Nepal

From the early 90's on, solar PV home systems (SHS) have found more and more acceptance by the mainly remote and poor rural communities, without a national grid connection for years to come. Despite the enormously high initial capital cost involved for the installation of a solar home system, several solar PV companies have sprung up in Nepal's capital, Kathmandu, meeting this fast growing need. By the mid 90's the solar PV market has grown to a substantial size, with about 10 solar PV companies competing for sales and profits. In these circumstances, providing quality products and after sales services were not included. Too great was the euphoria of a driving business, and too great the lack of experienced workmanship. The three major reasons and hindrances for a faster dissemination of solar home systems can be summarised as the prohibitive initial cost, the use of often-inadequate quality solar equipment, and inappropriate after-sales services.

In order to address these conditions, the Nepal Government established the Alternative Energy Promotion Center (AEPC) in November 1996. AEPC is an organization devoted to the development and promotion of renewable and alternative energy technologies in Nepal. It has an autonomous status under the Ministry of Science and Technology (MOST). The overall objective of AEPC is to popularize and promote the use of renewable energy technologies to raise the living standards of the rural people, to protect the environment and to develop commercially viable alternative energy industries in the country[46]. On a more broader basis, AEPC has set the following objectives:

- Short, medium and long term policy and plan formulation.
- Promotion of RET development programmes.
- Standardization, quality assurance and monitoring.
- Service and support.

- Subsidy and financial assistance.
- Strengthening AEPC and its partners.
- This implies that AEPC plays an active part as an intermediary institution between the operational level and the policy deciding levels in relevant ministries.

According to Nepal's national electricity expansion plan, 70% of the nation's population will not be grid connected in the year 2020 [47]. Through the DANIDA funded ESAP (Energy Sector Assistant Program), an AEPC partner program, NRp 90 million (US$ 1.286 million) have been provided for a first phase, i.e. five years Solar Home System program from 1999 – 2004, with a target of 25,000 installed SHS, and 35 Institutional Solar PV Systems (ISPS). This program aims to provide electricity for basic household consumption in rural households that live in areas that stand no chance of being connected to an electricity grid for the next five years or more. The fund also seeks to improve the quality of equipment and components used in the SHS, including local production and testing, by assisting in the establishment of a Solar Test Station.

The available subsidy for the SHS program, newly defined in 2003, is as following:

- Subsidy will be provided to SHS of 10 Wp, 20 Wp and 30 Wp or more.
- The maximum subsidy for SHS of 30Wp capacity or more will be NRp 8,000 per system (which is ~ US$ 114 @ 70 NRp / US$).
- Additional 50% and 25% subsidy per SHS system will be provided to the users in "more remote" and "remote" village development committees (VDC) of districts respectively. The "more remote" and "remote" VDCs of the remote districts are those decided by the Ministry of Local Development (MOLD) / HMG and as notified in the Nepal Gazette part IV. The category

"A" comprises of "more remote" VDCs, while category "B" represents "remote" VDCs.

- The SHS lower than 30 Wp will also be provided a subsidy. The amount will be 50% of its cost, but will not exceed NRp 8,000 per system.
- The level of subsidy will be reduced each year at the rate of 10%.
- The subsidy for a SHS for public institutions, such as the VDC buildings, school, club, health post etc., will be as high as 75% of the total cost[48].

During the first phase of this SHS subsidy program, from 1999 until November 2003, a total of 34,495 SHS have been sold and installed (thus almost 10,000 systems more than initially planned in the first 5 years phase), in 71 out of the total of 75 districts in Nepal. These SHSs amount to a total of 1,279 kW installed rated power output[49]. The following map shows the number of SHS installed in each of the 71 districts for the November 2003 status[50].

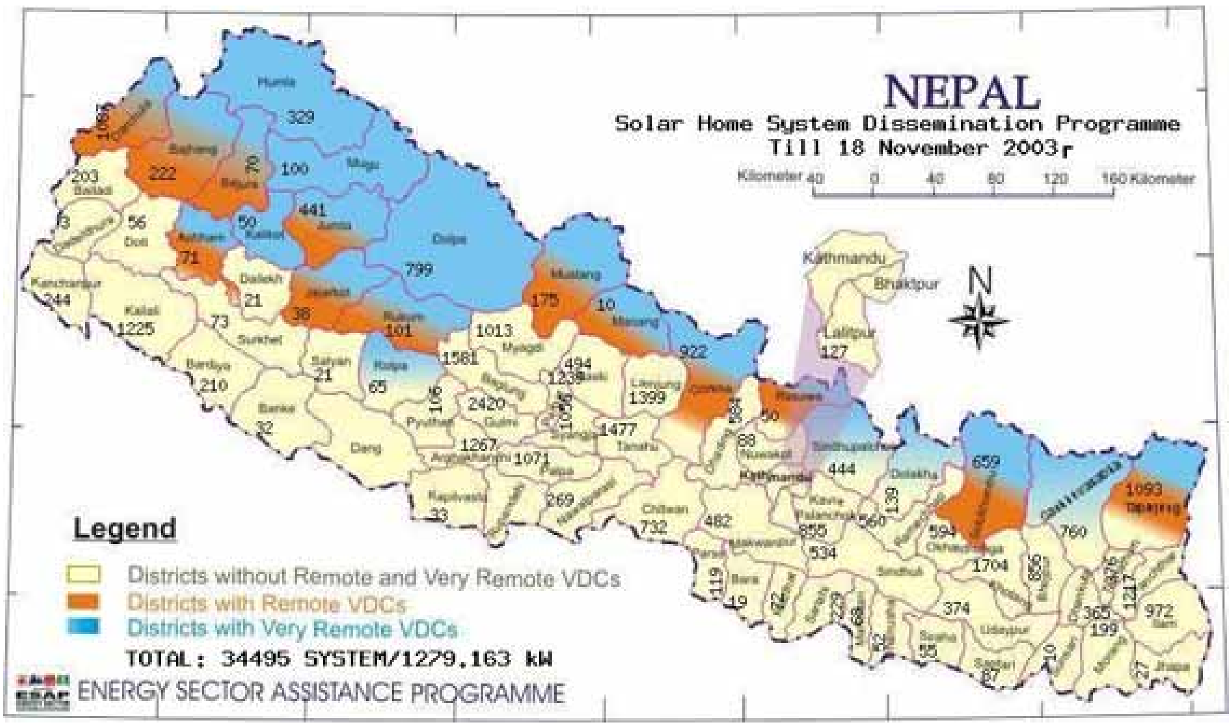


Figure 4-5: AEPC's first Phase (1999-2004) Solar Home System Dissemination Programme status 18th November

Figure 4-5 shows that in the Humla district (top left corner), with a population of 45,595 (2001)[51], 329 solar home systems have been sold and installed under the AEPC's first phase subsidy scheme until November 2003. Humla is here highlighted because that is where the solar radiation and irradiation is monitored and recorded (see Chapter 7) at the Simikot HARS (High Altitude Research Station), and where the Chauganphaya Village Solar PV System is installed (see chapter 12), some of the main focal points of this report.

4.6. Possible Ways for Rural Electrification Systems

In most homes, which are powered by a micro-hydro power plant, and sometimes even by a solar PV system, in the rural mountain areas of Nepal, 2 - 3 incandescent bulbs are installed, each with 25 - 60 Watt power consumption. A village with 50 homes, and three incandescent bulbs per home, needs a micro-hydro power plant with a power generation capacity of 10 kW. The people in the village do not know any other lighting technology, thus they never questioned the appropriateness of these lights, nor try to get more light out of the same power generation. An incandescent bulb has a life span of around 1,000 hours. To get a new incandescent bulb in the remote mountain areas is difficult, time consuming and expensive. Every single light bulb has to be flown in by airplane, then carried by porters to the main bazaar, before one can purchase one at an exorbitant price.

People in these remote areas have not been made aware of alternatives, nor have they been properly trained in the new technologies installed in their homes.

Behind most of the remote micro-hydro power plant projects is a financial strong and dedicated sponsor, without which such projects would hardly been able to take place. The equipment for a 10 kW and larger power plants weighs several thousand kilograms and is bulky. Once installed, experience shows that it is close to impossible to dismantled it, when it is in need of repair due to failure. The technical expertise is not available in the village and the high transport cost for porters and air freight are prohibitive for most of the poor mountain communities[52]. These issues raise serious questions of appropriateness and sustainability of this otherwise widely approved and acknowledged technology.

What is the basic energy service demand of a family in a remote mountain village? In order to be able to come up with an appropriate electrification solution it is important to understand the struggles of the local people in their context. Every home in the high altitude areas in Humla cooks with firewood on an open fire. Three stones, or a three-legged metal piece, called "odhan" (see Figures 4-6, and 4-7) hold one cooking pot at a time, while firewood is added from the sides, and underneath the cooking pots (Figure 4-6).

In order to provide light in the otherwise-dark homes (as most have only very small unglazed windows which are mostly closed due to the cold), the people burn the traditional "jharro", a pine wood stick full of resin (Figure 4-7). Needless to say that the open fireplace and the "jharro" burned all evening long create very unhealthy living health conditions.

Figure 4-6: Open fire place cooking

Cooking on open fires is the traditional and common way to cook the daily food. The mother, and often the children, sit around the smoky fire as the meals are prepared. Women and children are most likely to suffer from exposure to the indoor smoke pollution[53], causing health hazards such as respiratory diseases, asthma, blindness and heart disease[54].

Figure 4-7: Open fire place cooking and jharro burning. The traditional way of having a small dim light inside the home is the "jharro" (resin soaked pine wood stick burning to the left, with a one evening ration ready to be burned at the bottom left). While burning "jharro", thick black smoke is developed, adding to the already health hazardous condition of open fireplace cooking.

Through a survey conducted in the village (see Appendix 18.7.) and through personal interviews with the local people, what became clearly apparent are the following two main issues, raised by families as their most urgent needs:

- An appropriate and sustainable lighting solution to get rid of the "jharro".
- A smokeless stove to get rid of the smoke inside the home.

In this context, the question to be asked is, what options are available other than the smoky "jharro" for providing light for each home, light that is necessary for cooking, evening gatherings and children's study times.[55].

Many homes in the mid-hills and lower areas of Nepal without access to electricity use small kerosene wick lamps to meet the basic lighting demand in the home. Kerosene is subsidised by the Nepal Government, and thus for those with access to a road, the kerosene wick lamp is often the cheapest and quickest available solution.

But for the high altitude communities in Humla, with a much lower average income, and no access to a road head within 15 days walk, kerosene is definitely not an option. The costs of kerosene in the bazaar in Simikot (Humla's district center) is NRp 120 /liter (or US@ 1.71), which is four to five times the price in the mid-hill and lower areas, and equivalent to a days' salary. Thus kerosene wick lamps are not used in the homes in Humla for light.

In order to provide a possible solution for lighting options in this context it is important to start improvements at both ends, the power generation and the light power consumption. If less power is needed for the lights, less power needs to be generated. If a CFL (compact fluorescent light) light bulb is used, which consumes 7 – 11 Watt (and is comparable with a 35 – 55 Watt incandescent bulb with respect to light output, see Chapter 5, Table 5.3.), the power generation can be 5 times smaller for the same amount of homes and lights. A 2 kW pico-hydro power plant would be enough to provide the same lighting services, compared to the above 10 kW micro-hydro power example. Even less power needs to be generated if a 1 watt white light emitting diode (WLED) lights, as shown in Figures 12-12., and 12-25 and 12-26 in, are used. In that case, the power generation can again be reduced by a factor ten. However a WLED lamp does not provide equivalent light to a CFL bulb.

Considering the local community's needs, demands and financial capability (most of them are below the poverty line according to the Nepal Government's benchmark), a basic lighting system, affordable and with a high reliability, is what they need. Thus for the same amount of homes and lights with lower light output, a power generation system of 200 W instead of 10 kW is possible. A detailed cost and energy service analysis over the life span of these possible two hydro power generation systems, must be performed, but due to the lack of available data and information not possible within the scope of this report. However, considering the shear transport costs of a 10 kW micro-hydro power plant for the needed power house and equipment ($\geq$ 2,000 kg), compared to a 200 W solar PV system and equipment (~ 300 kg), at a road and air freight and handling rate of about 70 NRp (1 US$), besides the initial equipment cost, gives a clear indication. Further, one cannot forget the whole building, spare parts and training costs involved in both power generation plants.

The aim of this section is to show, that there are other power generation options, easier to transport, handle, install, maintain and repair, than was common thus far. Such small amounts of energy can be generated with a pico-hydro power plant, and as well with a solar PV system, if the local solar energy resource is available. Solar PV systems demand less in terms to maintenance, if the system is professionally designed, installed and:

- the local people are appropriately trained to understand the maintenance needs,
- are diligent to carry it out according to the maintenance schedule,
- and if the downfalls mentioned in section 4.5.1. are clearly avoided through the necessary precautions.

These are crucial factors in providing a community with electricity with high reliability and sustainability. Smaller systems are a lower financial burden for the local community, and thus more affordable without an external sponsor. That is important to create a feeling of future ownership and pride in the elementary village electrification system.

5. Lighting Technologies

5.1. Introduction

In the high altitude, remote mountain areas like Humla, people use "jharro", for lighting their homes at night. Candles, or kerosene, which have to be flown in and carried by porters, are just not affordable. The main problem with this type of lighting system is the limited amount of light they produce. Due to the dimness, it also causes eye strain for detailed, or fine work. Studying during the night is most difficult with this type of lighting. Resin lamps ("jharro") also produce large amounts of smoke, one main reason for increased respiratory chest and eye diseases, as well as a marked increase in the risk of lung cancer, particularly in women[56]. Smoke from solid fuel inside the home is one of the four greatest risks factors of death and disease in the world's poorest countries. No less than 2.4 billion people are exposed daily to heavy smoke in their home, as they cook and heat by burning biomass, mostly on open fire places. That kills over 1.6 million people each year, predominantly women and children [57].

Lighting by kerosene, as mentioned, is not affordable in the remote areas as transportation is difficult and expensive. Reasonable alternatives to these types of lighting is electricity powered lights using hydro power or solar power. The advent of compact fluorescent lighting (CFL) and white light emitting diodes (WLEDs) has opened up the opportunity for very small scale power to have a significant impact on the lighting needs of the remote communities.

This fits in with the aim of every power generation plant to be able to connect as many users as possible. This in particular is true for any power generation plant in the remote areas of the Nepal Himalayas, where the cost of electricity per household is a crucial issue.

As discussed in section 4.6, the approach which needs to be followed is an elementary electrification system, rather than an initially defined-watt-per-household threshold (for example 120 W/household), as this is still very common in most of the micro-hydro power plant projects all over Nepal. An elementary electrification system demands knowledge of the lighting needs and of the different lighting technologies that are available and appropriate. Three lighting technologies are discussed and analysed, in this section to provide data in regard to light output, life expectancy, cost and their availability. The last issue is of particular importance for the remote mountain communities, as without appropriate light life expectancy or replacement, a good power generation system loses all its advantages.

5.2. Primary Functions of a Lighting System

What is the appropriate light output for different tasks in a particular room, and what is the primary function of lighting? The Australian Government defined the primary functions of a lighting system in the home and the working place as the following[58]:

- To provide a safe visual environment.
- To make it possible to easily see the task.
- To provide a comfortable and pleasant visual environment.

The secondary function of the lighting system is to:

- Achieve the primary function as efficiently and cost-effectively as possible.
- Be easy to clean and to maintain.

Further, the Energy Management Advisory Booklet provides some additional information on safety. That includes:

- People must be able to safely orientate themselves and move about within buildings.

The task visibility defines how much light is required for a particular task, the area adjacent to the task and the surrounding surfaces. People have to be able to perform tasks for extended periods and should be able to easily see task details.

For this reason standards for “lighting levels” (illuminance) have been developed and are recommended. In Table 5-1 the Australian Standard AS1680-1990 with recommendations are provided for the maintained illuminance for various types of tasks, activities or interiors[59].

Class of task	*Recommended Illuminance in Lux[60] AUS Standard*	*Aimed Illuminance in Lux for Nepal's Rural Communities (measured in HARS in Simikot)*	*Characteristics of the activity/interior*	*Representative activities/interiors*
Movement and orientation	40	8	Interiors rarely visited with visual task limited to movement and orientation	Corridors; cable tunnels, indoor storage tanks; walkways
Rough intermittent	80	10	Interiors requiring intermittent use with visual tasks limited to movement, orientation and coarse detail.	Staff change rooms; live storage of bulky materials; dead storage of materials needing care; locker rooms; loading bays.
Simple tasks and work places	160	15	Any continuously occupied interior where there are no task requiring perception of other than coarse detail. Occasional reading of clearly printed documents for short periods.	Waiting rooms; staff canteens; rough checking of stock; rough bench and machine work; entrance halls; general fabrication of structural steel; casting concrete; automated process monitoring; turbine halls.
Ordinary or moderately easy tasks and work places	240	20	Continuously occupied interiors with moderately easy visual tasks with high contrast or large detail (> 10 min. arc).	School chalkboards and charts; medium woodworking; food preparation; counters for transactions.
Moderately difficult tasks and work places	320		Areas where visual tasks are moderately difficult with moderate details (5-10 min. arc or tolerances to 125 µm) or with low contrast.	Routine office work, e.g. Reading, writing, typing; enquiry desks. Inspection of medium work, fine woodwork, or car assembly need 400 lx.

Table 5-1: Recommended Illuminance
Column 1,2,4 and 5 from the Australian Standard AS1680-1990 for Interior Lighting, Part 1: General, principles and recommendations. Column 3: Measured minimum value needed for remote mountain homes in Nepal

For the rural Nepal context, only the first 4, out of 9 illuminance levels are reasonable, as in a rural Nepal context for the provision of any higher illuminance, the cost would be prohibitive. The 3rd column was added, aiming for illuminance values (in Lux) for homes in the remote mountain areas of Nepal according to measurements, recorded in the HARS in Simikot, by the writer and the HARS staff (see Figure 5-2) with CFL and WLED lights. They are considered to be the minimum satisfactory lighting level for tasks such as cooking, reading, writing and socializing in a local home in Humla.

As helpful as this standard is, giving some rough indication to how much light (illuminance) is needed for people to go about a task for a long time, the above mentioned figures are clearly for a developed country's context. That is also confirmed in the lighting management booklet stated, by saying that the recommended lighting levels in the standards are well above those required just to detect the task[61].

The higher the illuminance, the more power is needed. That in turn demands more investment on the power generation side. Just to detect the task and be able to fulfill it with the help of light rather than an open smoky fire place, is the context of our consumers. However, there is a limit of illuminance under which for example the eyes can get damaged. The question before us is: Does the smoked filled room due to the open fire and burning "jharro" cause more health damage than a dim light? That background dictates the level of illuminance aimed for in the context of rural mountain communities in Nepal. With that in mind, an additional illuminance column, "*Aimed Illuminance in Lux for Nepal's Rural Communities*", indicating an adjusted level of the Australian Standard for various tasks and living conditions of communities in the remote and impoverished high altitude mountain areas of Nepal is proposed.

As the main purpose of light is to eradicate the open fire places and “jharro” in the main rooms such as the kitchen, bedroom (which is one and the same in most cases) and the store room, for tasks such as cooking, indoor milling, education, and social gathering, the minimum illuminance aimed for are defined only to that living and working standard. The “*Aimed Illuminance in Lux for Nepal’s Rural Communities”* level defined represents the minimum needed levels of illuminance for the defined tasks, measured through practical light tests. The data provided in that column do not in any way represent a standard or a more widely acceptable recommendation by any official institution, but have been identified by the writer and the HRAS staff as the satisfactory minimum.

As. mentioned in section 4.6, the traditional 25, 40 or 60 Watt incandescent bulb is still very often the only light technology installed in the remote, grid-independent power generation plants in Nepal. The bulbs’ low life expectancy of around 1,000 hours, its high power consumption and its low efficiency demand comparable big power plants for just a few households.

But for an elementary electrification, i.e. just for lights, much lower power generation has to be considered. This in turn demands much lower power consumption by the lights. To achieve that, new and appropriate lighting solutions are demanded. In order for a light technology to be appropriate and sustainable for the remote mountain areas, it has to fulfill certain objectives.
These are:

1) Low power rating (as low as possible for appropriate lighting for the tasks defined).
2) High brightness efficiency, that is the amount of brightness per unit of energy consumed (lumens/rated power consumption in Watt).

3) High power factor[62] (for AC lights), 0.9 or higher, in order to minimise the reactive power consumption, and the harmonics otherwise created.

4) Long life expectancy, providing light for 8,000 –10,000 + hours (which is 4 - 6 years if the light is used for ~ 5 hours per day). High reliability makes it easier for the consumers living in a remote places where it is difficult to get spare parts (bulbs).

5) Affordable in price.

6) Readily available.

7) Easy to clean and maintain.

8) Not easily breakable.

9) Acceptable performance (within +/- 25 % of rated specifications) in harsh climate (with ambient temperatures between -10ºC - + 40ºC, and great variations in air humidity for prolonged time (> 90% during the monsoon).

5.3. Light, How it is Measured and Identified

Radiant light intensity (all wavelengths) is measured in lumens. The lumen is defined such that 683 lumens of light is provided by 1 Watt of monochromatic radiation at a wavelength of 555 nm. Luminous intensity, is measured in candelas (cd), the SI unit of luminous intensity[63]. It provides the measurement for the visible portion of a light source. Display intensity, therefore, is described in cd to indicate the light output useful to the observer.

The value of brightness is a key specification for any display, indicator or illuminator. The electrical power that goes into a light is measured in watts. Luminous flux[64] is the flow rate of light energy from the source measured in lumens. The total flux is the sum of the flux that is incident over the entire inside surface of a sphere that encloses the source. Intensity, in contrast, characterizes the flux density[65] at a position in the space of this surrounding sphere, so it is the flux per unit of solid angle.

5.4. Applicable Lighting Options

A first screening of the extensive range of the available lighting technologies resulted in three lighting technology options, which will be considered in more detail for the elementary electrification for lighting purposes.

- The traditional incandescent bulb.
- The CFL bulb.
- The WLED Light.

5.4.1. Incandescent Bulb

The incandescent bulb is one of the three light technologies chosen, despite its known inefficiency and rather short life expectancy, because it is an intimate part of most of our societies. It is the traditional light bulb and it can be found virtually everywhere, in essentially every home and business which is connected to an electricity network. It is also known by most people in Nepal, with wide user coverage, even into some of the remotest valleys of Nepal's Himalayan mountain range. Thus the incandescent bulb has a legitimate position to be included in this study of possible lighting technologies, even though it is not an obvious choice for an elementary electrification system for lights.

Because the incandescent bulb's filament is so thin, it offers a high resistance turning electrical energy into heat, and the filament glows, it incandesces. Metal atoms release mostly infrared light photons, which are invisible to the human eye. But if they are heated to a high enough level, around 2,200 ºC –2,500 ºC in the case of a light bulb, they will emit visible light as well. The problem with incandescent bulbs is that the heat wastes a lot of electricity. Heat is not light, and the purpose of the light bulb is light, so all of the energy spent creating heat, is wasted. It's low life expectancy of 750 – 1,000 hours, producing about 15 lumens per Watt of input power[66], its high power consumption and it's low efficiency (~ 95% of its power output is in the infrared spectrum, and only 4% - 5% in the visible spectrum[67]), demand substantial power generation plants even for small villages.

5.4.2. CFL (Compact Fluorescent Light)

The CFL bulb went through had a revolution in the urban areas of Nepal during the last 5 years (1999 – 2004), though to almost 100% the market has been flooded with cheap, (NRp 40 – 80 (0.57 US$ - 1.14 US$), low power factor and unreliable Chinese products. There are a few high quality brands such as Osram and Phillips, including Chinese ones such as Ultralamp[68], with high power factor, but at a price between NRp 350 – 700 (5 US$ - 10 US$). But unawareness among the wider population regarding power factor and quality, and the inherent long-term benefits of these lamps, makes it close to impossible for retail sellers to sell these high quality CFLs.

Fluorescent light bulbs use about a quarter of the energy of incandescent light bulbs (Table 5-2) while still maintaining the light output in the form of illuminance, as is stated by most of the CFL manufacturers' products (Figure 5-1).

Light Technology	***Relative Power Consumption in %***	***Relative Light Output in %***	***Remark***
Incandescent Bulb	100	100	
Fluorescent Bulb	20 - 25	100	Fluorescent lighting is much more energy efficient than incandescent lighting[69]

Table 5-2: CFL Bulb versa Incandescent Bulb energy demand

In Nepal the following range of high quality CFL bulbs from Ultralamp, an Australian brand CFL bulb manufactured in China, are available. Ultralamp compares their CFL bulbs with incandescent bulbs, based on the same light output (lumens). The following data (Table 5-3) is taken from their products:

Incandescent Bulb (Watt)	*CFL Bulb (Watt)*	*CFL Bulb Illuminance (Lumens)*	*CFL comparison with Incandescent bulbs*
35	7	350	With approximately the same light output in Lumens.
55	11	660	Each CFL bulb consumes 5 times less energy
75	15	900	CFL bulbs life expectancy is about 8,000 – 12,000 hours.
100	20	1200	CFL bulbs have about 5 -10 times longer life expectancy.

Table 5-3: CFL Bulb and Incandescent Bulb light output comparison

Further, fluorescent light bulbs also last five to ten times longer than incandescent bulbs. This can be seen by various manufacturers' CFL product specifications, which are assumed to have been tested. While an incandescent bulb lasts only 750 – 1,000 hours, a fluorescent light bulb can last for 8,000 - 12,000 hours. CFL bulbs have nominally an output of 25 - 80 lumens/Watt[70], while incandescent bulbs are commonly rated with around 15 lumens/Watt.

The Ultralamp product range, with the high power factor, are in the upper light output range with 50 – 66 lumens/Watt. Freere et al. have also observed that the CFL bulb's light output is significantly affected by the bulb temperature and full light output does not arise until the sufficient tube temperature has been reached[71].

All the lights for the HARS Simikot Solar PV System are 11 Watt, high power factor, CFL lights from the company Ultralamp (Figure 5-1). The reasons for choosing this light type and brand are:

1. The manufacturer states that this product has a high power factor of (0.9).
2. 11 Watt is sufficient for a room in which PC work and writing work is done in a remote location.
3. They have a life expectancy of 8,000 - 10,000 hours, or 4 - 6 years.
4. There is a good range of AC CFL bulbs available: 7 W / 11W / 15W / 20W
5. They are also available as DC CFL bulbs, though only with 7 W.
6. It has an affordable and realistic price with 380 NRp (5.43 US$) for a 11 Watt CFL.
7. It is imported by a Nepal company, based in Kathmandu.

Figure 5-1: Ultralamp High Power Factor CFL Bulb

It shows an 11 W high power factor CFL bulb and its technical specification. This CFL light is used in all 11 rooms of the HARS Simikot office, powered by the solar PV system.

Figure 5-2: CFL Light Output Measurement

Light measurement of an Ultralamp 11 W High power factor CFL in the HARS Simikot office with a Lux meter.

5.4.3. WLED (White Light Emitting Diode) Lights

The LED (Light Emitting Diode) already has a 40 year history of technical development and application, and it has become part of many people's daily life in the developed world. It is used for various common tasks, such as for colourful indicators (mainly red, green and blue) in PCs, battery chargers, TVs, mobile phones and most electronic games, and more recently in traffic lights, substituting the old traditional incandescent bulb, especially where the traffic lights must operate at any time, but where the grid is weak and unreliable.

A light emitting diode (LED) is a PN junction semiconductor diode that emits photons when forward biased (Figure 5-4). LEDs are highly monochromatic, emitting a pure colour in a narrow frequency range. The colour emitted from an LED is identified by peak wavelength and measured in nanometers (nm). The peak wavelength is a function of the LED chip material. For more on the LED history, development and technologies applied, see Appendix 18.1.1. WLED Lights.

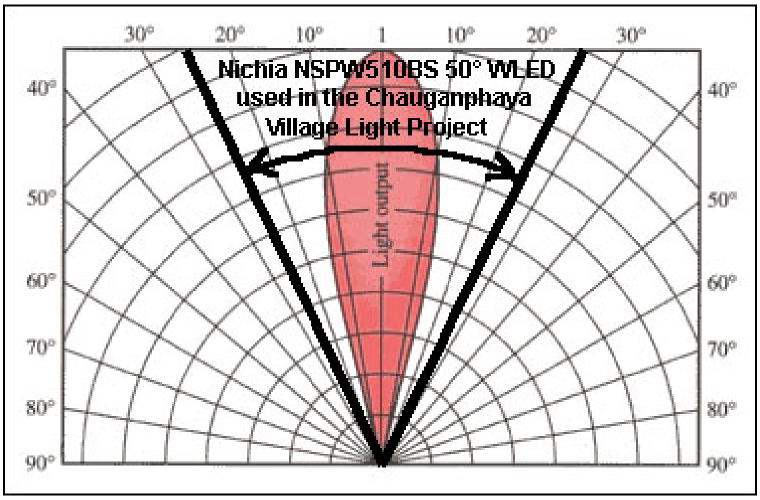


Figure 5-3 Nichia NSPW510BS 50° WLED Radiation Angle[72]

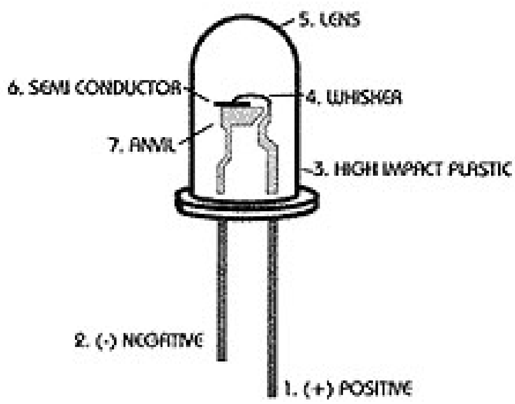


Figure 5-4 LED Physical Structure[73]

The mechanical construction of the LED lamp determines the dispersion or radiation pattern of the light. A narrow radiation pattern (Figure 5-1) will appear very bright when viewed on-axis, but the viewing angle will not be very wide. The same LED die could be mounted to give a wider viewing angle, but the on-axis intensity will be reduced.

In many developing countries kerosene is subsidised by the Government for the wide spread use by poor and remotely located communities, for cooking and burning wick lamps for lighting. The long-term health impact of kerosene is often underestimated and a lack of awareness among these communities does not enable them to recognise the danger their families are exposed to. Figure 5-5 shows the main dangers of kerosene wick lamps.

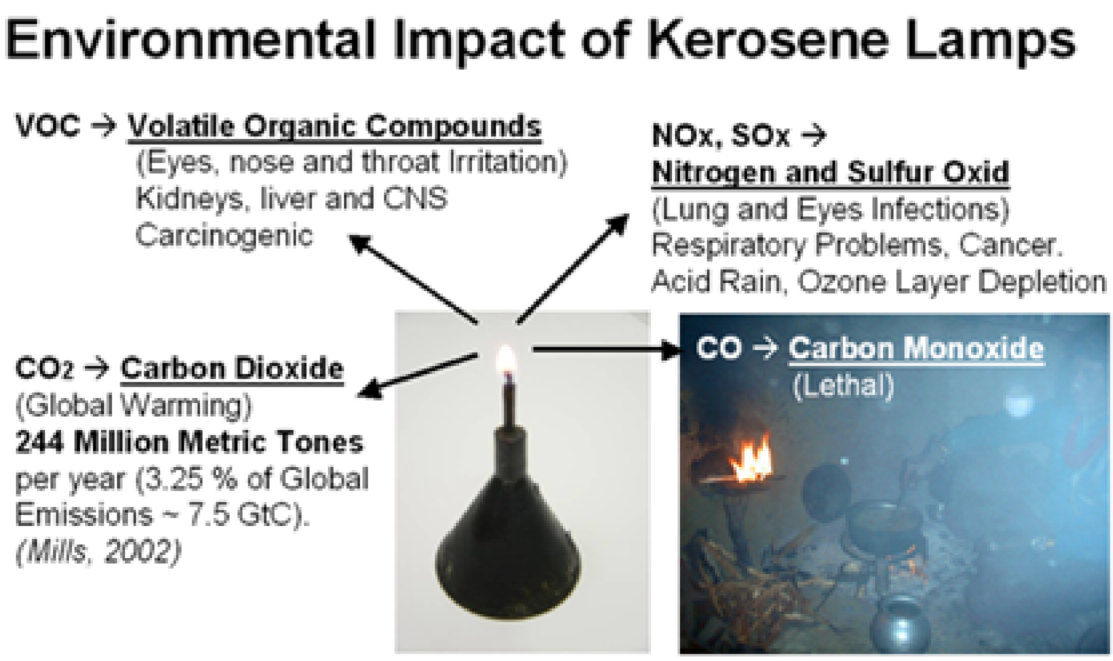


Figure 5-5: Environmental Impact of Kerosene Lamps
Used with permission from Rodolfo Peon, Light Up The World, University of Calgary, Canada.
Figure of the open fire cooking with smoke and “jharro” from Alex Zahnd

The Light Up the World "Lighting Sources Comparison" Table 5-4 shows clearly that the WLED lights have very favorable specifications and a promising future (Fig. 5-6) for applications in remote, poor communities, living in harsh conditions.

Lamp Type	Homemade Kerosene Lamp	Incandescent Tungsten Filament	Compact Fluorescent Lamp	WLED
Efficiency (Lumens/watt)	(equivalent) 0.03	5 - 18	30 - 79	25 - 50
Rated Life (Hours)	Supply of Kerosene	1 000	6 500 - 15 000	50 000
Durability	Fragile & Dangerous	Very Fragile	Very Fragile	Very Rugged
Lowest Power Consumption	0.04 – 0.06 liters / hour	5W	4W	0.1 W
CCT °K	~1 800°	2 652°	4 200°	5 000°
CRI	~ 80	98	62	82
$ After 50 000 hours	1251	175	75	65

Table 5-4: Lighting Sources Comparison
Used with permission from Rodolfo Peon, Light Up The World, University of Calgary, Canada
CCT °K: Correlated Colour Temperature in Kelvin degrees
CRI: Colour Rendering Index

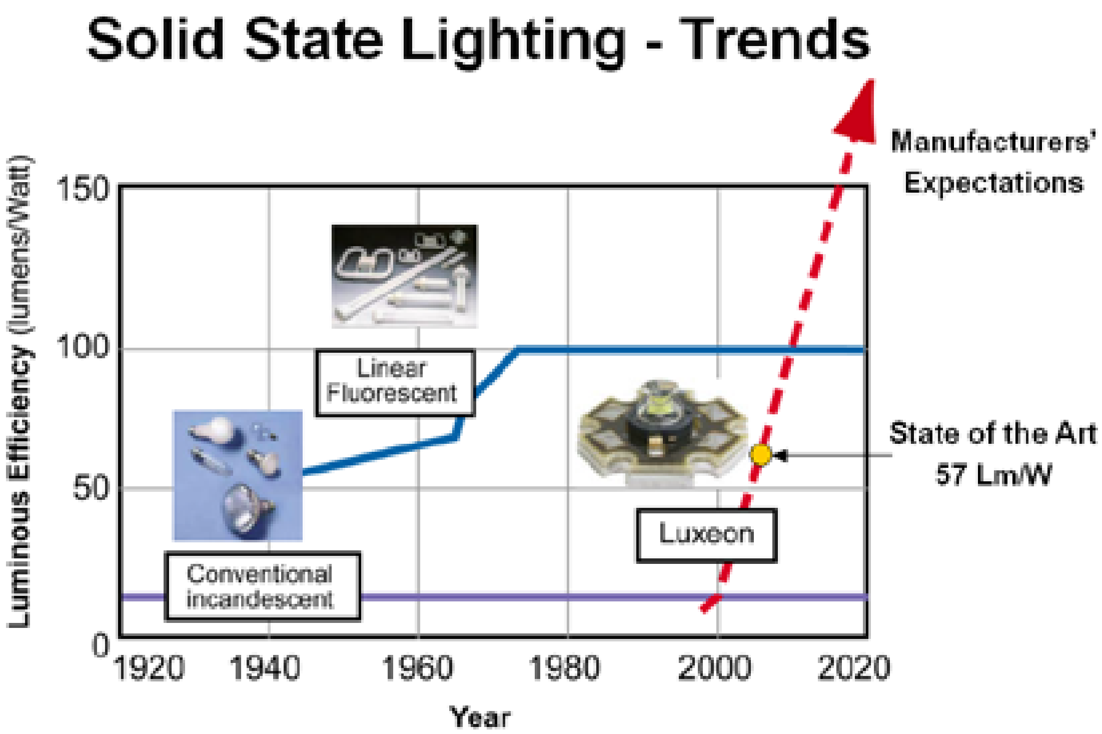


Figure 5- 6: Solid State Lighting – Trends
Used with permission from Rodolfo Peon. Light Up The World, University of Calgary, Canada

6. Comparison of Incandescent, CFL and WLED Lights

6.1. Comparative Investment Analysis of the Incandescent, CFL and WLED Lights

A comparative investment analysis for two incandescent bulbs (25 W and 55W), a 11 W CFL bulb and a 1 W WLED Light, has been done for the HARS in Simikot, where electricity is generated through a solar PV system at a rate of 1.027 US$ / kWh, and for the Chauganphaya Village, where electricity is generated through a solar PV system at a rate of 2.781 US$ / kWh. The results are presented in the following linked Excel worksheets (also added in Appendix 18.2.2.).

6.1.1. HARS in Simikot generated electricity cost of 1.027 US$ / kWh

HARS CFL 11W-Inc. Bulb 55 W

HARS CFL 11W-WLED 1W

HARS Inc. Bulb 25W-WLED 1W

HARS Inc. Bulb 55W-WLED 1W

6.1.2. Chauganphaya Village generated electricity cost of 2.781 US$ / kWh

Chaug CFL 11W-Inc. Bulb 55W

Chaug CFL 11W-WLED 1W

Chaug Inc. Bulb 25W-WLED 1W

Chaug Inc. Bulb 55W-WLED 1W

With these results, the light technology information in Chapter 5, and the following laboratory light test data for the three lighting technologies, it is possible to compare the three lighting technologies. That enables the ability to provide a recommendation for the most appropriate lighting technology for Nepal's high altitude and impoverished mountain communities.

6.2. Laboratory Light Tests Set-up

Each of the three light technologies, the incandescent bulb, the CFL bulb and the WLED light, were tested in a closed black wooden box at the Kathmandu University, in order to plot their related light output (illuminance) graphs in Lux (lumens/m^2). That enables a direct comparison of each technology's light output, dependent on the input power (Watt) and the distance from the light source.

The test conditions were set up as following:

- One wooden box (inside measurements 1.6 m height, 0.6 m square), which can be fully closed to avoid any entrance of light from outside. The inside walls are painted black. Each light source can be fixed in the middle of the black box, and the light output is measured between 5 cm and 140 cm distance from the light source outside diameter (see Figures 6-1, 6-2, 6-6).
- With a Lux meter the illuminance in Lux (Lumens/m^2) is measured for each of the three lighting technologies for every 5 cm height difference, starting at an initial distance of 10 cm, both in central vertical, and in 30 cm radius from the central light source in vertical height (see Figure 6-1).
- The Incandescent and CFL bulbs, both consuming 230VAC, are provided with stabilized 230VAC, to nullify any voltage fluctuation from the grid (see Figure 6-5).
- The Nichia WLED Light, (in need of at least 10.8 VDC at 70mA) is provided with a stabilized 12.5 VDC and 80 mA, (see Figure 6-3).
- A meter band, fixed inside the wooden box, is used to indicate the Lux meter's height distance to the measured light source (see Figures 6- 1, 6-2, 6-4).

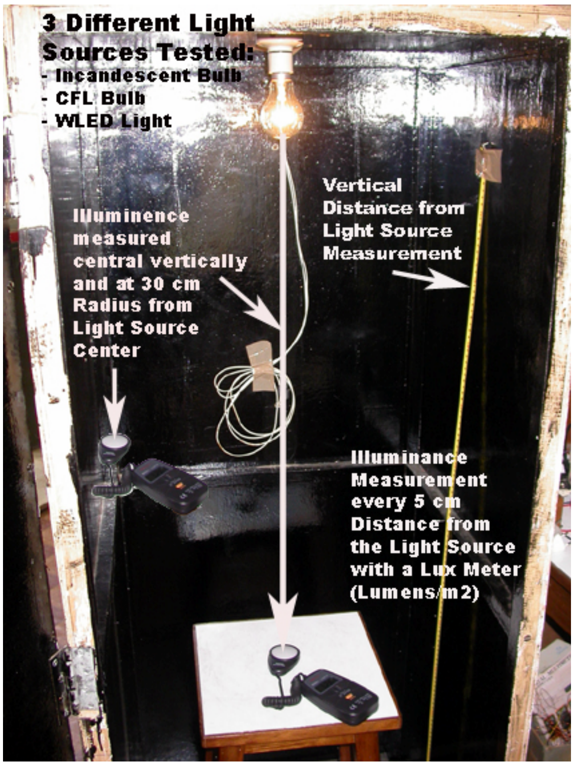


Figure 6-1: Light Measurement Box 1
Central vertical, and with 30 cm Radius vertical, each light is measured with a Lux meter from 10 cm onwards to 140 cm vertical difference from the light source center, in 5 cm steps.

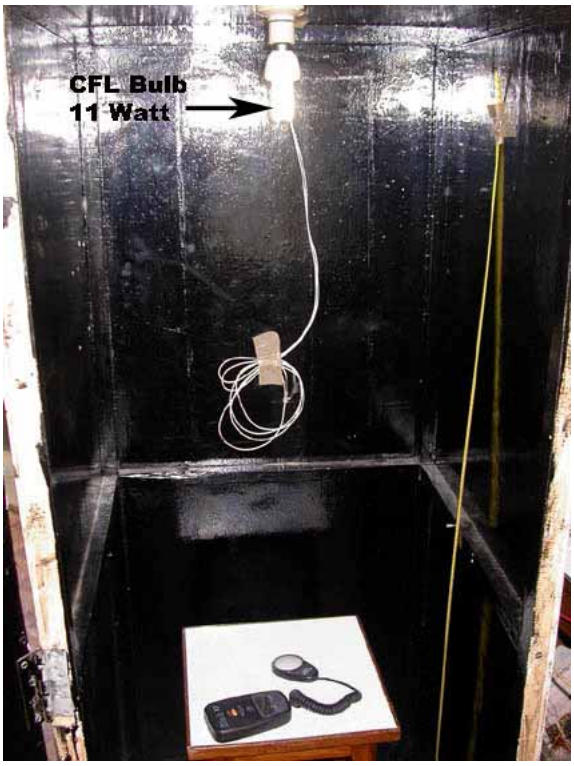


Figure 6-2: Light Measurement Box 2
Wooden Box with black painted walls, and a door which can be closed to prevent any incoming light from outside, provides an acceptable environment for the light tests.

Figure 6-3: WLED Measurement 1
The 9 diodes Nichia WLED light consumes in fact 3 x 3.6 = 10.8 VDC, @ 70 mA. 12.5 VDC @ 80 mA are constantly provided, in order to be slightly higher than what the WLED light needs. Internal the WLED cuts down the DC voltage to 10.8 VDC. That means that this WLED light consumes 864 mW under the test conditions.

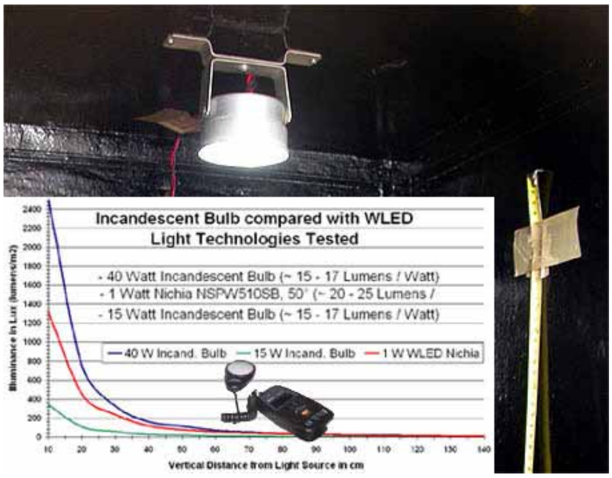


Figure 6-4: WLED Measurement 2
The aim of the 3 different light technology illuminance tests is to understand their different capability to illuminante a room of the same defined size. The red line in the graph shows the WLED in comparison to a traditional 25 W (green) and 40 W (blue) incandescent bulbs.

Figure 6-5: Variable Voltage Transformer
With this variable voltage transformer for the 25 W, 40 W, 60 W and 100 W incandescent bulbs, as well as for the 7 W, 11 W, and 15 W CFL bulbs were kept constant to provide equal comparable test conditions. The 230 VAC were periodically measured with a multimeter to make assure to have equal conditions for each light bulb.

Figure 6-6: Light Box
The 160 cm high wooden box with black walls inside.

The following lights were tested in the wooden black box (technical specifications are taken from the manufacturer's data):

- 1 W WLED Nichia Light with 9 single NSPW510SB WLEDs with each 50° light output angle and 1,800 mcd luminous intensity
- 7 W Ultralamp CFL with 350 Lumens.
- 11 W Ultralamp CFL with 660 Lumens.
- 15 W Ultralamp CFL with 900 Lumens.
- 15 W Incandescent Bulb (from "Super", one of India's best company).
- 25 W Incandescent Bulb.
- 40 W Incandescent Bulb.

The following graphs show the light output in Lux (Lumens/m^2) of the 15 W, 25W and 40 W incandescent bulbs, the 7 W and 11 W CFL bulbs and the 1 W Nichia WLED light.

1. Each light's illuminance was measured centrally vertically underneath the light source, starting from 10 cm from the light source, in vertical distances of each 5 cm, up to a total distance of 140 cm (Figure 6-7).
2. Each light's illuminance was measured at a horizontal radius of 30 cm from the light source in vertical distances, from 10 cm on, each 5 cm, up to a total distance of 140 cm (Figure 6-8).

6.3. Light Test 1: Central Vertical Light output measurement

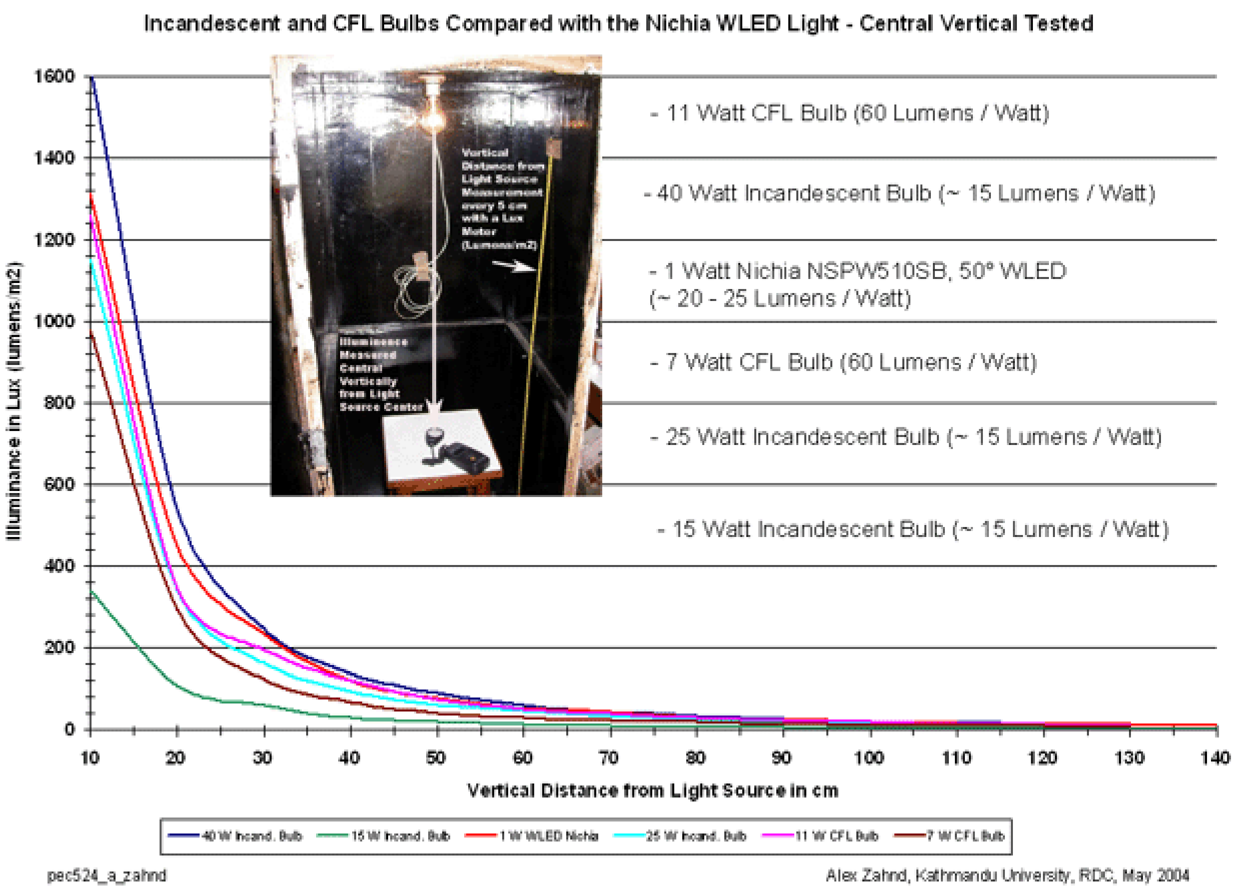


Figure 6-7: Plotted Graph for the Central Vertical Light Illuminance measured in Lux (Lumens/m^2)

The graphs plotted for the central vertical distances under the light source for the defined six lights show clear common trend, which is the expected high illuminance close to the light source, with rapidly dropping brightness as it gets further away.

While the 40 W incandescent bulb has the highest illuminance for the first 20 cm vertical distance, the WLED ranks second in place, closely followed by the 11 W CFL and 25 W incandescent bulb. The 7 W CFL bulb has an expected lower light output than the 11 W CFL bulb. The 15 W incandescent bulb is significantly lower already in the first 20 cm, and thus clearly manifests its low efficiency. From 20 cm – 30 cm vertical distance, the incandescent and CFL bulbs show a greater drop in light output compared to the WLED light, though at a distance of 40 cm, the 11 W CFL bulb has caught up with the Nichia WLED, providing about the same illuminance. These small irregularities though can be accounted within the possible accuracy of the test equipments and test set up.

From 40 cm – 70 cm vertical distance all the lights tested drop in similar fashion, with the 25 W, 40 W incandescent, the 11 CFL bulbs and the WLED light about to provide the equal amount of light at 70 cm vertical distance. Only the 15 W incandescent bulb is still clearly behind the other lights' performances. From a vertical distance of about 120 cm onwards the difference between the first 5 lights' (excluding the 15 W incandescent bulb) light output are increasingly smaller (± 2 Lux), a range which lies within the accuracy of the test set up and measuring equipment, and thus they can be considered as insignificant.

While the WLED light has a 11 – 40 times lower power consumption compared to its closest rivals, the 11 W CFL and 25 W and 40 W incandescent bulbs, its performance is not as much behind. In fact it ranks at second position in regard to light output (Lumens/m^2) for the first 60 – 80 cm of central vertical distance from the light source, right behind the 40 W incandescent bulb, but ahead of the 11 W CFL and 25 W incandescent bulbs performance. From 80 cm – 140 cm the first 5 lights are rather similar and probably within the accuracy of the laboratory and Lux meter measuring set up. Thus, from 80 – 140 cm vertical distance, the WLED light is comparable to the other, more power consuming lights, in regard to its illuminance. With a light output angle of 50°, the Nichia NSPW510SB WLED performs under this central vertical test at its best, as the other lights' light output angle is all around the light source and not as bundled as in the WLED.

6.4. Light Test 2: 30 cm Horizontal Radius from Light Source, Vertical Light output measurement

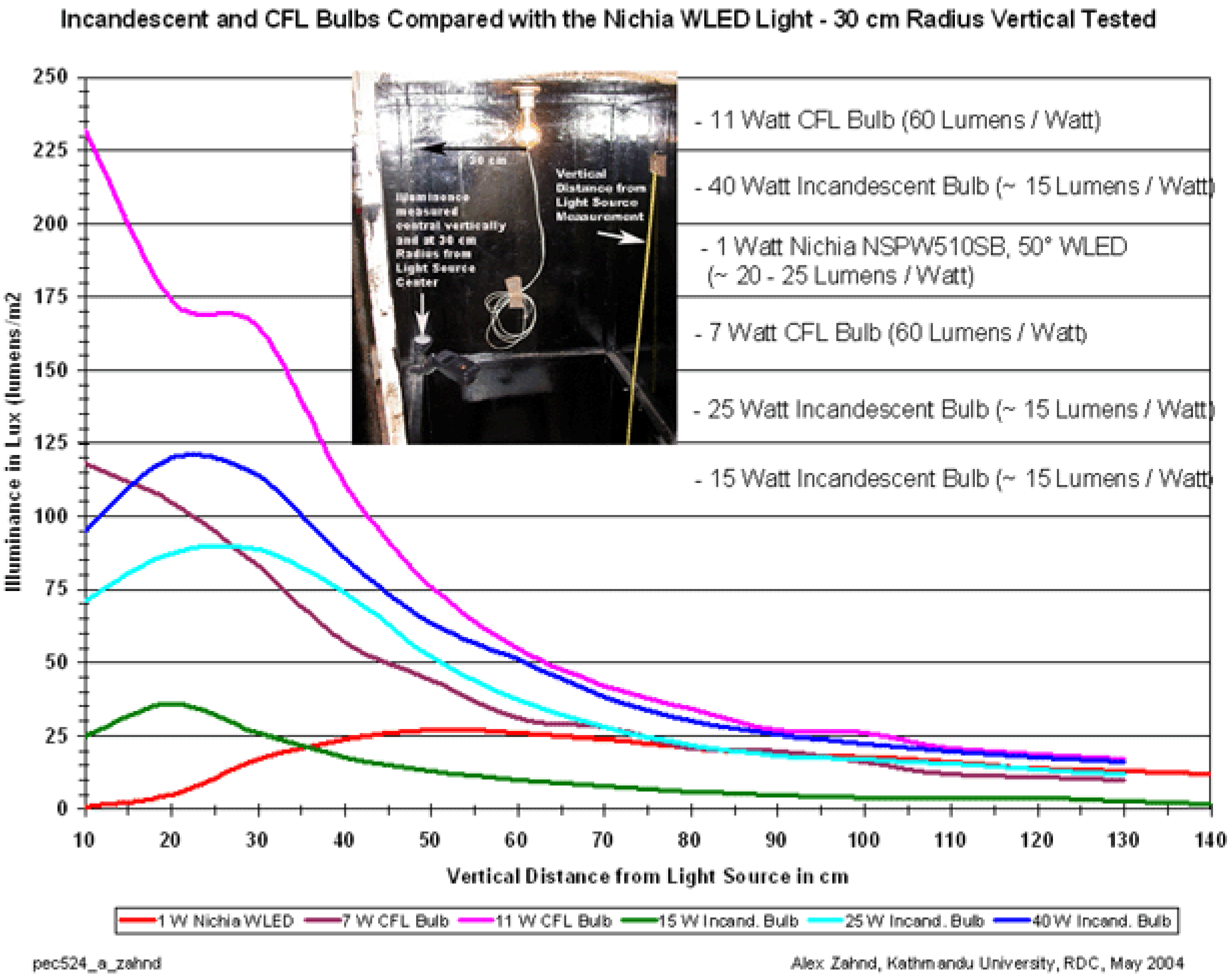


Figure 6-8: Plotted Graph for the 30 cm Horizontal Radius Light Illuminance measured in Lux (Lumens/m^2)

The graphs plotted, for the 30 cm horizontal radius from the light source in vertical distances underneath the light source for the defined six lights, show a clear common trend. Expected high illuminance close to the light source for the CFL bulbs within a vertical distance of up to 30 cm. That can be explained due to the shape of their bulb, which is much larger in the vertical distance, compared to its rivals, the incandescent bulbs, or even much more compared to the WLED light. All three incandescent bulbs indicate the same trend. Initially their light output is lower than at 20 cm – 25 cm vertical distance. Thus their illuminance rises from close to the light source to their maximum illuminance between 20 cm – 30 cm vertical distance, before again the light output drops in similar fashion rapidly.

The CFL bulbs both drop in a similar angle compared to the incandescent bulbs, once the vertical distance is bigger than 35 cm – 40 cm. The WLED light sticks out of the plot due to its completely different curve, compared with all the other 5 light output curves. Within the first 30 cm of vertical distance, the WLED light hardly puts out any light, and thus performs the least out of all 6 tested lights. Only from 35 cm vertical distance on, it overtakes the 15 W incandescent bulb by increased illuminance. At about 80 cm vertical distance it equals the light output of the 25 W incandescent and 7 W CFL bulb, though still clearly behind the 11 W CFL and 40 W incandescent bulbs. While the 7 W CFL and 25 W incandescent bulb drop slightly below the WLED light with their light output values from a vertical distance of 100 cm onwards, the WLED does not reach at any stage the illuminance of the 11 W CFL and 40 W incandescent bulbs under these test conditions.

Thus it can be summarised, that the WLED light's performance in the 30 cm horizontal radius (from the light source) measured vertical light output is much lower throughout the test, compared to its main rivals, the 11 W CFL and 40 W incandescent bulbs. It comes up to the 7 W CFL and 25 W incandescent bulbs illuminance once the vertical distance is greater than 100 cm. These test conditions clearly indicate the WLED light's strength, as a direct in-axis light source, and its weakness, the low wide angle illuminance.

6.5. Incandescent Bulb Summary

Incandescent bulbs, simply known as the "light bulb", are globally by far still the most popular lighting technology, including in Nepal. Its popularity is due to the simplicity with which it can be used and the low price of both the lamp and the fixture in urban areas. Also, the lamp requires no special equipment, like a ballast, to modify the characteristics of its power supply. For comparison sake, a village with 50 homes, each home with 3 incandescent bulbs @ 55 Watt (nominally comparable to a 11 W CFL bulb), demands a power generation of about 10 kW (including some 20% overall losses). But its advantages assure it a place in most homes and businesses for the foreseeable future.

The advantages of an Incandescent Bulb are:

- Low initial cost.
- Widely and easy available (though this is not true for remote mountain areas).
- Excellent colour rendition.
- Instant starting.
- Can take up to <10% higher voltage without damage.
- Works at any voltage below rated voltage (though with proportional decreased light output).
- Inexpensive dimming capability.
- Small size, which allows it to be used in point fixtures, such as spot lamps.
- Wide variety of shapes, sizes, colours and wattages are available.

- Output unaffected by high or low ambient temperatures.
- Simple to operate and install.
- Requires no ballast.
- High brightness light source.

The disadvantages of an Incandescent Bulb are:

- Relatively short useful life (~1,000 hours) with limited over-voltage tolerance (from ≥ 10% over voltage on, life is reduced by about 75%).
- Very inefficient source of light. 4% - 5 % of the wattage goes to produce light in the visible spectrum; and 95% - 96% of the wattage is in the infrared spectrum.
- High heat component can create hidden energy costs due to increased cooling needs.
- Easy to break, and thus can cause serious injuries when disposed inappropriately. Also during long transport by airplane and porters, the filament can easily be damaged through the vibrations and shocks.
- There is an increased thermal shock and mechanical stress on the filament that results from the full voltage hitting the cold filament, every time the bulb is switched on.
- With an average of 15 lumens/Watt, it has the lowest illuminance of all three tested technologies.
- In a country like Nepal, where electricity is very costly (compared to the average income), the incandescent bulb is by far the most expensive to run.
- Light output is sensitive to voltage fluctuations.

Keeping in mind the life conditions of the rural high altitude mountain communities, it is clear that the incandescent bulb does not provide an appropriate and sustainable solution for an elementary electrification for light, as the incandescent bulb is a high power consuming, and highly inefficient light technology.

6.6. CFL Bulb Summary

Overall, a typical CFL tube is four to six times more efficient, and with an eight to ten times longer life time expectancy, compared to an incandescent lamp[74]. That means in turn that any local mini-grid generated power plant can be four to six times smaller in its rated power output. Such a power plant will be much cheaper to build, cheaper and easier to transport, as well as easier to maintain and repair under normal circumstances. The CFL technology is well developed, more and more widely available, and providing satisfactory results under various climate conditions.

The advantages of a CFL Bulb are:

- Energy efficient.
- Long life time (8,000 – 12,000 hours), or 8 - 10 times (some even mention 10 to 20 times[75]) longer life compared to incandescent bulbs.
- Good colour rendition available.
- Instant starting with electronic ballast.
- Can take up to +/- 10% higher and lower voltage differences.
- Small size, which allows it to be used in point fixtures, such as spot lamps.
- Wide variety of shapes, sizes, colours and wattages are available.
- Simple to operate and install.
- Ballast and CFL tube are available separately.
- High brightness light source.
- They are cooler to touch.

- They spread light over large areas without excessive glare.
- They reduce the electricity bill substantially (4 -6 times).
- Most fluorescent tubes made today do not flicker anymore (otherwise causing e.g. headaches).
- They activate gas rather than a metal filament (as in the incandescent bulb), allowing them to convert 30 percent more energy into light[76].
- Good lumen/Watt (average for the Ultralamp CFL of 60 lumens/Watt according to the manufacturer's data.
- Both AC and DC CFL bulbs available.

The disadvantages of a CFL Bulb are:

- Higher initial cost does not make them attractive enough for poor people.
- Cannot usually be used with a dimmer switch (although this is not a desirable option in the rural areas of Nepal).
- The light output is affected by low ambient temperatures (practical experience from the HRSAS in Simikot shows, that the light output reduces by 20% - 30% at ambient room temperatures between 0°C – 10°C).
- Often requires about a second to light.
- Requires about 15 - 30 seconds to approach maximum brightness[77].
- Easy to break, and thus can cause serious injuries when inappropriate disposed. Also during long transports by airplane and porters, CFL bulbs can easily brake through the vibrations and shocks.
- High quality CFL bulbs are very difficult to get in the remote areas of Nepal.
- Some have large bulb, and thus may not fit in some light fixtures.

The CFL bulb clearly presents a superior option, both technically, as well as economically (see the comparative investment analysis worksheet for incandescent bulbs, CFL bulbs and WLED lights in Appendix 18.2.2.) for a rural elementary electrification scheme, as compared to the incandescent bulb. The CFL bulb, in its AC and DC version, has a great potential to find increased entry into the offices and projects of the rural places, where there is a demand for a high level of illuminance (PC, writing and reading), long life and reliability. At the low end of the power spectrum a CFL bulb consumes only 7 – 11Watt, or 20% - 30% of a comparable incandescent bulb. For comparison sake again let's assume a village with 50 homes, each home with 3 CFL bulbs @ 11 Watt (comparable to a 55 W incandescent bulb). This power plant demands a power generation of about 2 kW only (including 20% overall losses).

6.7. WLED Light Summary

By nature the WLED light is a solid state form of lighting, without any filament or internal gas. The robustness and ability to perform under harsh and difficult conditions in reliable and durable ways, are strong positive points in favour of WLED lights. But the major weak point, shown clearly in the second test conditions (30 cm horizontal radius from the light source measured vertical distances), is that the WLED, with its focal light output angle, is not ideal for conditions where light is needed all around. The CFL and incandescent bulbs provide much better services for these demands.

Research and development activities in the area of WLED lights clearly focus on that issue, and already over the last 3 - 5 years various wider angle WLED lights, up to 110°, have come on the market. But again, in order to have the same light output at a defined vertical distance with such a wide angle WLED demands a much higher lumens/Watt output, which is at the time of writing, mere still limited to about 60 - 70 lumens/Watt for a few laboratory based prototypes[78].

LEDs are current-driven devices (whereas incandescent bulbs are voltage-driven devices), thus the drive current and light output are directly related. As a rule, an incandescent source is 4% - 5 % efficient, but for LED lights it is rather difficult to find reliable efficiency data. Efficiency values for LEDs of 10% -15%)[79], and even up to 75%[80] have been found in the literature. This range is too big to define one reliable figure. In this case it is better to rely on the lumens/Watt rate as a standard way of rating the lights. This figure accounts for all of the light produced by a bulb. With values ranging between 15 – 25 lumens/Watt for LEDs and 15 - 17 lumens/Watt for a standard incandescent bulb, the LED light has an approximately 20% higher lumens/Watt illuminance per rated power consumption. But while the incandescent bulb will hardly undergo major drastic improvements, the leading LED manufacturing companies such as Nichia, Lumiled or Cree, speak already of 50 – 70 Lumens/Watt in the foreseeable future (in 1 - 2 years). That will give the LED light a favourable position in the years to come. Thus the LED in general, and the WLED in particular, seems to be a promising choice for providing light for elementary electrification systems in remote and impoverished communities, for the long term future. Again let's compare. A village with 50 homes, each home with 3 WLED light @ 1 Watt. A village with 50 homes, each homes with 3 WLED lights needs a power generation capacity of 180 W (including some 20% overall losses). That is a factor 55 smaller than the power plant size needed with 55 W incandescent bulbs, or 11 times smaller than the power plant size needed with 11 W CFL bulbs. It has to be mentioned though that this is just from the power generation point of view with unequal light (lumens) output, as the lab tests clearly demonstrated.

The general advantages of a WLED Light are:[81]

- Low energy consuming, only 4% (see Excel worksheets in Appendix 18.2.2.) of the energy of a 25 Watt incandescent bulb, and only 9% of the energy of an 11 Watt CFL, though with limited light services. But this is acceptable in rural areas.
- Reducing the electricity cost by 80% and more, compared to incandescent bulbs.
- Long lasting, with a service life of around 100,000 hours, thus reducing/eliminating replacement costs.
- Ability to illuminate an object, surface or task well, if it is centrally vertical underneath the light source (measured up to a distance of 140 cm).
- Low in maintenance needs (just periodical cleaning).
- Providing a good quality light output, with minimum ultraviolet and infrared radiation.
- Save to handle. No heat, noise, vibration or high voltage.
- Small in size, their high intensity and low weight and volume, make them useful for lighting tight spaces.
- DC power supplied, causing no flickering.
- Able to provide a great flexibility in imaginative lighting designs.
- Since they have no filament, they cannot be easily damaged under circumstances when a regular incandescent bulb would break.
- Waterproof through the epoxy layer.
- Not susceptible to cold (in fact even slightly higher output in colder environment), and thus ideal in cold high altitude places such as the Himalayas.

- Easy to transport even through rough terrain where they get badly shaken.
- Virtually indestructible mechanically.
- Enormous future potential with many fields of applications.

With these advantages the WLED light's possible application can be defined as:

- An appropriate solution for elementary electrification through a solar PV system.
- An approved technical solution to bring light to many homes with a minimal power demand, thus minimizing the power generation equipment and therefore costs and maintenance needs to a minimum.
- An apt lighting solution for basic "first time" lighting inside a home, to read, work and socialize.
- A suitable light source for the poorest communities with its low running costs.
- A sustainable light solution for the remotest mountain communities, with a long life expectancy.

The disadvantages of a WLED Light are:

- Still high cost**,** although the prices keep falling.
- Still low lumens/Watt light output.
- The focused light field, which limits their specific lighting tasks to clear identified jobs such as reading lights, desk lamps, night lights, spotlights, security lights. They do not radiate light in 360 degrees as an incandescent bulb does.

- Slightly cooler light colour compared to the warm yellow light of the incandescent bulb, which people are more used to for residential use.
- They need to have defined current limitation (e.g. the Nichia NSPW510 BS used for the Chauganphaya Village WLED lights have a maximum forward current flow of 25mA (Figure 5-7 and 5-8 in Appendix 18.1.2.), in order to guarantee the expected long life.
- They need an additional AC-DC converter, if they are intended to run direct from an AC grid (as they run on 3.6 Volt DC, as in Diagram 5-5 can be seen).

For a week long data monitoring of two different WLED brands (Nichia and Lumiled WLEDs) see Appendix 18.2.1. Figure 6-11.

6.8. Recommendations for an Elementary Lighting Technology for Remote Communities

The following list from "Other Power - Efficient Lighting"[82] provides helpful comparable data of the approximate lumens/Watt illuminance range for the various lighting technologies on the international market, to which one compare the test results for our three lighting technologies.

Light Technology	Power (Watt)	Lumens/Watt	Remark
T8 fluorescent	32	85 - 95	Fluorescent tube lights for home lighting.
F40T12 fluorescent	40	60 - 65	Standard cool white fluorescent tube light for home and business.
CFL		30 - 60	usually 48 – 60 Lumens / Watt.
T3 tubular halogen		20	Small halogen lamp for domestic homes and spot lighting.
WLED		15 - 19	With potential steep increasing future light output (> 60–80 Lumens/Watt)[83]. The Nichia NSPW510 BS, used in Chauganphaya has already 23 Lumens /Watt[84].
Incandescent Bulb	100	17	Standard 100 Watt incandescent.
Incandescent Bulb	7	6	Incandescent night light bulb.
Incandescent Bulb		< 6	Incandescent flashlight bulbs.

Table 6-1: Approximate Lumens/Watt Illuminance Range for the Various Lightning Technologies on the International Market.

Each of the three investigated lighting technologies has its established place and preferred application in the society. The incandescent bulb, as the most common and widely available light bulb, has provided people in their homes, businesses and factories with valuable light, for over a century now. That will undoubtedly continue for years to come in the more urban areas, where electricity is widely and easily available, for an affordable price. The CFL bulb had a quick entry into the market, as it was promoted as the energy bill saving device. Though low quality products, not providing what they promised, did not give the CFL bulb the possible momentum it otherwise could have had (as e.g. is the case in Nepal), especially in urban areas and in countries where electricity is either expensive or generated mainly from fossil fuels.

If the data and information in this study for the three light technologies gathered is compared with the context for which the study is undertaken, the WLED light shows strong overall advantages and thus is the most suitable technologically, in regard to the objectives previously set out for the community in context.

The choice for WLED lights for a comparable context in the remote Nepal Himalayan mountain communities in Jumla, western Nepal is confirmed by Craine's study of an optimized lighting system for a village electrification. His study concluded that the cost of a micro-hydro power plant installation can be up to half, using fluorescent lighting, with no reduction in lighting service[85], and about six times lower if WLED lights are used. He goes on to say that WLED systems still do not offer the energy services (Lumens/Watt) as efficiently as the fluorescent tube and CFL lighting technologies, though they are superior to kerosene lighting.

The WLED lights over all are providing the most appropriate and sustainable lighting solution for the target group's living conditions, because they are:

- providing the minimum needed lighting service.
- financially affordable (with a life cycle cost analysis).
- sustainable (long life expectancy).
- minimal in their maintenance needs (easy and simple to clean).
- minimal in their running cost.
- easy to install anywhere the household owners want the WLED lights.

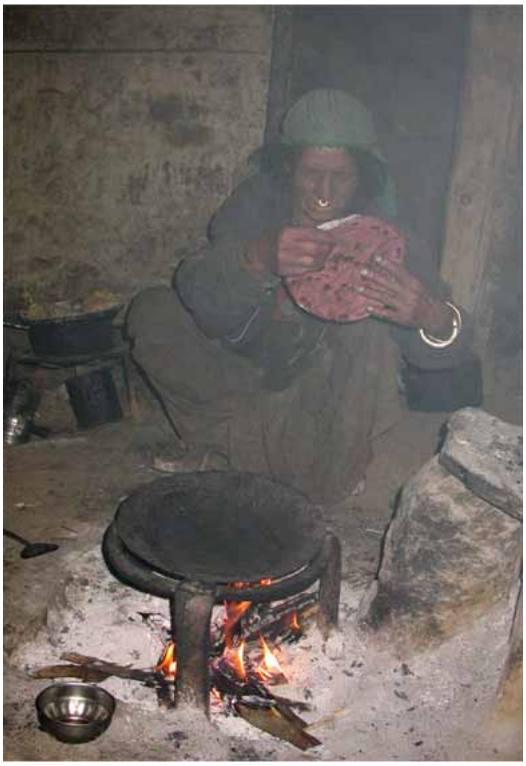


Figure 6-9: Home with Open Fire Place
A home with NO Lights and OPEN fire cooking (one dish at a time) and heating. The home is full of smoke, causing major respiratory diseases especially for women and children. Daily 20 – 40 kg fire wood is consumed, with great danger of children falling into the open fire

Figure 6-10: Home with Smokeless Metal Stove
A home with 3 WLED Lights and a smokeless metal stove for cooking (making a whole meal at the same time through its three burners), providing hot water, and heating at the same time. Thus NO smoke inside the home, NO danger for children, better hygiene (through the hot water) and half the amount of daily fire wood consumption, are the results.

7. Solar Irradiation Monitoring and Data Recording

7.1. Introduction to Solar Irradiation

In order to design and calculate sustainable and appropriate solar PV systems for homes or villages, it is crucial to know what amount of solar energy is available in the particular location, throughout the year.

The energy output of the sun, reaching the top of the earth's atmosphere, called the solar constant, is the extraterrestrial solar radiation. This value can be taken as constant with 1,367 W/m^2, as can be seen from Figure 7-1 and other references[86].

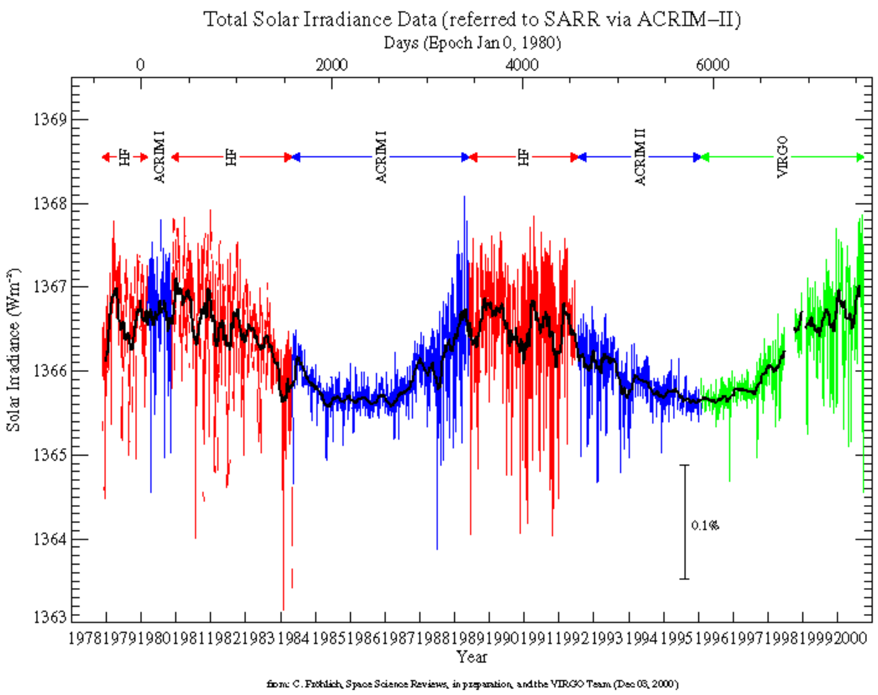


Figure 7-1: Solar Constant Measurement from 1980 – 2000
The Solar Constant G_{SC} = 1,367 W/m^2. Extraterrestrial Solar Irradiation fluctuation from 1980 – 2000, according to the sun's solar activities, measured by different satellites, as indicated on the graph. (From: C. Froehlich, Space Science Review, December 2000)

The energy output of the sun varies slightly according to its solar activity, estimated to be < ± 1.5%, due to the different periodicities and variations related to the sunspot activities[87]. The variation of the earth's distance though leads to extraterrestrial radiation variation in the range of ±3%.[88], with an average distance of 149.5 million km from the sun (with a ± 1.7% difference according to the month[89]). Thus an average value of 1.367 kW/m^2,[90] [91] [92] [93] the solar constant, at the top of the atmosphere (on a surface directly facing the sun), is generally considered as constant. Absorption and scattering, particularly by dust and water vapour in the atmosphere though, reduce the solar irradiance to about 1 kW/m^2 on the surface of the Earth. 10% - 50%[94] of this power comes from scattered, diffuse light on an average sunny to slightly clouded day.

The solar radiation arrives on the earth at a maximum flux density of about 1 kWh/m^2, in a wavelength band between 0.3 µm and 2.5 µm[95]. This is called short wave radiation[96]. Thus it is possible to use this maximum flux density, apply some correction factors for additional losses through the atmosphere if the location demands it, and multiply it with an average amount of peak sun hour per day (PSH = Peak Sun Hours), to calculate the daily solar irradiation, if no other instruments or data are available. But such a method is only approximate and not accurate enough for the design and calculation of a solar PV system.

Instead, to design and calculate the performance of a solar PV system in a reliable and professional way, previously measured and recorded solar radiation data at the location in question or from a nearby similar location are used. The most common available data is the hourly beam and diffuse solar radiation on a horizontal surface. As most of the solar PV modules are not mounted on a horizontal surface (not even at the equator, as at least a 5° slope is needed to have the rain water running off the modules), the solar radiation has to be calculated for an inclined surface. For this the directions from which the beam and diffuse components reach the solar PV module's surface need to be known.

It is generally not advisable to base predictions or calculations of the available solar radiation for a particular location by just applying a defined factor, counting for the attenuation of the extraterrestrial radiation by the atmosphere. Instead, to predict the available solar energy for a defined location, i.e. measurements of the solar radiation (W/m^2) falling on the identified location in question[97], a pyranometer is used, measuring the total (beam and diffuse) radiation, as well as the albedo radiation (the radiation reflected by the ground).

To measure and record this locally received solar radiation over time is the best way to come to a set of solar irradiation data (kWh/m^2 per day) for the place in question. This is particularly useful and exact (if monitoring and data recording can take place over several years to include also the "good" and "bad" years) as all the otherwise difficult to define parameters, effecting the incoming solar radiation, are taken into account.

Obtaining accurate solar irradiation (W/m^2 per day) data is of great importance for solar photovoltaic system designing. Mainly three different technologies are used to measure solar radiation.

- A thermopile detector pyranometer (consisting of two dissimilar metallic wires with their ends connected).
- A thermomechanical sensor (where the suns' radiant flux is measured through the bending of a bimetallic strip).
- A photoelectric sensor (made of a semiconducting material such as silicon, basically a calibrated polycrystalline silicon photovoltaic cell).

The photoelectric sensor's accuracy with 15%[98] is not as high as for the two other technologies, but their instantaneous response to solar irradiation changes, their low price, the direct output signal (in mV) without external power source, and the low maintenance requirements (no need to calibrate them yearly), make them an ideal pyranometer to measure the global solar irradiation in a remote and difficult location.

7.2. Solar Irradiation Data for Simulation and Calculation Tools

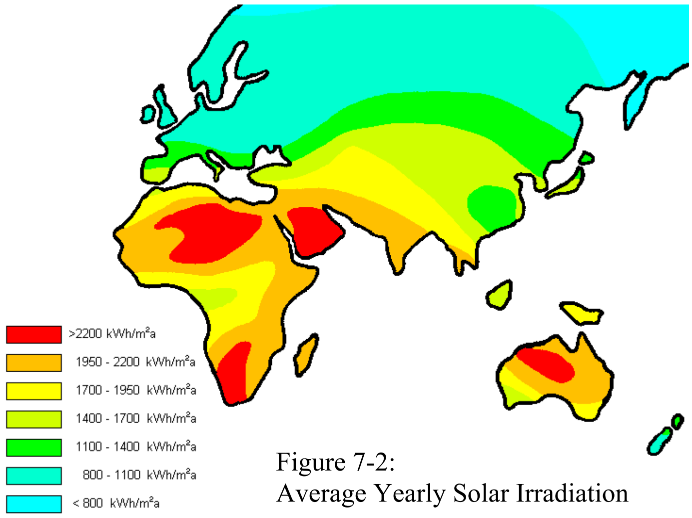


Figure 7-2:
Average Yearly Solar Irradiation

Meteorological stations around the world are equipped with high quality pyranometers. They usually provide the hourly global solar irradiation on a horizontal surface. Often meteorological or solar PV system simulation software demand the input of hourly data, and if needed, are usually calculated for an inclined surface. If daily or monthly[99] solar irradiation data are of interest, they can be derived by summarising the hourly data. Quarter yearly (according to the season) or even average yearly solar irradiation maps (Figure 7-2) are also available. This allows a quick and fairly accurate initial estimation of the available solar energy resource calculation for a geographical area.

It is not uncommon that in developed countries the network of available solar irradiation data measurement station is quite close, so that for a particular geographical location a near by data bank can be consulted, with may be some degree of extrapolation.

Unfortunately, that is not at all the case in developing countries, and in particular not in extremely remote areas. How such a situation has been addressed in the case for the Chauganphaya solar village PV system, will be described in more detail in the following chapters.

7.3. Solar Irradiation Monitoring and Data Recording in Nepal

Kamal Rijal states in an article in the *Water Nepal* magazine[100]:

> "In Nepal, global solar radiation is measured at only one station. This limitation is due to the complexity and cost of the standard apparatus as well as the work necessary for the calibration and maintenance of the instruments. As a result, global solar radiation has to be estimated from climatic parameters, which are more easily measured in meteorological stations".

The only global solar radiation data measurement station in Nepal is located in the capital Kathmandu, situated at 27° 42' Northern latitude, and 82° 22' Eastern longitude, at 1,337 m.a.s.l.[101]. Since 1975 data has been gathered with a bimetallic actinography with a seven day chart. Small meteorological stations have been built since 1968, in 32 other places all over Nepal (though not in the district of Humla), measuring the daily duration of bright sunshine with Campbell Stokes sunshine recorders. The Campbell Stokes recorder, closest to Humla, is situated in Jumla, a 7 days walk south. The 2 next closest ones are both 15 days walk away from Humla, in Surkhet, and in Dadeldhura. Not only are these latter two places too far away in regard to the distance to have any relevance to the Humla solar irradiation condition, the whole climate of these two places is very different, as they are both at the foot of the mid-hills (at altitudes of 1,200 m –1,800 m), while Humla is beyond the high range of 6,000 – 8,000 m peaks of the Himalayas, enjoying a much drier and more sunny climate, at an average altitude of 2,500 – 3,500 m. Only Jumla, with a similar climate (though at about 700 m lower altitude) is comparable, though still too far away distance wise (7 days walk south of Humla).

Rijal states that only 29, out of the 32, meteorological stations installed with a Campbell Stokes recorder, have been able to provide reliable data over a time period of 4 years or more, as the others either were not yet in operation for such a long time period, or they have too many missing data.

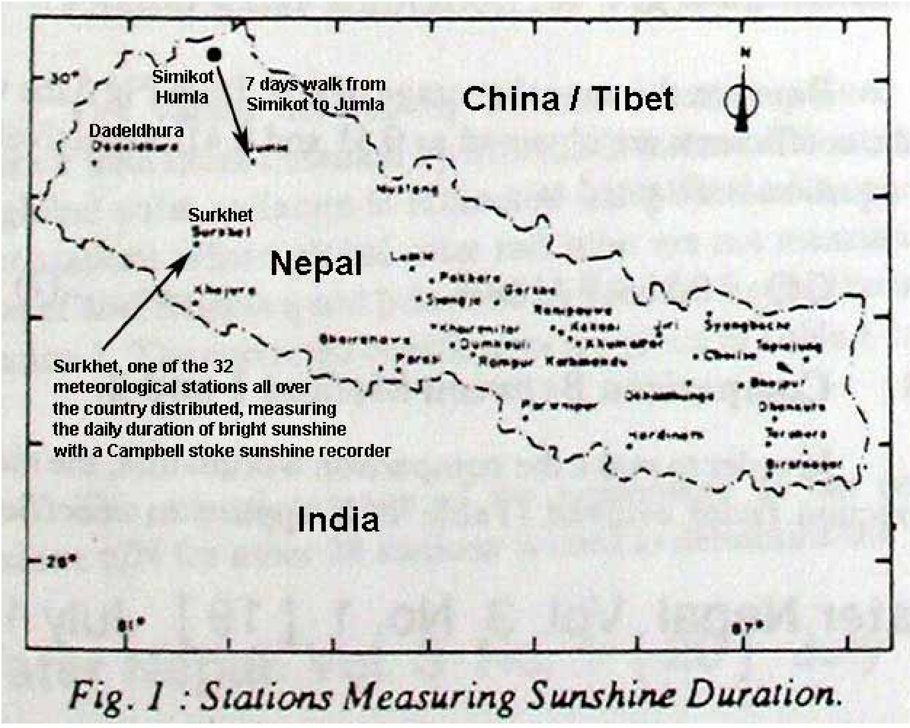


Figure 7-3: 32 Meteorological Stations Distributed all over Nepal

Figure 7-3[102] shows the geographical positions of all 32 meteorological stations distributed all over Nepal, measuring the daily bright sunshine hours with a Campbell stoke recorder.

As can be seen, way more recorders are positioned in mid and eastern Nepal than in the western region. There is no recorder installed further north than Jumla, which is still a 7 days walk away from Simikot in Humla.

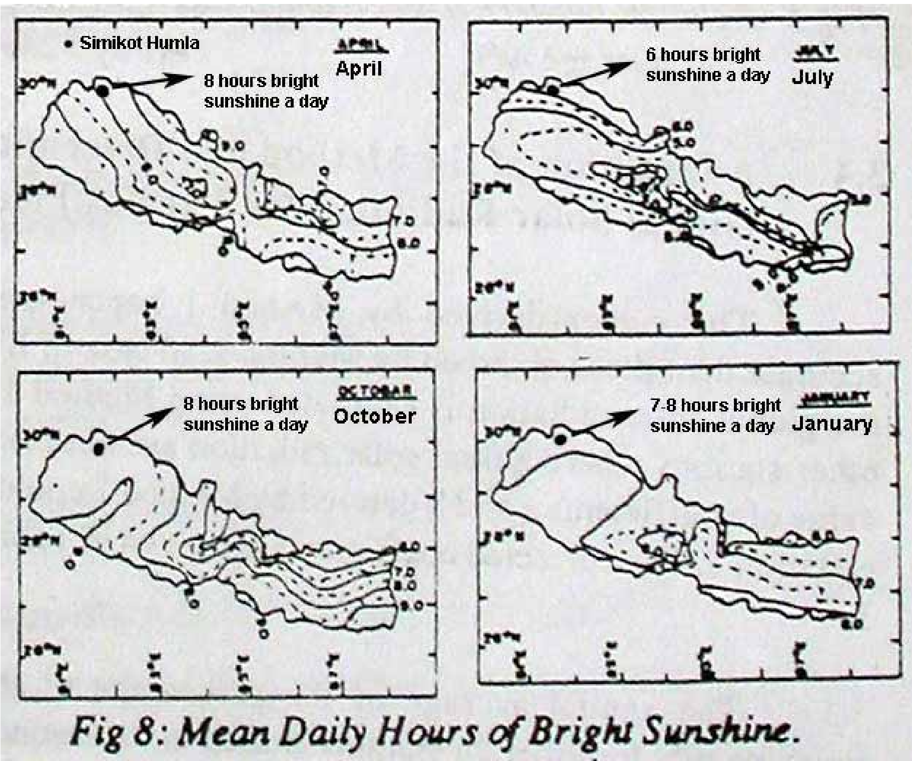


Figure 7-4: Mean Daily Hours of Bright Sunshine April / July / Oct. / Jan.

The mean daily hours of bright sunshine for the four months April, July, October and January are shown in the Figure 7-4[103].

The north-western area in the midst of the Himalayas, beyond the huge 7,000 – 8,000 m peaks, enjoys long daily hours of bright sunshine, as the main rain falls go down at the south slope of the big mountain range.

That in turn indicates a high daily value of solar irradiation throughout the year, as the following data confirms.

Figure 7-5[104] depicts the global solar radiation (W/m^2) all over Nepal, distinguished in 5 zones, dependent on the amount of solar radiation. Simikot lies in the highest solar radiation zone, estimated to receive 2,250 W/m^2 annually, adding all 12 monthly average global radiation values (187.5 W/m^2). That amounts to an annual solar irradiation of 1,642.5 kWh/m^2 per year (187.5 W/m^2 x 8760 hours), or a daily average of 4.5 kWh/m^2 per day throughout the year, with approx. 3.4 kWh/m^2 as the minimum in December and with 5.8 kWh/m^2 as the maximum in April (see Figure 7-6).

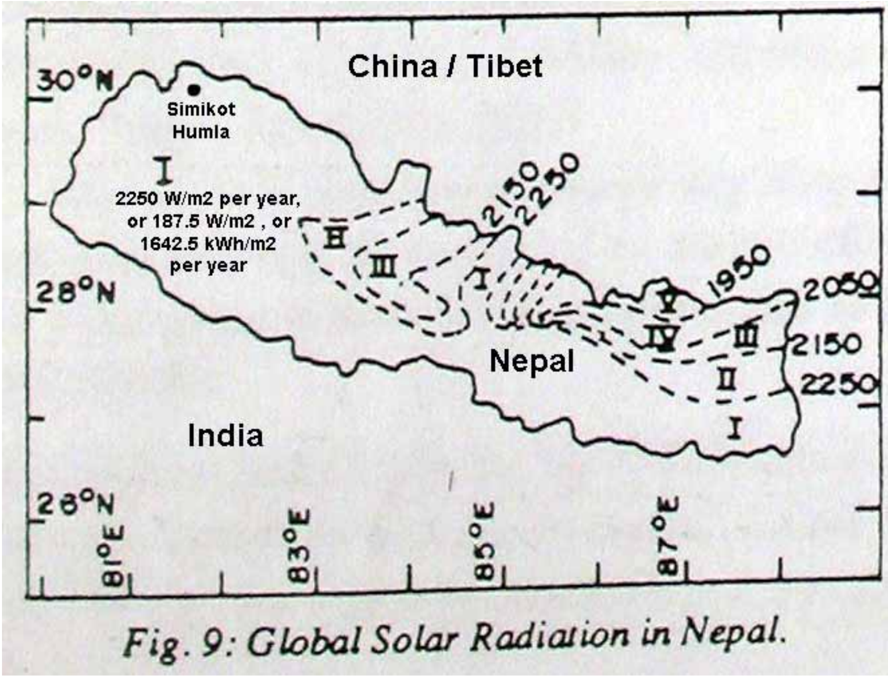


Figure 7-5: Estimated Global Annual Solar Radiation for Nepal.
These data are based on the measured daily bright sunshine hours of 29 meteorological stations with a Campbell stoke recorder.

Table 4
Monthly Global Solar Radiation in W/m^2

Place	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
TYPE I													
Sub-type Ia													
Hardinath	161.6	193.3	223.0	246.7	258.1	230.8	230.8	221.3	203.5	201.3	176.1	158.2	2495.02
Biratnagar	164.0	191.8	223.7	241.9	252.6	228.2	223.5	214.6	199.3	197.0	174.0	159.6	2470.08
Parwanipur	162.7	189.8	214.8	241.4	258.2	225.1	227.4	207.6	196.9	207.1	173.9	152.9	2457.60
Parasi	156.5	189.4	218.3	249.4	256.5	232.6	227.6	210.8	197.7	187.3	174.2	158.1	2453.50
Sub-type Ib													
Bhairahawa	151.1	183.1	215.3	244.4	256.5	239.9	222.2	205.7	203.9	199.1	165.4	148.6	2434.60
Khajura	151.1	184.9	215.5	242.2	254.9	247.6	218.9	205.5	196.8	201.2	168.6	164.6	2433.80
Tarahara	157.6	185.9	215.6	238.3	249.1	228.4	216.5	209.4	192.8	196.3	170.9	155.5	2416.30
Surkhet	150.1	179.5	212.8	243.4	255.0	242.5	208.4	295.1	200.6	203.4	163.4	149.5	2398.80
Mustang	140.6	164.0	196.7	239.4	246.2	250.2	237.3	216.9	216.3	181.1	149.3	134.4	2374.23
Rampur	146.5	181.5	215.1	244.3	253.0	234.5	204.4	198.9	194.5	196.2	158.4	138.5	2365.80
Sub-type Ic													
Kathmandu	150.5	183.8	213.4	229.0	240.5	220.1	211.6	197.2	176.7	190.7	161.4	144.3	2329.10
Jumla	146.4	174.7	202.4	224.2	242.6	228.4	214.1	194.9	197.9	199.9	157.4	143.6	2326.50
Gorkha	155.7	177.8	206.7	232.2	237.0	223.9	206.4	198.9	186.2	191.1	157.0	148.0	2320.70
Dadeldhura	142.2	168.5	195.0	241.0	249.8	233.9	210.5	179.6	170.6	197.3	153.1	141.6	2283.00
TYPE II													
Dumkauli	137.2	175.7	206.7	228.8	237.2	217.4	198.2	192.9	185.9	182.2	146.6	126.7	2235.50
Dhankuta	152.7	177.9	208.2	223.7	225.1	207.8	185.4	174.4	183.9	192.2	154.7	147.7	2233.60
Okhaldhunga	147.1	173.0	212.0	225.1	225.2	200.8	190.9	181.1	169.5	178.0	152.3	145.3	2200.30
Bhojpur	146.5	173.5	204.8	216.7	214.4	200.7	189.1	188.0	175.9	179.7	153.9	142.8	2186.00
Pokhara	138.4	167.5	195.1	214.2	220.1	214.1	202.0	185.9	180.6	179.4	151.3	134.7	2183.30
Khumaltar	140.4	175.7	196.2	211.3	223.5	197.4	205.4	196.3	172.1	173.1	153.3	136.8	2181.50
TYPE III													
Sub-type III (a)													
Taplejung	144.9	165.3	195.4	211.4	219.6	207.2	187.7	185.3	173.3	180.6	143.3	134.1	2148.12
Khairenitar	127.2	155.5	189.9	210.8	221.6	217.0	206.3	195.5	192.8	170.7	136.5	120.3	2143.60
Sub-type III (b)													
Lumle	137.0	157.5	189.7	207.6	208.6	191.4	182.1	171.2	164.7	178.1	139.9	138.0	2069.80
Syangja	127.0	166.4	193.1	207.7	204.7	199.1	1993.6	180.4	169.8	161.2	134.3	127.6	2064.90
TYPE IV													
Sub-type IV (a)													
Jiri	139.1	163.9	190.9	207.9	206.2	184.0	174.6	162.8	157.9	165.0	141.8	130.5	2024.70
Sub-type IV (b)													
Chialsa	137.6	164.9	190.1	196.8	197.7	178.1	176.3	166.9	156.6	162.5	136.4	130.3	1994.20
Ranipauwa	129.2	175.6	191.2	212.1	224.5	168.9	153.8	139.4	129.8	172.3	145.5	131.5	1974.80
TYPE V													
Syangboche	127.9	148.0	175.6	212.3	199.5	164.4	168.8	151.9	142.8	154.0	134.2	123.5	1902.00
Kakani	136.7	156.9	195.0	188.5	203.7	170.7	158.3	149.9	139.2	149.4	122.6	125.9	1897.00

Table 7-1[105]: Monthly Global Solar Radiation in W/m^2 for 29 Meteorological Stations in Nepal
All the daily bright sunshine hour data, recorded with Campbell Stokes recorders at the 29 meteorological stations in Nepal. The recorded data builds the basis to calculate the monthly global solar radiation (W/m^2).

The two meteorological stations (listed in Table 7-1), positioned closest to Simikot Humla, are Surkhet and Dadeldhura, each 15 days walk south and south-west of Simikot. Both of these places have an average annual solar irradiation of approximately 1,710 kWh/m^2 per year. That shows, that while these values are indicative they are not close enough, nor do they represent the high altitude region of Simikot. Further, the data from all these 29 stations, with the exception of Kathmandu, has been measured with the Campbell Stokes recorders, recording the daily bright sunshine hours, rather than with pyranometers. That shows the urgent need for a more exact and detailed solar radiation measurement and data recording in Simikot, which is what will be addressed in the next chapter.

7.4. Solar Irradiation Monitoring and Data Recording Parameters and Equipment for Humla

7.4.1. Solar Irradiation Measurement

As no recorded solar irradiation data is available for the village of Chauganphaya, nor for any other area in Humla, it was decided to record the solar irradiation in the High Altitude Research Station (HARS) of the Kathmandu University in Simikot, Humla. HARS is just some 5.35 km air distance away from Chauganphaya village, and thus it is expected to be possible to extrapolate the data with a satisfactory degree of accuracy. The HARS was chosen, as it is the newly built Kathmandu University High Altitude Research Station, with the available equipment (three pyranometers, data logging equipment, PC and the needed AC power, to measure and record the solar radiation. To do all that would be impossible in the Chauganphaya village due to the insecure political condition and the lack of suitable infrastructure.

In Chapter 7.1., it was mentioned that there are mainly three different pyranometer technologies applied for solar radiation measurements. With the limitations in regard to finance, the impossibility to calibrate highest quality pyranometers on a periodical basis, and the harsh climate the pyranometers will be exposed for years to come, it was decided to purchase three calibrated silicon photovoltaic cell pyranometers, 80SPC from SolData from Denmark[106].

7.4.2. Data Monitoring Parameters

Kathmandu University's HARS in Simikot Humla was built in 2003 – 2004 with the aim to have the products of the KU-RDC renewable energy technology research projects installed and tested under field conditions. With these projects in mind, a detailed data monitoring and data recording system for HARS was designed and installed. In the following, the solar radiation monitoring and data recording system is explained, with more detailed information and explanation in the Appendix 18.3.

7.4.3. Data Monitoring and Recording Equipment

Figure 7-6 shows a block diagram with the main data monitoring and recording equipment purchased. A more detailed list, with the technical specifications, can be found in the Appendix 18.3.3.

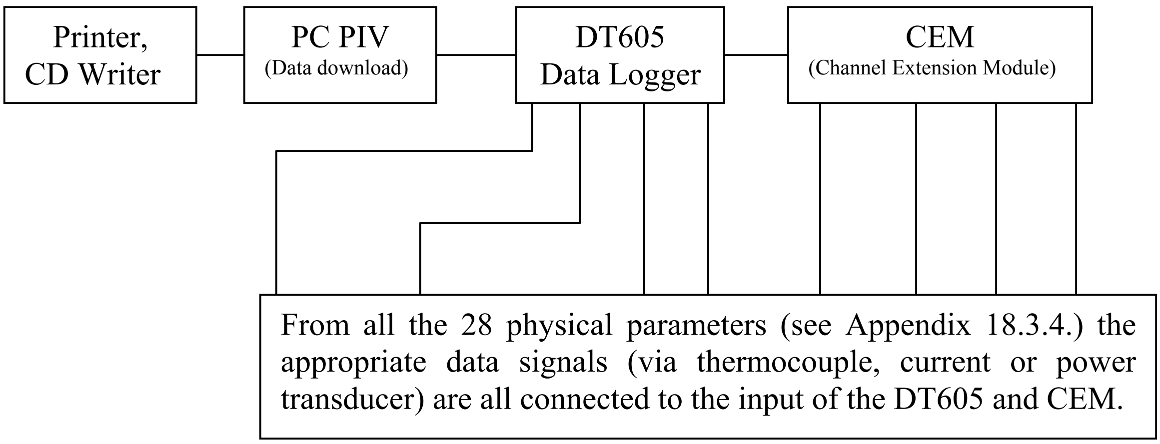


Figure 7-6: Block Diagram for DataTaker DT605 Monitoring and Data Recording System with the Incoming Parameters and Periphery Equipment

7.5. Solar Irradiation Monitoring and Data Recording Equipment Set Up and Installation

The installation of the whole data monitoring and recording system in the HARS in Simikot Humla took place during a three week field trip by the writer in March – April 2004.

7.5.1. Pyranometer Installation

For the three 80SPC pyranometers appropriate installations had to be made. Two pyranometers installed, the horizontal and the 30° south, are positioned on customised aluminum frames and mounted at a distance of 1.2 m ahead of the house wall, to avoid any possible reflections or shading. The 3rd pyranometer is installed on one of the three 2-axis self-tracking PV module frames, tracking the sun all day, along with the solar PV modules. The 2-axis self-tracking frame allows the solar PV modules to be under a perpendicular angle to the sun, from the first sun shine in the early morning to the last sun shine in the evening, and thus utilise the sun's total energy reaching the earth's surface to its maximum. That increases the daily energy generated, with the available solar radiation, substantially.

In order to verify exactly how beneficial such a 2-axis self-tracking PV module frame is, in the sense of how much more energy can be generated compared to the 30° south and the horizontal installed 80SPC pyranometer, one 80SPC pyranometer is installed on the 2-axis self-tracking frame. The following Figures 7-7 and 7-8 show the installations of the 3 silicon photovoltaic pyranometers 80SPC.

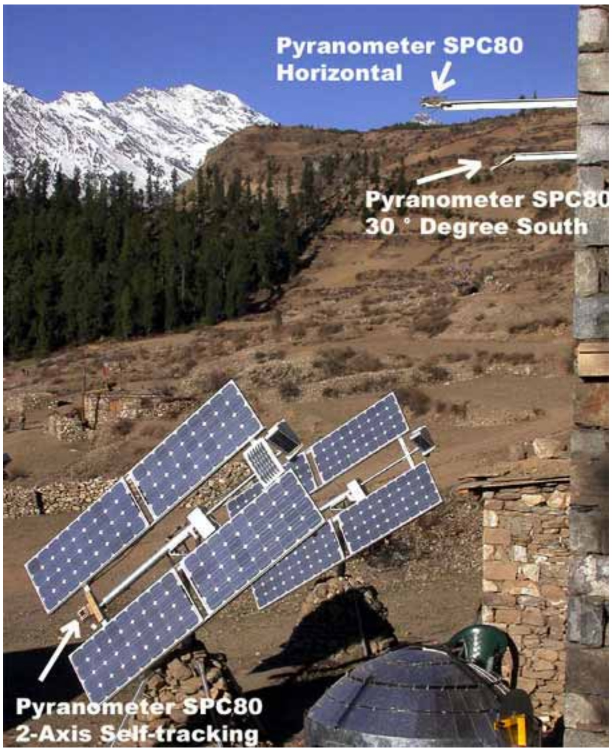


Figure 7-7: The Installations of the 3 SolData 80SPC Pyranometers.
Both, the horizontal and 30° pyranometers are mounted on customized aluminum frames, while the third one is mounted on the middle of the three 2-axis self-tracking solar PV module frames in the HARS. The places are carefully chosen to avoid any shading at any time of the year, enabling easy cleaning every 2nd day, and a safe and reliable wiring to the data logger (the pyranometer on the self-tracking frame is wired underground).

Figure 7-8: 80SPC SolData Pyranometer
One of the three SolData 80SPC silicon photovoltaic pyranometer.

Each pyranometer is provided with the multiplication factor, 152mV/(kW/m^2) in the above case, which is included in the dataTaker software to calculate and record the actual solar irradiation.

Every 10 seconds a measurement is taken and averaged over one minute. This value is recorded and periodically downloaded. Out of these values, hourly, daily, and 30 days solar irradiation data are extracted and plotted.

7.6. Data Handling

Undoubtedly, the recording of 37 parameters with 4 different time schedules (see for more details in the Appendix 18.3.4.), will provide a huge amount of continuously incoming data, which has to be handled with great care and caution, in order that this installed monitoring system will provide the intended benefit and results for years to come. In order to address the issue of handling these huge amount of generated data, 10 sessions, each with a particular "topic" and the relevant data, are developed with the DeLogger 4 Pro, the dataTaker in house software for their products. The aim of these sessions is to clearly distinguish the area of data monitoring and their results according to defined topics. That means, that each session is defined with specific data, which, once downloaded from the DT605 external and internal memory, is stored in its pre-defined sessions on the desktop PC connected to the dataTaker logger. In that way a huge amount of weekly downloaded data can be handled with comparable ease, once that system is set up and running smoothly.

Each of the 10 sessions is considered an own data bank, and thus can be handled as such. Individual data can be looked at, and investigated in table, or graphical form. Further, all defined parameters within one session are closely related to each other (one reason why they are joint in one session). Their connections and dependence on each other can be investigated and presented either through tables, or even more interesting, through graphical display (see the detailed sessions and there recorded parameters in the Appendix 18.3.12.). These sessions build a good framework to keep track of, and to interpret, the different data individually as well as in their relationship to each other, without getting lost in the mass of available data.

The DT605 logger and all the parameters monitored and recorded was fully installed and tested during March – April 2004, and from May 2004 onwards the actual data is being monitored. The DT605 logger is running under 4 time schedules on a 24 hour basis. Once a week the recorded data is downloaded on to the desktop PC and stored according to the sessions. The maximum storage place available with the running programme is 2 x 28 days before the data has to be downloaded. After every downloading procedure, a CD is burnt with the new raw data. That CD is sent to Kathmandu to the writer for checking and interpretation of data. At the same time a developed filing system on the main Humla desktop PC is keeping all the data backed-up, so that no data is lost.

All data is checked, according to predefined maximum and minimum values. The three solar radiation measurement with the three SolData pyranometers, the maximum and minimum values are defined as: Maximum 1,500 W/m^2, and Minimum 0 W/m^2.

The maximum value has been defined, because experience of the possible local solar radiation values shows, that during the late spring (May – June) and summer (July – September) times, the sky in Humla is often covered with cumulus humilis (which are a sign of good, high barometric pressure, weather), and cumulus congestus clouds[107]. Through the sudden covering and opening up again through passing clouds, very high solar radiation values, with over 1,400 W/m^2, can be measured with the pyranometer. Therefore, the maximum value for the solar irradiation is defined at 1,500 W/m^2. [108]

The solar PV modules also experience that effect, and generate, although only for a very short time period, a higher power output, in proportion to the solar radiation.

This value has to be recorded in order to be able to have an accurate daily solar irradiation value (kWh/m^2 per day). The defined maximum and minimum values for the various parameters are listed in the Excel spreadsheet data bank (see Appendix 18.3.11. Table 7-11).

7.7. Aim of Data Interpretation

It is important that data recorded, checked and evaluated is presented in such ways that they are expressive and understandable to third parties. The whole data monitoring system was developed and built in order to monitor and record the solar irradiation in this remote area of the Nepal Himalayan mountains for the first time. The monitoring system is also designed and installed with a view to be an ongoing monitoring station, in order to gather valuable data on the solar irradiation as well as on all the other, defined parameters, mentioned under Appendix 18.3.4, over the next years. This data will enable the design of more appropriate solar PV electrification systems, in the future, either for home systems or village systems such as the Chauganphaya village project.

Thus while the long-term aim for the monitoring and data recording system is bigger, because of which already all the 37 parameters are presently recorded, the immediate aims are:

- Record the solar irradiation data prevailing in the HARS in Simikot for three different positions, the horizontal, 30° south inclined, and on the 2-axis self-tracking frame. First, this makes it possible to have relevant solar irradiation data for the local situation. And second, it helps to determine how much more solar irradiation is available with the 2-axis self-tracking frame on a daily average, compared to the fixed 30° south position (the standard installation angle all over Nepal for solar PV modules), over a period time.
- Record the actual power output of the solar PV modules (BP275F) installed in the HARS in Simikot, Humla, in order to use this experience for the Chauganphaya solar PV elementary village electrification system.

- Find out the average efficiency of the BP275F solar PV module under the prevailing solar irradiation conditions in Simikot Humla.
- Record the HARS battery bank related input power and output load demand data under the prevailing solar irradiation and ambient temperature conditions. Estimate the battery bank's life expectancy and condition through its lifetime, and apply it to the Chauganphaya solar PV village elementary electrification battery bank.

7.8. Presentation of the Measured Data

All the above defined data are monitored, in order to be able to draw reasonable, applicable conclusions for the Chauganphaya village solar PV system, as the same main PV system equipment is used. But during the initial stage of the Chauganphaya village design and calculation, no actual data, based on real data recording, was available for either the power generation of the solar PV modules, or for the battery bank, and thus the system was designed with reasonable assumptions according to the simulated local conditions and the provided equipment parameters.

In order to present the above main results in understandable and expressive ways, several graphical diagrams as Excel spreadsheets have been developed. In the following pages three examples of such spreadsheets are provided, while short descriptions only are given for the others.

7.81. The Meteorological Graphs

The meteorological graph series contain all the relevant meteorological data recorded and presented in graphical forms. That includes:

- The three daily (with minute values) solar radiation (horizontal, 30°, and on the 2-axis self-tracking frame) graphs, presented on one sheet in three different colours over one day. The sheet includes the actual received solar irradiation (kWh/m^2 per day) values for each pyranometer, to enable direct visible and numerical comparison.

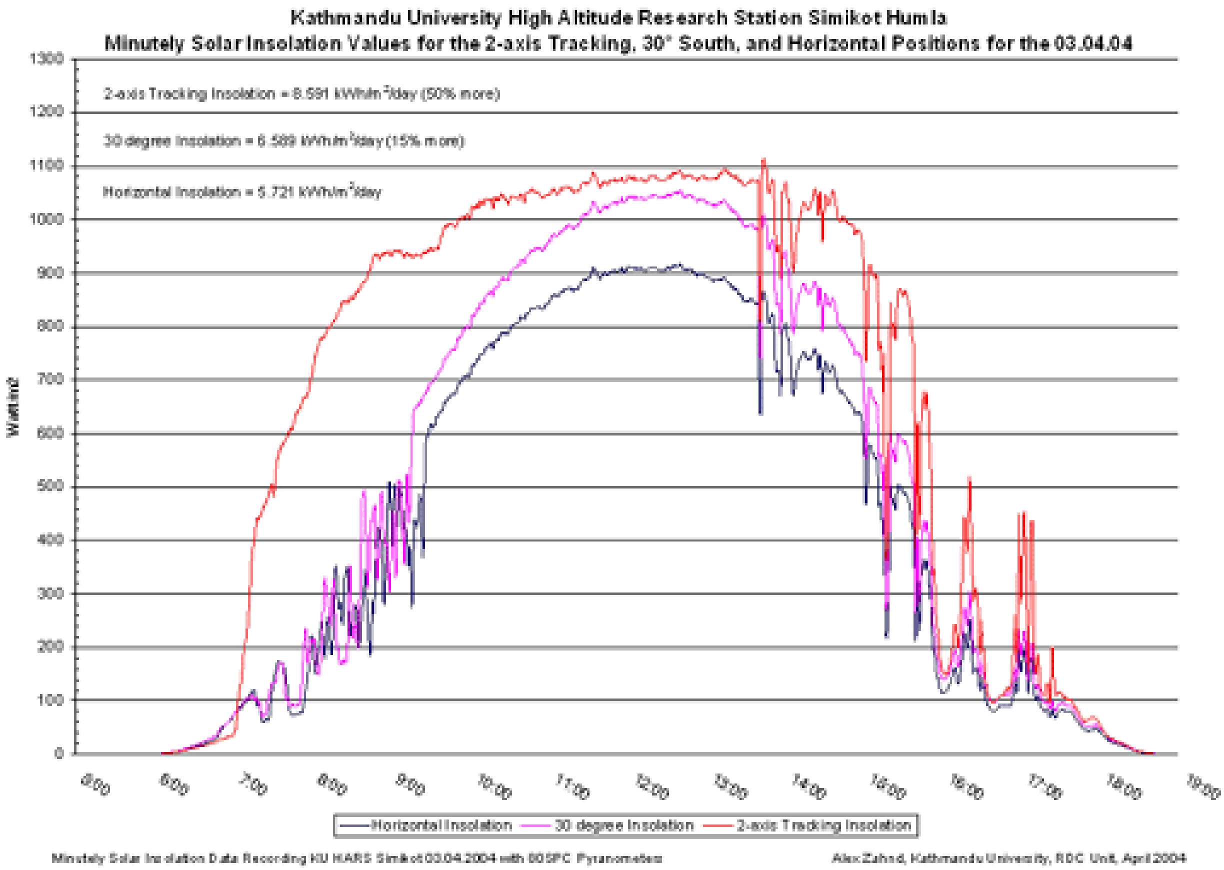


Figure 7-9:Minute Global Solar Irradiation Data Recording at the HARS in Simikot for the 3rd April 2004.

The three graphs illustrate the clear difference between the pyranometer installed on the 2-axis self-tracking frame system, compared to the one fixed, at 30° south, and the horizontal installed pyranometers. Despite the clouded sky throughout the afternoon, the possible solar energy utilisation of the tracking system taken over the whole day is 30.4% higher than the one installed 30° south, and even 50.2% higher than the horizontally installed pyranometer.

- The three daily (with hourly values) solar radiation, the ambient, the solar PV module back-side, and the battery bank temperature graphs, presented on one sheet in different colours over one day. The sheet includes the actual solar irradiation (kWh/m^2 per day) values received (to enable direct visible and numerical data comparison), and the averaged ambient, solar PV module backside day (6:00 AM – 18:00 PM), and battery bank temperatures.

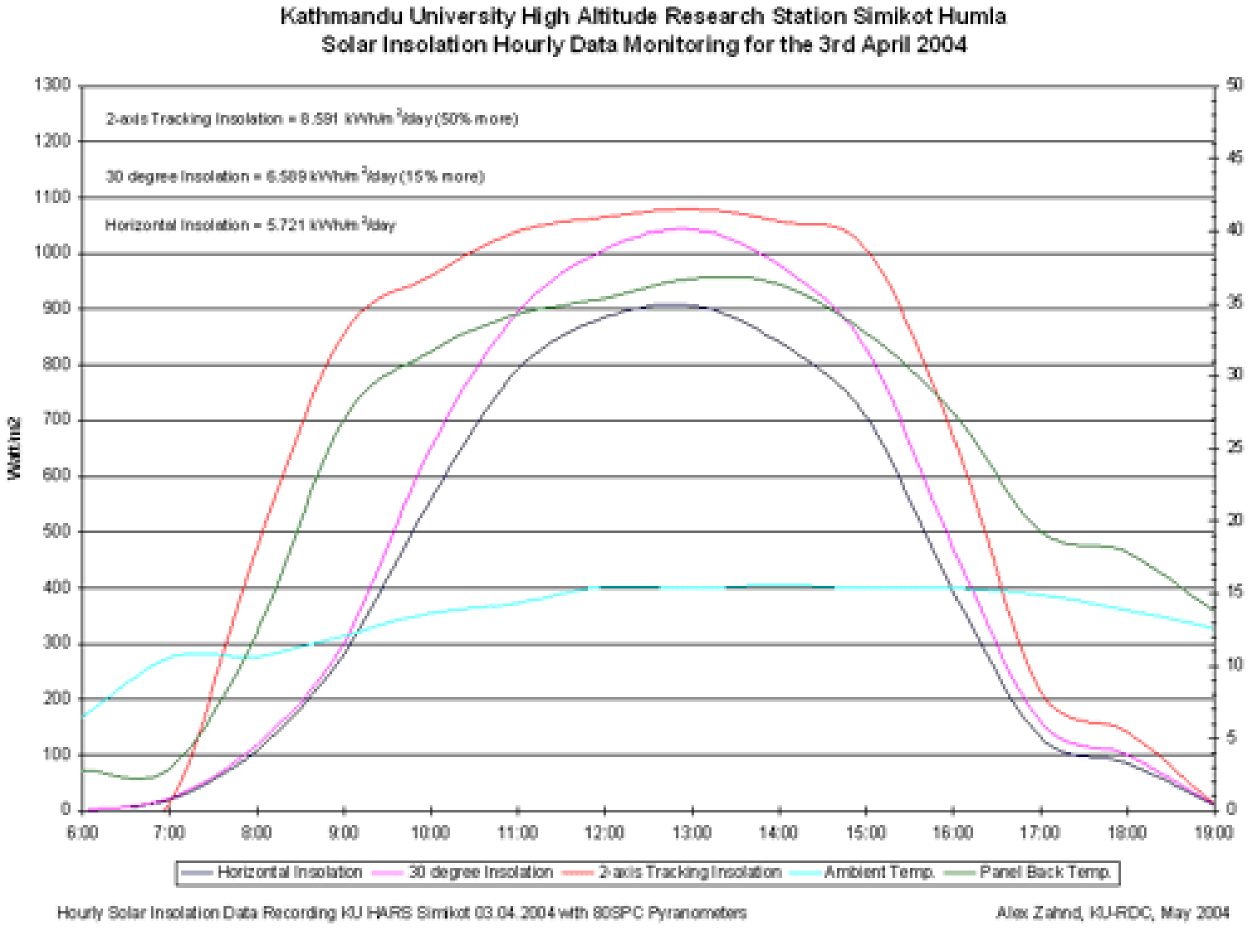


Figure 7-10: Hourly Global Solar Irradiation Data Recording at the HARS in Simikot for the 3rd April 2004. Averaged hourly graphs show no short time fluctuations.

Same solar irradiation graphs as in Figure 7-9, but the hourly averaged minute values. The short time differences due to by-passing clouds, or big trees throwing shadows on the horizontal and 30° south pyranometers in the early morning hours (from about 7:15 AM – 9:15 AM), are not directly visible, as the plotted minute averaged data. Further, the ambient, and solar PV module backside temperatures are also plotted to calculate the power output drop of the PV modules due to increased temperatures during the sunshine hours.

- Weekly data of the three daily (with hourly values) global solar irradiation, the ambient temperature, the solar PV module backside, and the battery bank temperature graphs, on one sheet in different colours over one week. The sheet includes the solar irradiation (kWh/m^2 per week) values received, and the averaged ambient, solar PV module backside, and battery bank temperatures.

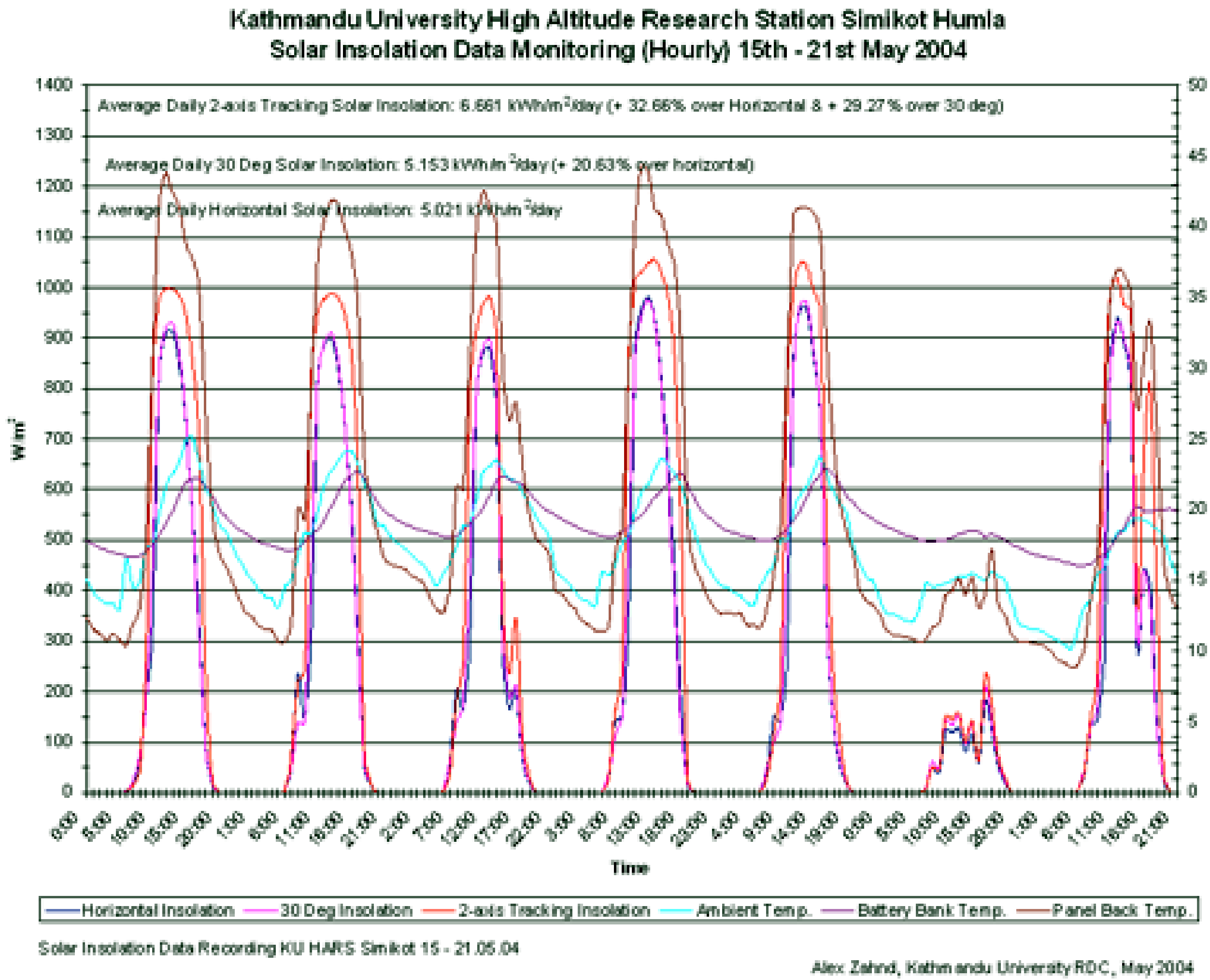


Figure 7-11: Weekly hourly Solar Irradiation Data Recording at the HARS in Simikot 15th – 21st May 2004. The energy output on the 2 axis-self-tracking frame is 29.27% higher than the 30° south and even 32.66% higher than the horizontally measured data. The graph's x- axis is sub divided into hourly steps over the 7 days.

These hourly graphs present the meteorological conditions over one week, with the averaged ambient and solar PV module temperature included, as this value is in direct relation to the solar radiation. The coldest ambient temperature is always around 6:00 AM (as the earth radiates heat throughout the night without any energy gain), just before sunrise. The PV modules lose the most energy during the mid day radiation, with a Δt of up to 20 °C, which means an 8.8% power output loss for the BP275F modules (with a temperature coefficient of -0.44%/°C). Also interesting to note is the battery bank's variation of temperature, which varies during the sunny days between 18 °C in the early morning and 22 °C between 16:00 PM and 18:00 PM, as clearly the charging of the battery bank caused an increase in internal temperature due to the chemical reaction. But as the battery bank is well insulated in the wooden box, with Styrofoam (see Figure 7-19 in Appendix 18.3.7.), the temperature difference over the course of a day remains within the ideal range of 15 °C – 25 °C.

- Monthly data, with 4 averaged weekly values of the three solar irradiation, the ambient, the solar PV module backside, and the battery bank temperature graphs, presented on one sheet in different colours over one month. The sheet includes the solar irradiation (kWh/m^2 per month) values received, and the averaged ambient, solar PV module backside day, and battery bank temperatures.

7.8.2. The Power Graphs

The power graphs series contain all the power and energy generated relevant data, recorded and presented in graphical forms. That includes:

- Minute power graphs, presenting the solar PV array power output over one day. The sheet includes the actual measured energy (kWh/m^2 per day) value for the whole PV array as well as for a single 75-Watt BP275F PV module.
- Hourly power graphs. This sheet includes the solar PV power output, battery bank power input and output, the inverter power output, as well as the solar PV modules, and cells efficiency graphs over one day. The sheet includes the actual measured energy values (kWh/m^2 per day), for the whole PV array, a single PV module, the battery bank, a single battery (kWh/day), the inverter (kWh/day), and the average daily efficiency for the PV cells and modules.
- Hourly Battery Bank Power graphs. This sheet includes the battery bank voltage, the current input/output, and the related power input/output data over one day. It also includes the battery bank's temperature, and the ambient temperature. Further it includes the actual measured input and output energy values (kWh/day), for the whole battery bank, a single 12 VDC 100 Ah

battery, and the average ambient and battery bank temperature with its maximum and minimum values.

- Weekly power graphs. This sheet includes the solar PV power output, battery bank power input and power output, the inverter power output, as well as the battery bank's voltage and temperature graphs over one week. The sheet includes the measured energy values (kWh/m^2 per week), for the whole 900 W PV array, a single 75 W PV module, the whole battery bank, a single battery (kWh/week), and the inverter (kWh/week). It includes also the average battery bank temperature value.
- Monthly power graphs (with 4 averaged weekly values). This sheet includes the solar PV power output, battery bank power input and power output, the inverter power output, as well as the battery bank's voltage and temperature graphs over one month. The sheet includes the actual measured energy values for the whole PV array (kWh/m^2 per month), a single PV module, the whole battery bank, a single battery (kWh/month), and the inverter (kWh/month). It includes also the average battery bank temperature value.

7.8.3. The WLED Graphs

The WLED graphs series contains the 2 different WLED lights related data, recorded and presented in graphical forms. That includes:

- Per minute graphs. This sheet includes the two WLED power consumption, voltage and current graphs over one day. The sheet includes the actual measured power consumption (Wh/day) value for each of the two different WLED lights, and the average room temperature value.
- Hourly graphs. This sheet includes the two WLED power consumption, voltage and current graphs over one day. The sheet includes the actual

measured power consumption (Wh/day) value for each of the two different WLED lights, and the average room temperature value.

- Weekly graphs. This sheet includes the two WLED power consumption, voltage and current graphs over one week. The sheet includes the actual measured power consumption (Wh/week) value for each of the two different WLED lights, and the average room temperature value.
- Monthly graphs. This sheet includes the two WLED power consumption, voltage and current graphs over one month. The sheet includes the actual measured power consumption (Wh/month) value for each of the two different WLED lights, and the average room temperature value.

7.9. Applying HARS Data for the Chauganphaya Village

While the HARS Simikot irradiation data recording station is at latitude of 29.967° North and longitude 81.817° East, at an altitude of 3,000 m.a.s.l., the Chauganphaya village is 5,35 km air distance away, at a latitude of 30.000° North and longitude 81.774°East, at an altitude of 2,643 m.a.s.l. (see map Figure 7-12 for more details).

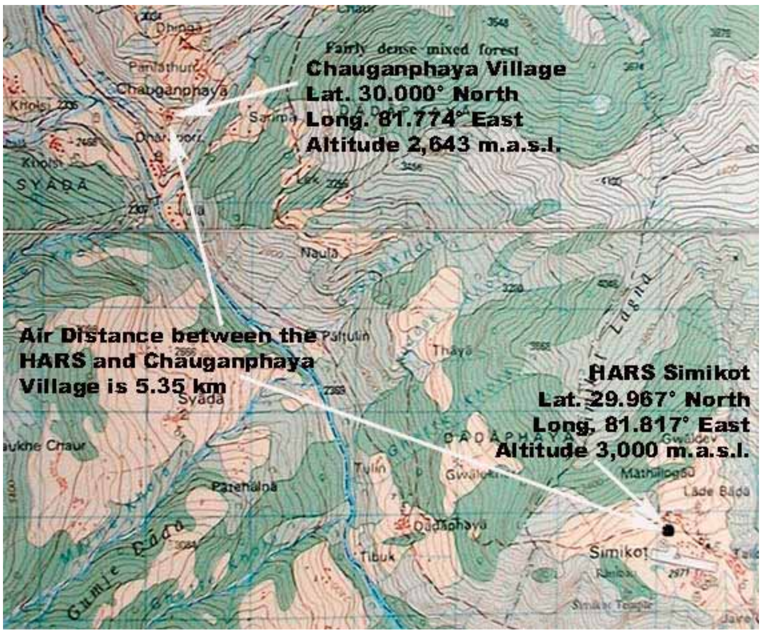


Figure 7-12: Map Simikot - Chauganphaya

Figure 7-12 shows a detailed map[109] of the Simikot – Chauganphaya area. The air distance between Simikot (at 3,000 m altitude) to Chauganphaya (at 2,643 m altitude) is only 5.35 km, with an altitude difference of 357 m.

On the foot path from Simikot to Chauganphaya (as there are no roads within 15 days walk south of Simikot) is one small pass to cross. The air distance alone would not demand any solar irradiation extrapolation. But the two factors:

- Altitude difference of 357 m
- High Horizon (average horizon height around the village is 23.9°, compared to Simikot with 12.9°) all around Chauganphaya

demand that the solar irradiation data measured and recorded in the HARS in Simikot may have to be adjusted for the Chauganphaya village.

A suggestion by METEONORM V5 for the solar irradiation data recording stations and the actual project site: "...if your project is near a weather station, this station can be selected. The distance from the nearest station should not be greater than 20 km, and the altitudes should not differ by more than 200 m."[110]. It is obvious that the terrain and the local geographical conditions matter. The METEONORM solar energy calculation software, provides guidance by stating some limits for the horizontal as well as vertical distance for which solar irradiation data can be applicable to a satisfactory degree. To keep within these suggested limits one can be assured that the solar irradiation data are accurate for the location in question and that the calculations or simulations are within the defined accuracy range. Nevertheless, it is always important to see these figures as a guideline rather than a rule, since it is the local geographical conditions that ultimately determine the applicability of the solar irradiation data for a place in the vicinity.

In the case of the Chauganphaya village solar PV project, the air distance between the measured data is only 5.35 km, though with an altitude of 2,643 m (compared to Simikot with 3,000 m), Chauganphaya lies 357 m lower. While the air distance is well within the suggested limits, the altitude difference is greater than the suggested value, and thus some consideration should be given if any adjustment to the HARS recorded solar irradiation data has to be made for the Chauganphaya village conditions. With the METEONORM V5 the Chauganphaya and the HARS station in Simikot and the Chauganphaya Village have been simulated, with higher and lower altitude values, in order to find out the different results. With these averaged differences an appropriate extrapolation for the Chauganphaya village data can take place.

Tables 7-1 and 7-2 show the results simulated with the METEONORM V5 software when the altitudes of Simikot and Chauganphaya have been slightly changed, with otherwise the same parameters. This indicates if there is any influence on the solar irradiation if the altitude difference of each location is changed.

Software Inputs	*Software Outputs*								*Remarks*
Simikot Altitude	H G_h	%	H D_h	%	H B_n	%	T_a	%	
2500 m	1626	0	745	- 2	1521	+ 0.2	12.4	+ 20.2	Simulated altitude
3000 m	1626	0	760	0	1518	0	9.9	0	Real altitude
3500 m	1626	0	784	+ 3.1	1495	- 1,5	7.4	- 33.8	Simulated altitude

Table 7-2: Simikot Solar Irradiation Dependent on Different Altitude Simulations

Where:

H G_h = Irradiation of global radiation horizontal in kWh/m^2

H D_h = Irradiation of diffuse radiation horizontal in kWh/m^2

H B_n = Beam irradiation in kWh/m^2

T_a = Air temperature in °C

Table 7.1 shows that while the global irradiation for the whole range of +/- 500 m altitude for the HARS in Simikot remains the same, the diffuse irradiation changes only between –2 % and +3%, and the beam irradiation changes even less with values between –1.5% and +0.2%. Considering the small variations for Simikot's altitude variations, there are no data adjustments needed. The decreasing beam irradiation with increased altitude is surprising. The opposite result was expected. A check with the Sandia Photovoltaic Performance Model I-V Curve Tracer revealed the same trend. The BP275F solar PV module generates 0.2% less power output at 3,500m than at 3,000m altitude, with the same global solar irradiation of 1,000 W/m^2, and even a slightly lower solar PV cell temperature of 0.11% at the higher altitude. It is not clear why this occurs and its implication for these results. But the actual differences are small and do not significantly alter the overall results. Thus they can be said to fall within the range of the simulation and calculation accuracy.

Software Inputs	*Software Outputs*								*Remarks*
Chauganphaya Altitude	H G_h	%	H D_h	%	H B_n	%	T_a	%	
2300 m	1428	0	747	0	1174	+ 0.34	13.4	+ 12.7	Simulated altitude
2643 m	1428	0	747	0	1170	0	11.7	0	Real altitude
3000 m	1428	0	772	+ 0.46	1139	- 2.7	9.9	- 18.2	Simulated altitude

Table 7-3: Chauganphaya Solar Irradiation Dependent on Different Altitude Simulations

Table 7.3 shows that while the global irradiation remains the same for the whole range of + 357 m and – 343 m altitude for the Chauganphaya village, the diffuse irradiation changes, though insignificantly, and the beam irradiation changes very little with values between –2.7% and +0.34%.

In the light of these simulation results for the altitude difference of 357 m of the Chauganphaya village compared to Simikot, no data adjustments seems to be justified, as the simulated results are not significantly different.

Software Inputs	*Software Outputs*								*Remarks*
Simikot-Chauganphaya	H G_h	%	H D_h	%	H B_n	%	T_a	%	
3000 m	1626	0	760	0	1518	0	9.9	0	Simikot
2643 m	1428	- 13.5	747	- 1.7	1170	- 22.9	11.7	+ 15.4	Chauganphaya
357 m altitude difference	198	- 13.5	13	- 1.7	348	- 22.9	+ 1.8	+15.4	Differences

Table 7-4: Simikot and Chauganphaya Solar Irradiation with Real Altitude Simulations

Clear differences are recognised in the direct comparison of the Simikot and Chauganphaya village simulated results, without including the surrounding horizon. The global yearly horizontal irradiation is 13.5% less in Chauganphaya than in Simikot, with an even greater difference for the yearly horizontal beam irradiation of around 23%. The averaged yearly ambient temperature too is around 1.8 °C warmer. Thus the 357 m altitude difference and air distance of 5.35 km does obviously have some influence on the annual global solar irradiation.

And if the horizon of both the places are considered and included into the simulation, the differences are even more magnified, especially because Chauganphaya's location suggests a significant lower yearly solar irradiation as the village is surrounded by high mountain ranges, with an average horizon height of 23.9° (see in the Appendix 18.3.14., PVSyst3.3.1 Chauganphaya and Simikot Simulation Report page 2), compared to Simikot which has an average horizon height of 12.9°

Software Inputs	*Software Outputs*								*Remarks*
Simikot-Chauganphaya	H G_h	%	H D_h	%	H B_n	%	T_a	%	With Horizons
3000 m	1604	0	751	0	1505	0	9.9	0	Simikot
2643 m	1257	- 27.6	668	- 12.4	935	- 61	11.7	+ 15.4	Chauganphaya
357 m altitude difference	347	- 27.6	83	- 12.4	570	- 61	+ 1.8	+15.4	Differences

Table 7-5: Simikot and Chauganphaya Solar Irradiation with Real Altitude and Horizon Simulations

These data show clear differences. The yearly global horizontal irradiation in Chauganphaya is 27.6% lower, while the horizontal beam solar irradiation is even 61% lower than in Simikot, i.e. if for both places their actual surrounding mountain ranges are included.

Thus it can be said that while the actual air distance between Chauganphaya village and Simikot should not have made any difference (as it is much less than the suggested maximum 20 km), it clearly shows that a global solar irradiation difference of 10% - 15% has to be expected and thus calculated for, according to Table 7-4. The 357 m lower altitude though, does not seem to make such a big difference, as the simulated solar irradiation values did not change significantly over the range of altitudes simulated in table 7-1 and 7-2, for both places. But the biggest difference in the amount of global solar irradiation received, is caused by the difference of the actual surrounding horizons of both the places. That can be seen if the horizon values (see Appendix 18.3.14. PVSyst3.3.1 Chauganphaya and Simikot Simulation Report page 2) are included into the yearly solar irradiation simulation for both places. Chauganphaya village receives over 25% less horizontal global solar irradiation throughout the year, with even less than half, of the horizontal yearly beam irradiation. That shows that the global solar irradiation measured and recorded in the HARS in Simikot needs to be adjusted downwards for Chauganphaya by about 25%, considering the local geographical differences of the two places.

7.10. Five Months Data Results and Discussion

Since May 2004 the solar radiation data has continuously been monitored and recorded in the HARS in Simikot Humla. The HARS Simikot program leader has been trained to download the data on a weekly basis (usually Saturday night) from the DT605 data logger to the PC. On the PC, a back-up copy is saved and a CD written from the weekly data file. That CD is sent via any passenger on the next flight from Simikot to Nepalgunj, in the south of Nepal. In Nepalgunj the CD is handed over to our Nepalgunj based project staff, who then sends the CD in a mail bag by bus to Kathmandu, to the writer's P.O. Box. From there it is collected and all new data is evaluated for errors and invalid data. The remaining data is presented in various Excel graphs in order to have a quick and easy understanding, as e.g. in Figures 7-9 to 7-11 is presented.

Problems that occurred during the last 5 months of data monitoring and downloading.

- various software related download problems between the data logger and the PC in the beginning.
- the inexperience of the person downloading the data.
- the person responsible was either in the field or on project related work outside of Humla.

These issues caused the loss of 10 days data in between 22nd August – 31st August 2004, so that there is no undisturbed continuity of the actual measured HARS Simikot solar irradiation data.

Nevertheless, the available data is very valuable for what it is, as it provides an initial comparable data set to the NASA data base and METEONORM simulated solar irradiation data, measured at the actual local place with the actual solar radiation received over the course of the days recorded. Even though it is not yet clear if the year 2004 is a good, medium or bad solar radiation year, the available data are indicative of the possible differences between the three data.

In the following table the recorded weekly and monthly solar irradiation data for the HARS in Simikot for the months May 2004 – September 2004 are presented:

The following data have been adjusted (the monthly average was taken) due to incomplete daily recorded data:

- August 22nd – 31st : 10 days with an average of 3.97 kWh/m^2 per day, representing the monthly average value for August.

	Horizontal Weekly and Monthly Solar Irradiation in kWh/m^2					
	May	June	July	August	September	Remark
Week 1	41.51	29.61	27.97	32.20	40.67	Real Data recorded
Week 2	40.67	39.41	22.47	25.90	37.73	Real Data recorded
Week 3	35.14	29.47	31.29	25.20	24.08	Real Data recorded
Week 4	27.93	27.65	30.87	27.79	33.53	Aug. Data extrapolated
Week 5	17.61	13.58	10.44	11.91	9.44	Aug. Data extrapolated
Monthly	162.86	139.72	123.04	123.00	145.45	Total 694.07 kWh/m^2
%	0	0	0	0	0	

Table 7-6: HARS Horizontal Weekly and Monthly Solar Irradiation in kWh/m^2

	30° South Weekly and Monthly Solar Irradiation in kWh/m^2					
	May	June	July	August	September	Remark
Week 1	42.63	30.59	29.54	33.88	45.85	Real Data recorded
Week 2	41.37	37.80	24.36	29.26	43.33	Real Data recorded
Week 3	36.05	30.45	33.74	28.21	28.28	Real Data recorded
Week 4	29.82	27.58	33.11	30.45	40.18	Aug. Data extrapolated
Week 5	17.73	18.81	11.46	13.05	11.62	Aug. Data extrapolated
Monthly	167.60	145.23	132.21	134.85	169.26	Total 749.15 kWh/m^2
%	+ 2.91	+ 3.94	+ 7.45	+ 9.63	+ 16.37	Difference in Percent over Horizontal is + 7.9 %.

Table 7-7: HARS 30° South Weekly and Monthly Solar Irradiation in kWh/m^2

	2-axis Self-Tracking Weekly & Monthly Solar Irradiation in kWh/m^2					
	May	June	July	August	September	Remark
Week 1	51.38	37.52	37.17	43.54	63.98	Real Data recorded
Week 2	49.98	50.33	31.15	35.14	58.80	Real Data recorded
Week 3	46.62	37.24	42.56	33.53	35.07	Real Data recorded
Week 4	35.70	35.91	42.42	37.38	55.44	Aug. Data extrapolated
Week 5	22.80	17.54	14.04	16.02	14.80	Aug. Data extrapolated
Monthly	206.48	178.54	167.34	165.61	228.09	Tot. 946.06 kWh/m^2
%	+ 26.78	+ 27.76	+ 36.01	+ 34.64	+ 56.82	Difference in Percent over Horizontal + 36.3 %
%	+ 23.20	+ 22.92	+ 26.57	+22.81	+ 34.76	Difference in Percent over 30° South + 26.3 %

Table 7-8: HARS 2-Axis Self-Tracking Frame Weekly and Monthly Solar Irradiation in kWh/m^2

The Tables 7-6 to 7-8 show the following:

Between the horizontal and the 30° south installed pyranometer, there is no significant difference during the month of May and June. That is understandable when one considers the angle of the sun (the angle between the horizontal and the line to the sun)[111] during these two months between 11:00 AM and 13:00 PM, when the highest solar radiation is received on the solar PV modules.

Month	Date	Time	Sun Angle	Diff. to 30° South	Diff. to 0° Horizontal	Remarks
May	1	11:00	71.47°	11.47°	18.53°	Difference of the pyranometer perpendicular to the sun.
May	1	13:00	66.12°	6.12°	23.88°	
May	31	11:00	77.21°	17.21°	12.79°	
May	31	13:00	70.65°	10.65°	19.35°	
June	1	11:00	77.29°	17.29°	12.71°	
June	1	13:00	70.76°	10.76°	19.24°	
June	30	11:00	77.28°	17.28	12.72°	
June	30	13:00	72.73°	12.73°	17.27°	
				12.94°	17.06°	Average angle difference perpendicular to the sun.

Table 7-9: Sun Angle between the Horizontal and 30° South Surface for the Months May and June for Simikot, Humla

The slightly greater average difference of the horizontally installed pyranometer in comparison to the 30° south installed pyranometer to the actual sun radiation angle, shows the 2% increased received solar irradiation on the 30° south installed pyranometer. The 2-axis self-tracking solar PV module frame achieves significantly higher average solar irradiation values than both, the horizontal (+ 31.1%) and the 30° south (+ 24.97%). These values can be considered to be the minimum average yearly values, as these data are measured during the 4 monsoon months (June – September), when the sun shines the least as compared to the average annual sunshine days. That means that the yearly average solar irradiation received on the solar PV modules installed on the 2-axis self-tracking frame in comparison to the horizontal and the 30° south installed, will be even an estimated 10% - 15% higher.

Thus it can be concluded that the 2-axis self-tracking frame enables the installed solar PV module to generate approximately 40% - 45% more than a horizontal, and about 35% - 40% more energy on an average day than a 30° south fixed installed solar PV module over the course of one year.

8. Solar Irradiation and related Data from the NASA Web site

8.1. Introduction

As discussed in section 7.3., there is very little reliable solar radiation or irradiation data available for Nepal, and especially not for areas in the North-West, for places such as Humla. That does not help to make accurate calculations for the design of appropriate solar PV systems, such as for the Chauganphaya village. So in order to still aim for a satisfactory degree of safety, the PV system is designed to be bigger than normally be the case with reliable data. That again has direct effects on the costs of the system.

Two alternatives are available. First, a software package with a meteorological database from over 7,000 meteorological stations, such as METEONORM, can be used. It provides reliable extrapolated solar irradiation data for any geographical location in the world. Two restrictions in using this software though have to be mentioned.

1. It is an expensive software package (500 Euro in July 2004).
2. In the case of a very remote place such as Chauganphaya or Simikot, the software is very limited in using the amount of data available for the extrapolation, which is directly related to the quality of the calculated data. In the case of the Chauganphaya village in Humla, after identifying its geographical position for the extrapolation of the meteorological data, the software informs the user through a pop-up menu, how many stations are available for the extrapolation of the global horizontal solar irradiation (Gh), the days per month with precipitation (Rd) and ambient temperature (Ta):

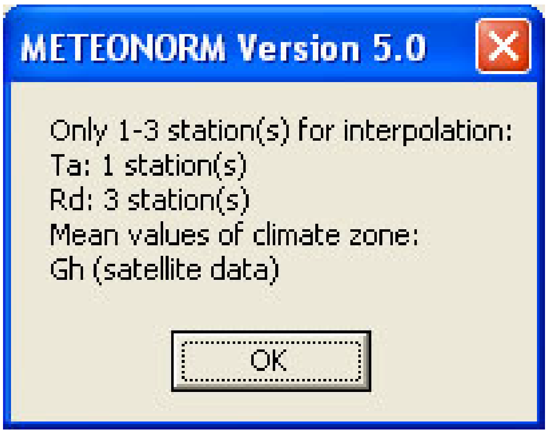


Figure 8-1: METEONORM V5 Pop-Up Menu for the Meteorological Data Extrapolation.

The pop-up menu (Figure 8-1) for the extrapolation of the Chauganphaya meteorological data shows the user, that only very few, maximum 1-3 stations are available to calculate the geographical place in question. That of course has a direct influence on the quality of the extrapolated data, and thus the calculated data has to be taken with appropriate caution.

Second, the Internet based NASA meteorological data bank, available for free under:

http://eosweb.larc.nasa.gov/ .

In the following section a whole range of NASA satellite data, generated for Nepal, and specifically for Simikot and Chauganphaya are presented. One example, the 30° south tilted solar irradiation is provided in the main text as an example, while the others are added in the Appendix 18.4., 18.4.1 – 18.4.6 serving as a valuable data and information tool for the people in the high altitude areas of Nepal, as they have no access either to electricity or an Internet connection. The first part presents data and information in graphical form for the country Nepal as a whole, to see the various influences on the meteorological data due to Nepal's extreme geographical and resulting climatic conditions. While relating to these data, one has to always keep in mind that the two places of interest are at about 30° Northern latitude and close to 82° Eastern longitude. The second part of the data presentation is in table form, to provide more exact NASA meteorological data, extrapolated for both the HARS Simikot and Chauganphaya village geographical location. The last three tables (Appendix 18.4.6.) serve as a check, using the available data for the nearest degree in latitude (30° North) and the two nearest degrees in longitude (81° and 82° East), extrapolating the values for the exact geographical location of Simikot and the

Chauganphaya village. These results can be compared with the figures presented in the various graphics and tables. A satisfactory closeness has been achieved, with <5% difference in values.

8.2. NASA Solar Irradiation and Related Data for Simikot and Chauganphaya

NASA offers an extensive and detailed meteorological database. It is free of cost, though one has to be a registered user.

Through the definition of the four geographical coordinates of the location in question (see the latitude and longitude axis in the graphics and the geometric South - North (29° - 30°) and West-East (81° - 82°) of the 22 meteorological data tables in 18.4.5.), a wide range of meteorological data for the defined square or right angle shaped earth surface can be generated and downloaded.

For the HARS in Simikot and the Chauganphaya village the following data have been defined, generated, downloaded and prepared in presentable forms:

1. Average horizontal solar irradiation from 1983 – 1993 for Nepal for each month (see Appendix 18.4.1.).
2. Average 30º towards Equator tilted solar irradiation from 1983 –1993 for Nepal (see 8.3).
3. Average surface albedo from 1983 –1993 for Nepal (see Appendix 18.4.2.).
4. Maximum monthly NO SUN Days from 1983 –1993 for Nepal (see Appendix 18.4.3.).
5. Average annual NASA data from 1983 –1993 for Nepal (consisting of annual air temperature at 10 m height; annual air pressure; annual direct normal irradiance; annual diffuse horizontal radiation; annual 10 m wind speed for terrain similar to airports); average US navy 10-minute elevation, (see Appendix 18.8.4.).

6. 22 tables of various meteorological NASA satellite data recorded for the Simikot and Chauganphaya, with the geometry boundary layers of 29° - 30° Northern latitude and 81° - 82° Eastern longitude (see Appendix 18.4.5).
7. Extrapolated NASA Surface Meteorology and Solar Energy, consisting of Monthly average Clear Sky Irradiation ($kWh/m^2/day$) for July 1983 - June 1993; Monthly average Irradiation on horizontal surface ($kWh/m^2/day$) for July 1983 - June 1993; Monthly average Irradiation Clearness Index K (0 to 1.0) for July 1983 - June 1993, (see Appendix 18.4.6).

Data of 1 - 5 are all presented in graphical form, and the data 6 – 7 are presented in table form.

A Word of Caution:

It has to be mentioned that in all the following Figures (Chapters 8.3 and Appendix 18.4.1 - 18.4.6.), the latitude and longitude lines are not very precise. Knowing the precise geographical location of the HARS in Simikot (29.967º North / 81.817º East Long, at 3,000 m.a.s.l.), and the Chauganphaya Village (30.000º North / Long. 81.774º East, at 2,643 m.a.s.l.), and the actual position on the map of Nepal for both the places, the coordinates indicate an estimated 0.5º – 1º deviation, in both, the latitude and longitude. The actual geographical locations of the two places in question are shown in the graphs at about 29º - 30º Northern latitude and 81º Eastern longitude, instead of 30º North and 81.8º East.

8.3. Average 30º towards Equator Tilted Solar Irradiation from 1983 –1993 for Nepal

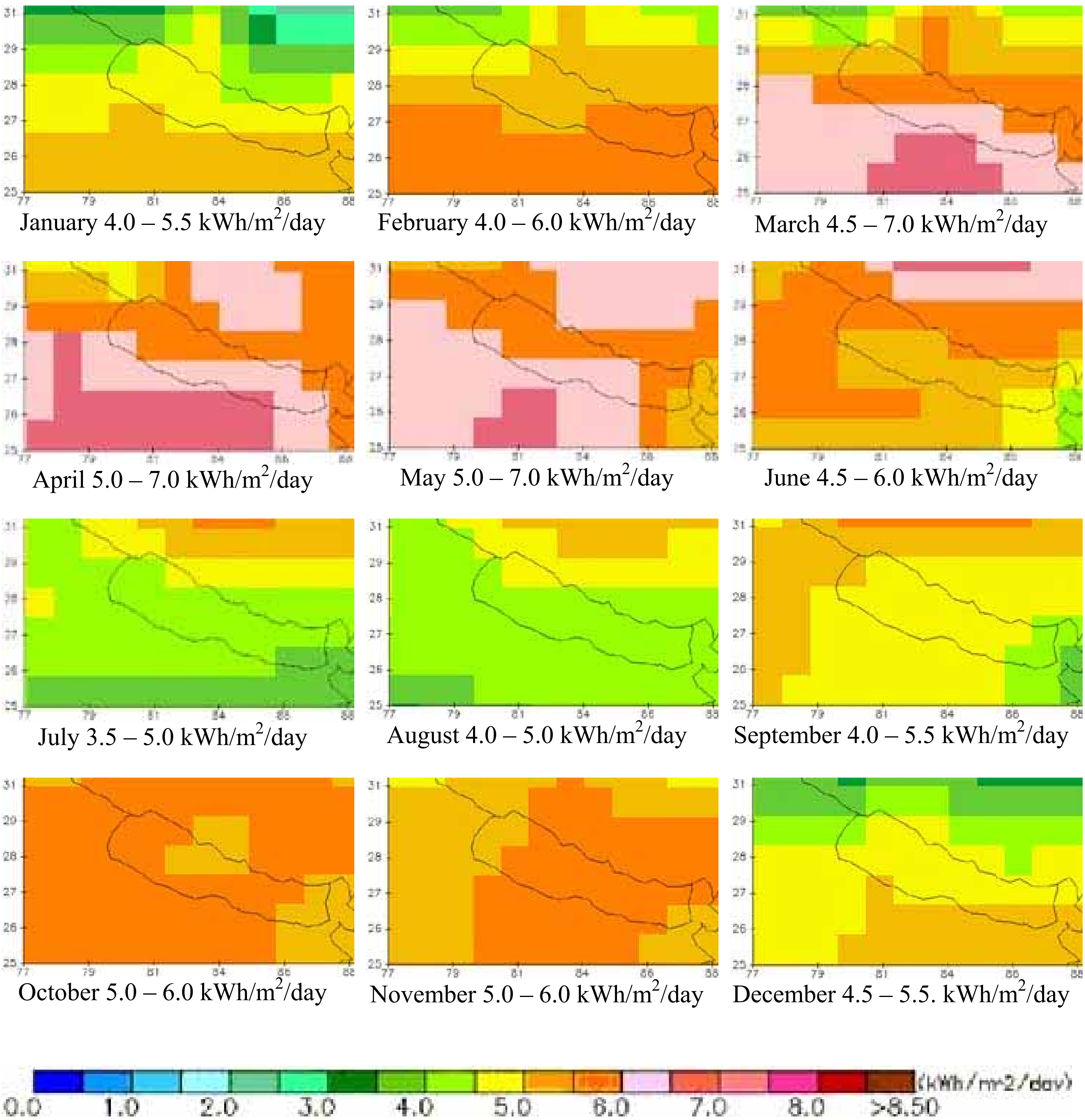


Figure 8-2: Average 30º towards Equator Tilted Solar Irradiation from 1983 –1993 for Nepal

For the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E, at 3,000 m.a.s.l.), and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E, at 2,643 m.a.s.l) in Humla, Nepal, the following monthly solar irradiation (kWh/m²/day) on a 30 º tilted surface towards south are applicable:

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Aver.
Simikot	4	4	5	5	6	6	5	5	5	6	5.5	4.5	5.2
Chauganphaya	4	4	5	5	6	6	5	5	5	6	5.5	4.5	5.2

Table 8-1: Simikot and Chauganphaya NASA Graphical Monthly Solar Irradiation 30º South Tilted

These solar irradiation maps are from the NASA web site: http://eosweb.larc.nasa.gov/

9. Solar Irradiation Simulation with METEONORM V5 for Humla

9.1. METEONORM V5 Global Meteorological Database Software Introduction

METEONORM V5 is a comprehensive computer program with an extensive climatological database for solar engineering applications at every location of the globe. It is a software packet for the calculation of solar radiation and irradiation on arbitrarily orientated surfaces at any desired location on earth.

The user inputs a particular geographical location for which meteorological data are required, and the software supplies such data for any desired location in the world as monthly, daily or hourly values in a range of alternate output formats. These can be further used in other solar engineering simulation software such as PVSyst3.31, which is used later on for the HARS and Chauganphaya solar PV village design.

9.2. Assumptions for the Simikot HARS Solar PV System

The extrapolation of the latitude, longitude, and altitude of the Simikot HARS was carried out with data read out of the "Simikot VDC" map[112], the most accurate Nepal Government map for the area, with a scale of 1:50,000. It matched well with the data provided by Mr. Jan Remund (from METEONORM) who could locate Simikot quite exactly with satellite data. The results are:

- 29° 58' 02" Northern Latitude (29.9670°)
- 81° 49' 02" Eastern Longitude (81.8170°)
- 3,000 m.a.s.l. (metres above sea level)

Further, the following additional values have been defined and input in the software to generate the Simikot related meteorological data:

- An inclined surface of 35° direct south for the global irradiation (Figure 9-6 in Appendix 18.5.2.).

- An albedo value of 0.27 (Figure 9-6 in Appendix 18.5.2.).
- In order to include the surrounding mountain ranges all around Simikot, a NASA-90m-horizon-model was created, as can be seen in Figure 9-1[113].

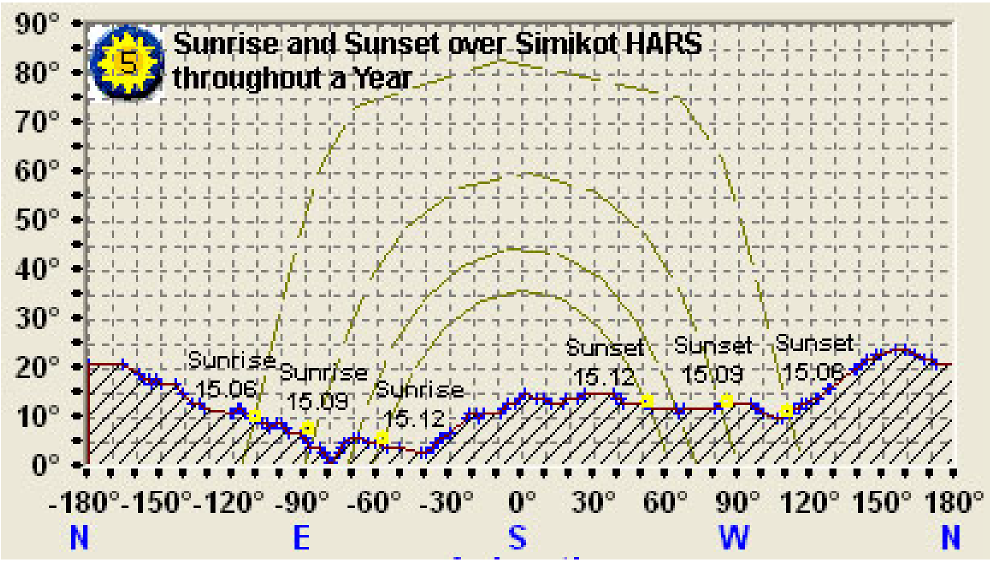


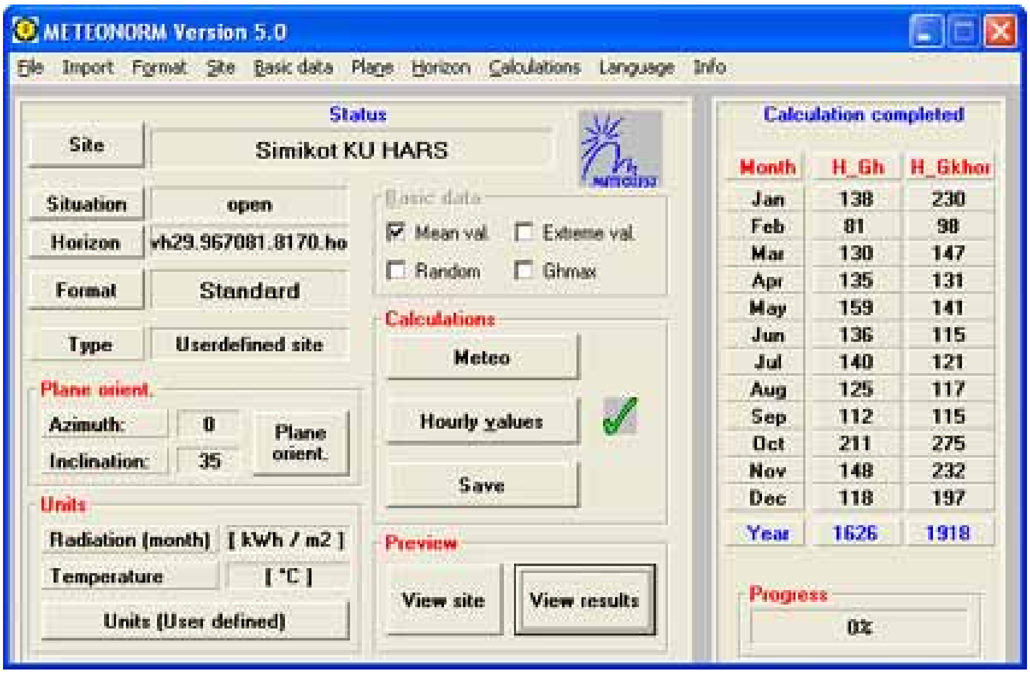
Figure 9-1: Sunrise and Sunset over Simikot HARS Diagram
Sunrise and sunset times over the Simikot HARS throughout the year, according to Simikot's 360° surrounded mountain ranges and peaks, calculated with the NASA-90m-horizon-model, and integrated in the METEONORM software Horizon Figure, to simulate the daily number of sun hours and solar irradiation (kWhm^{-2} day^{-1}).

The sun rises (3 yellow points in the East) over Simikot at the following times of the day (from left to right):

- 15th June: 5:30AM
- 15th September: 6:00AM
- 15th December: 7:00AM

The sun sets (3 yellow points in the West) over Simikot at the following times of the day (from right to left):

- 15th June: 17:30PM
- 15th September: 16:30PM
- 15th December: 15:15PM



General input menu of the METEONORM V5 software for the geographical location of the Simikot HARS meteorological data generation. The hourly values of the mean values over the last 10 years will be extrapolated including the high horizon, the inclination, and the Albedo value. The results are presented in this simulation in the standard format, to have the widest range of data available.

Figure 9-2: METEONORM V5 Meteorological Data generation for the Simikot HARS.

For further processing of the METEONORM generated meteorological data, the PVSyst. software format is chosen for the METEONORM hourly and monthly simulation, since the software packet PVSyst3.31 (see for more details chapter 10) is used for the actual solar PV system design afterwards. But for the sake of more detailed simulation parameter results, the "Standard" format is chosen for a second hourly and monthly simulation (as can be seen in Figure 9-2). The detailed standard format simulation results for the HARS Simikot are presented in Appendix 18.5.4.

9.3. Summary of the METEONORM Meteorological Data Simulation for Simikot

The most important meteorological data related to Simikot, generated through the METEONORM Hourly and METEO values, for the understanding of the available solar energy resource and its application are:

- Annual global horizontal solar irradiation of 1,626 kWh / m^2 per year (hourly standard format value). That results in an average daily solar irradiation of 4.455 kWh / m^2 per day.
- Annual global solar irradiation on a fixed, 35° south tilted, horizontal surface of 1,918 kWh / m^2 per year (Appendix 18.5.4. Figure 9-7 from the hourly standard format value). That results in an average daily solar irradiation of 5.255 kWh / m^2 per day.
- Ambient temperature between a minimum monthly average of 3° C in January and a maximum monthly average of 15° C in June. The maximum daily temperature can go as high as 27° C in May and the minimum can go as low as - 13° C in January (Appendix 18.5.5., Figure 9-11, METEO Format).

9.4. Comparison of simulated METEONORM Solar Irradiation Data for the Simikot HARS Solar PV System with the NASA Satellite Data as well as with the Monitored and Recorded HARS Data.

The following table provides the average monthly solar irradiation data for the three different data sources, the METEONORM software simulation for Simikot, the NASA satellite data and the Simikot HARS monitored and recorded data from May 2004 – September 2004.

Comparative Solar Irradiation Data (kWh / m^2) for Simikot, (METEONORM, NASA and Simikot HARS) in Humla, in Nepal

Solar Irradiation	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*	*Aver.*	*Diff %*	*Remark*
	Tot	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Year*	*Day*	*Year*	*Position*
METEONORM	138	81	130	135	159	136	140	125	112	211	148	118	1,626	4.455	0	Horizontal
METEONORM	230	98	147	131	141	115	121	117	115	275	232	197	1,918	5.255	+ 18.0	Fix 35° S
NASA Sat Graph[114]	93	98	140	150	186	180	155	155	150	155	120	93	1,675	4.589	+ 3.0	Horizontal
NASA Sat Graph	124	112	155	150	186	180	155	155	165	186	165	155	1,888	5.173	+ 16.1	Fix 30° S
NASA Data[115]	104	110	147	172	195	186	152	147	142	146	123	102	1,726	4.729	+ 6.2	Horizontal
NASA Data[116]	173	174	214	197	204	191	161	164	174	224	192	180	2,248	6.159	+ 38.3	Fix 29° S
NASA Data[117]	158	149	175	181	187	170	144	149	161	187	182	162	2,004	5.491	+ 24.5	Fix 29° S
NASA Data[118]	179	158	176	187	197	185	152	151	161	202	203	187	1,938	5.31	+ 23.6	At Opt. ° S
NASA Data[119]	58	50	37	24	10	4	7	17	33	47	56	60		33.5		Opt. Angle S
HARS Simikot					163	148	128	123	145							Horizontal
HARS Simikot					168	147	139	135	169							Fix 30° S
HARS Simikot					207	188	174	166	228							Tracking

Table 9-1: METEONORM Simikot, NASA and HARS Solar Irradiation Compared
Comparison of the Average Monthly Solar Irradiation in kWh / m^2, resulting from the METEONORM software simulation for Simikot, NASA graphical and Satellite data (for both Simikot and Chauganphaya the same), and local monitored and recorded data in the HARS Simikot Humla Nepal.

9.5. Results and Discussion for Simikot

As presented in detail in Chapter 7, the Simikot HARS is monitoring the solar irradiation values of three different positions, the global horizontal irradiation, the global irradiation on a 30° South horizontal surface, and the global irradiation on the plane of the array of a 2-axis self-tracking solar PV modules frame (see Figure 7-7). The whole monitoring station was installed during March – April 2004. Various difficulties due to the remoteness, inability to communicate and time pressure, it was possible to gather data continuously, only from May 2004 onwards. Thus, while this short time monitoring and recording can not provide representative or reliable data yet (as that is e.g. the case with the long-term NASA satellite data), it still points towards the possible differences of received solar energy, if it can be measured at the actual geographical location under the prevailing conditions. Thus in the long-term, after years of collecting such data, it will be very valuable and also more applicable than the NASA satellite or METEONORM software generated data.

Nevertheless, in order to provide an initial comparison between monitored and recorded HARS solar irradiation data, with the METEONORM simulated and the NASA satellite solar irradiation data over a period of 5 months (May – September), the following table is given.

	Solar Irradiation May - September	Difference in %	Remarks
METEONORM Fix 35° S	609	0	
NASA at optimum angle	846	+ 38.9	
NASA Maximum Value	894	+ 46.7	
HARS 2-axis self-tracking frame	963	+ 58.1.	+ 7.7% NASA max.
HARS Fix 30° South	758	+ 24.5	

Table 9-2: Comparative Solar Irradiation May – September for HARS Simikot

The optimum monthly angle south for the solar modules in Table 9-1 over the course of one year is between 4° in June and 60° in December. According to that, the 2-axis self-tracking solar module frame is designed. It can be adjusted by hand weekly, or twice a month, for its south-north inclined position between 5° and 60°, as in the Figure 10-2 for the PVSyst3.31 input data can be seen.

9.6. Assumptions for the Chauganphaya Village Solar PV System

As in section 9.3. for the Simikot HARS, so also for the Chauganphaya village, the extrapolation of the latitude, longitude, and altitude was first carried out with data read out of the "Chauganphaya VDC" map[120], with a scale of 1:50,000. But with a detailed Figure (see Figure 12-1), Mr. Jan Remund from METEONORM could define the village's location and height exactly with the NASA-90m-horizon-model, providing the following latitude, longitude and altitude data.

- 30° 00’ 00” Northern Latitude (30.000°)
- 81° 46’ 26” Eastern Longitude (81.774°)
- 2,643 m.a.s.l. (meters above sea level)

Further, the following additional values have been defined and input in the software to generate the Chauganphaya related meteorological data:

- An inclined surface of 35° direct south for the global irradiation (Appendix 18.5.6., Figure 9-16).
- An albedo value of 0.27 (Appendix 18.5.6., Figure 9-6).
- In order to include the surrounding mountain ranges all around Chauganphaya, a NASA-90m-horizon-model was created, as can be seen in Figure 9-3.

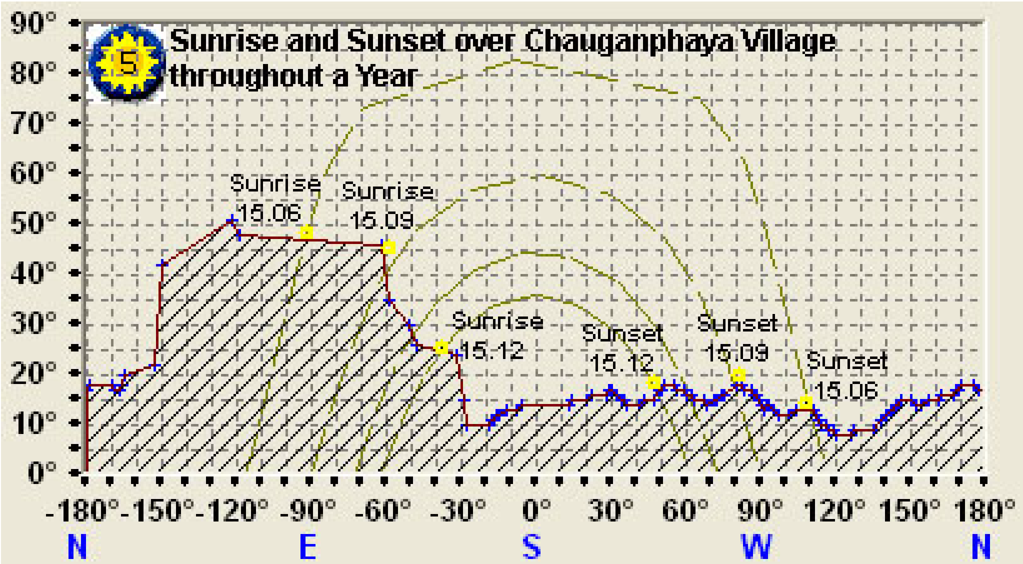


Figure 9-3: Sunrise and Sunset over Chauganphaya Village diagram
Sunrise and sunset times over Chauganphaya village throughout the year, according to the village’s 360° surrounded mountain ranges and peaks, calculated with the NASA-90m-horizon-model, and integrated in the METEONORM software Horizon Figure, to simulate the daily number of sun hours and solar irradiation (kWh/m^2 per day)

The sun rises (3 yellow points in the East) over Chauganphaya at the following times of the day (from left to right):

- 15th June: 8:30AM
- 15th September: 9:00AM
- 15th December: 9:00AM

The sun sets (3 yellow points in the West) over Chauganphaya at the following times of the day (from right to left):

- 15th June: 17:15PM
- 15th September: 16:00PM
- 15th December: 14:45PM

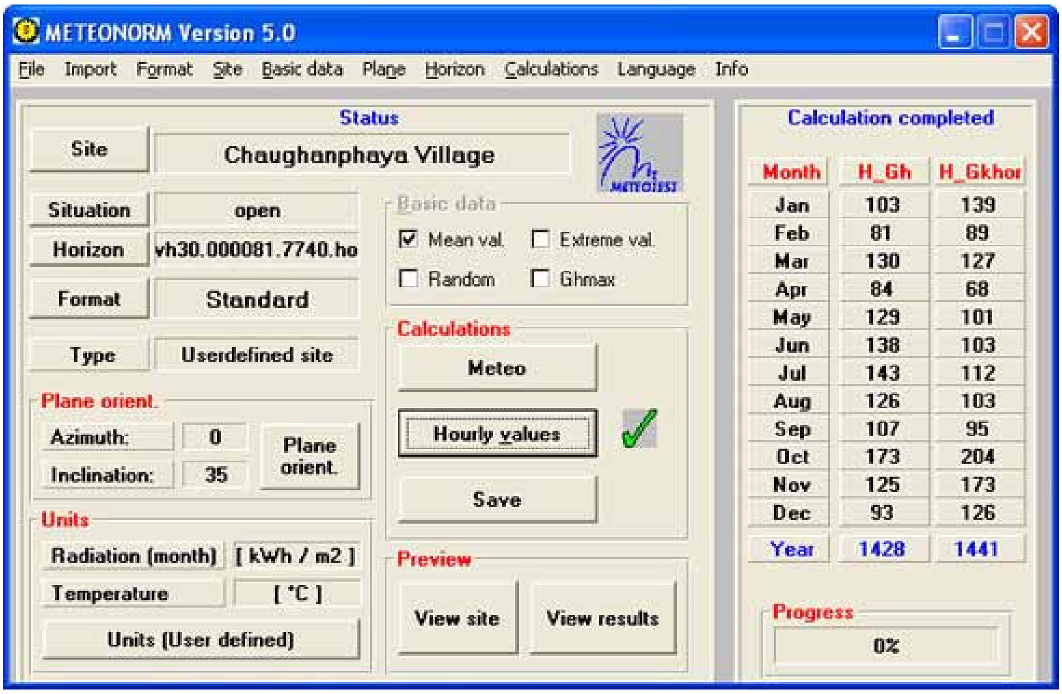


Figure 9-4: METEONORM V5 meteorological data generation for the Chauganphaya village.

General input menu of the METEONORM V5 software for the geographical location of the Chauganphaya village meteorological data generation. The hourly values of the mean values over the last 10 years will be extrapolated including the high horizon, the inclination, and the Albedo value. The results are presented in this simulation in the standard format, to have the widest range of data available.

9.7. Summary of the METEONORM meteorological data Simulation for Chauganphaya

The most important meteorological data related to Chauganphaya, generated through the METEONORM Hourly and METEO values, for the understanding of the available solar energy resource and its application are:

- Annual global horizontal solar irradiation of 1,428 kWh / m^2 per year (hourly standard format value). That results in an average daily solar irradiation of 3.912 kWh / m^2 per day.
- Annual global solar irradiation on a fixed, 35° south tilted, horizontal surface of 1,627 kWh / m^2 per year (Appendix 18.5.7., Figure 9-17 from the hourly standard format value). That results in an average daily solar irradiation of 4.458 kWh / m^2 per day.
- Ambient temperature between a minimum monthly average of 4.7° C in January, and a maximum monthly average of 16.6° C in June. The maximum daily temperature can go as high as 29.3° C in May and the minimum can go

as low as -8.5° C in January (Appendix 18.5.8., Figure 9-18, METEO format).

9.8. Comparison of simulated METEONORM Solar Irradiation Data for the Chauganphaya Village Solar PV System with the NASA Satellite Data as well as with the Monitored and Recorded HARS Data

Table 9.3 provides the average monthly solar irradiation data for the 3 different data sources, the METEONORM software simulation for Chauganphaya, the NASA satellite data and the Simikot HARS monitored and recorded data from the May 2004 – September 2004.

Comparative Solar Irradiation Data (kWh / m^2) for Chauganphaya village in Humla (METEONORM, NASA) and Simikot HARS in Humla, Nepal

Solar Irradiation	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*	*Aver.*	*Diff %*	*Remark*
	Tot	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Tot*	*Year*	*Day*	*Year*	*Position*
METEONORM	103	81	130	84	129	138	143	126	107	173	125	93	1428	3.912	0	Horizontal
METEONORM	157	100	145	78	113	116	124	118	110	231	193	143	1627	4.458	+ 13.9	Fix 35° S
NASA Sat Graph	93	98	140	150	186	180	155	155	150	155	120	93	1,675	4.589	+ 3.0	Horizontal
NASA Sat Graph	124	112	155	150	186	180	155	155	165	186	165	155	1,888	5.173	+ 16.1	Fix 30° S
NASA Data[121]	104	110	147	172	195	186	152	147	142	146	123	102	1,726	4.729	+ 6.2	Horizontal
NASA Data $_{max}$ [122]	173	174	214	197	204	191	161	164	174	224	192	180	2,248	6.159	+ 38.3	Fix 29° S
NASA Data[123]	158	149	175	181	187	170	144	149	161	187	182	162	2,004	5.491	+ 24.5	Fix 29° S
NASA Data[124]	179	158	176	187	197	185	152	151	161	202	203	187	1,938	5.31	+ 23.6	At Opt. ° S
NASA Data[125]	58	50	37	24	10	4	7	17	33	47	56	60		33.5		Opt.Angle°S
HARS Simikot					163	148	128	123	145							Horizontal
HARS Simikot					168	147	139	135	169							Fix 30° S
HARS Simikot					207	188	174	166	228							Tracking

Table 9-3: METEONORM Chauganphaya, NASA and HARS Solar Irradiation Compared
Comparison of the Average Monthly Solar Irradiation in kWh / m^2, resulting from the METONORM software simulation for Chauganphaya, NASA graphical and Satellite data (for both, Chauganphaya and HARS the same data) and local monitored and recorded data in the HARS Simikot Humla Nepal.

9.9. Results and Discussion for Chauganphaya

As concluded in section 7.10, solar PV modules installed on a 2-axis self-tracking frame are estimated to generate approximately 40% - 45% more energy than in the horizontal, and about 35% - 40% more energy on an average day than installed on a tilted 30° south position, over the course of one year.

As per the conclusion drawn in section 7.9., that the received Chauganphaya solar irradiation is approx. 25% lower than in Simikot, and the differences between the METEONORM simulated yearly differences between the two places of approx. 18% (at 35° fixed including the high horizon), it is realistic to say that an approx. 20% - 25% solar irradiation reduction for the monitored HARS Simikot values are applicable for the Chauganphaya village conditions. With 20% reduction chosen, the Chauganphaya 2-axis self-tracking frame provides the following solar irradiation values for the months May – September.

Adjusted Chauganphaya Solar Irradiation (kWh/m^2 per day) Values for the Months May - September

	May	Av %	June	Av %	July	Av %	Aug.	Av %	Sept.	Av %	Tot.	Tot %	Remark
METEONORM	113	0	116	0	124	0	118	0	110	0	581	0	Fix 35° S.
Chauganphaya	166	+46.9	150	+ 29.7	139	+12.3	133	+12.5	182	+65.8	770	+32.5	2-axis self-tracking

Table 9-4: Adjusted Chauganphaya Solar Irradiation Values for the Months May - September

Thus it is expected that the 2-axis self-tracking frame generates about 32.5% more energy than the METEONORM simulation with a fixed 35° South angle. This is over the months May – September, which is the rainy season and therefore the worst season throughout the year in regard to full sunshine days (see Appendix 18.5.8., Figure 9-19 and 9-18, sunshine duration values SD). Again, considering that the other months of the year have significantly more sunshine hours per day, it is realistic to say, that the 2-axis self-tracking frame allows the mounted solar PV modules to generate 35% - 40% more energy over the course of a year compared to a fixed, 35° South, angle installed solar PV array.

But as the HARS measured solar irradiation data have been measured only over five months, and that during the rainy season, they can only be considered as indicative but and not yet as representative. Therefore, to be on the safe side, for the Chauganphaya village solar PV system simulation in PVSyst3.3.1 the METEONORM software simulated data have been used.

10. Solar PV System Simulation with PVSyst3.31

10.1. Introduction

PVSyst3.31[126] is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone and DC-grid (public transport) PV systems, and includes an extensive meteo and PV system component database, as well as general solar energy tools. This software is geared to the needs of engineers, architects, researchers, as well as for educational training.

10.2. The HARS Solar PV System Definition

Besides providing power to the whole research station, the HARS solar PV system also serves as a test facility, as the power output of the PV array is monitored and the data recorded, in order to gain more valuable practical experience on the locally available solar energy resource. In order to design the HARS solar PV system, the PVSyst3.31 software tool was used. The various steps in defining the HARS solar PV system, the software inputs and the software output data are now explained.

10.2.1. Energy Service Demands

In order to define a solar PV system the energy service demands have to be clearly defined. The following list defines the energy services for the HARS in Simikot:

- AC electricity for PCs, laptops, printer, light, battery chargers and radio.
- Energy services have to be guaranteed between 5 – 8 days without sunshine.
- Battery bank should last around 8 years.
- Maximum power rating at any possible time: 600 - 800 W (2 PCs, 2 laptops, one printer, 10 room lights and a battery charger).
- Maximum 5% - 10% of the time the loss of load (LOL) is acceptable.

10.2.2. Load Demand Definition

The actual load is defined by the various equipment used, either periodically (e.g. daily) or more sporadically. The following is a typical daily load profile of the energy services needed in the HARS in Simikot.

No:	Equipment	Power (Watt)	Hours in Use	Energy (Wh)	Remarks
1	11 W CFL Lights (10 rooms)	11	3	363	Average 3 hours light a day
2	PC PIV	180	5	900	Pentium 4 with 15” monitor
3	PC Celeron	100	3	300	With 14” monitor
4	Laptop 1	60	4	240	Toshiba Pentium 2
5	Laptop 2	80	3	240	Gateway Pentium 4
6	Printer	60	1	60	Bubble Jet
7	Battery Charger	15	20	300	For staffs’ flash lights
8	Unforeseen daily loads	96	1	96	~ 4% of total load 1-7
	TOTAL Daily Load			**2,500**	Average Daily Load

Table 10-1: HARS Average Daily Load Demand

The following graph shows the PVSyst3.31 input of an average daily load distribution for the HARS load demand.

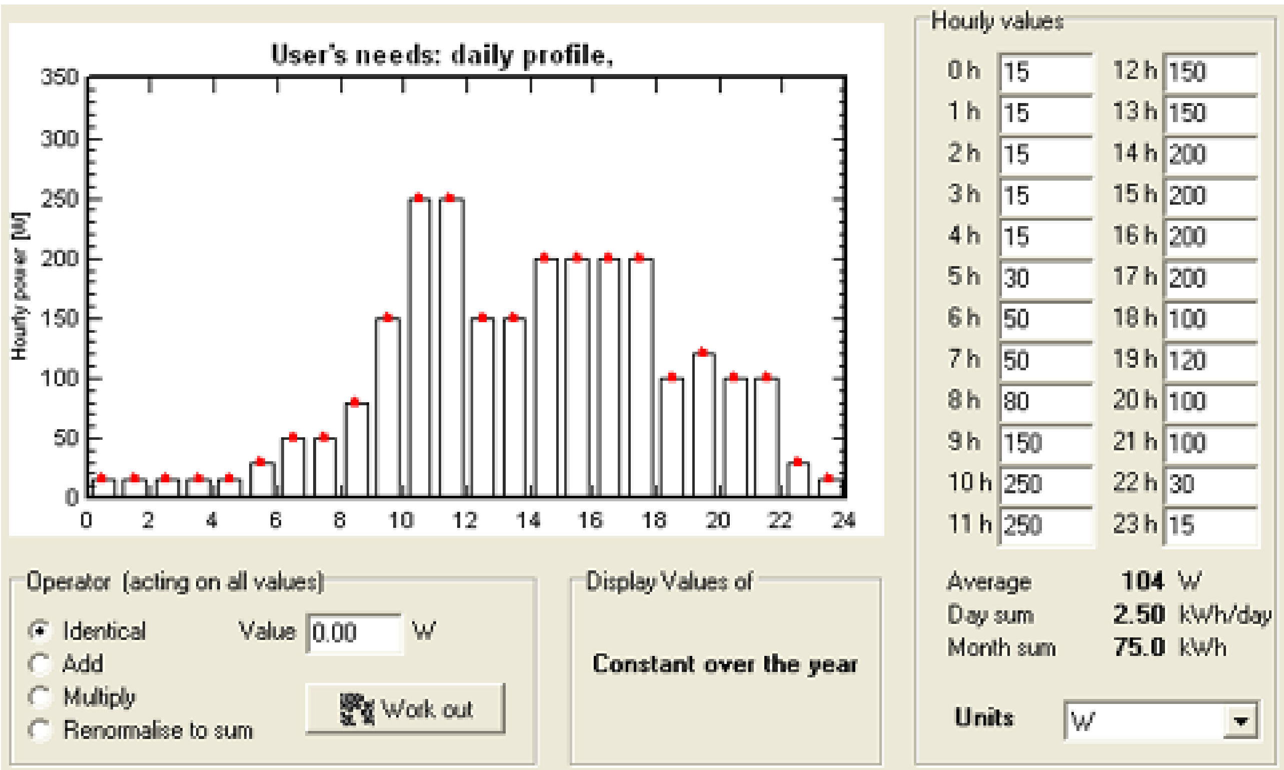


Figure 10-1: PVSyst3.31 Daily Energy Demand Profile Input Menu for the HARS Energy Demands.

10.2.3. Solar Irradiation

With the METEONORM software, a PVSyst3.31 software compatible, hourly meteorological file has been created. The daily average solar radiation is 5.22 kWh/m^2, or 5.22 Peak Sun Hours (PSH) @ 1 kW/m^2, for a 35° south tilted surface (for more details on the simulation and results see chapter 8).

10.2.4. 2-Axis Self-Tracking Solar PV Frame

As a self-tracking frame with 4 x 75W solar PV modules each is considered for the HARS system, the following detailed input data are provided to the software.

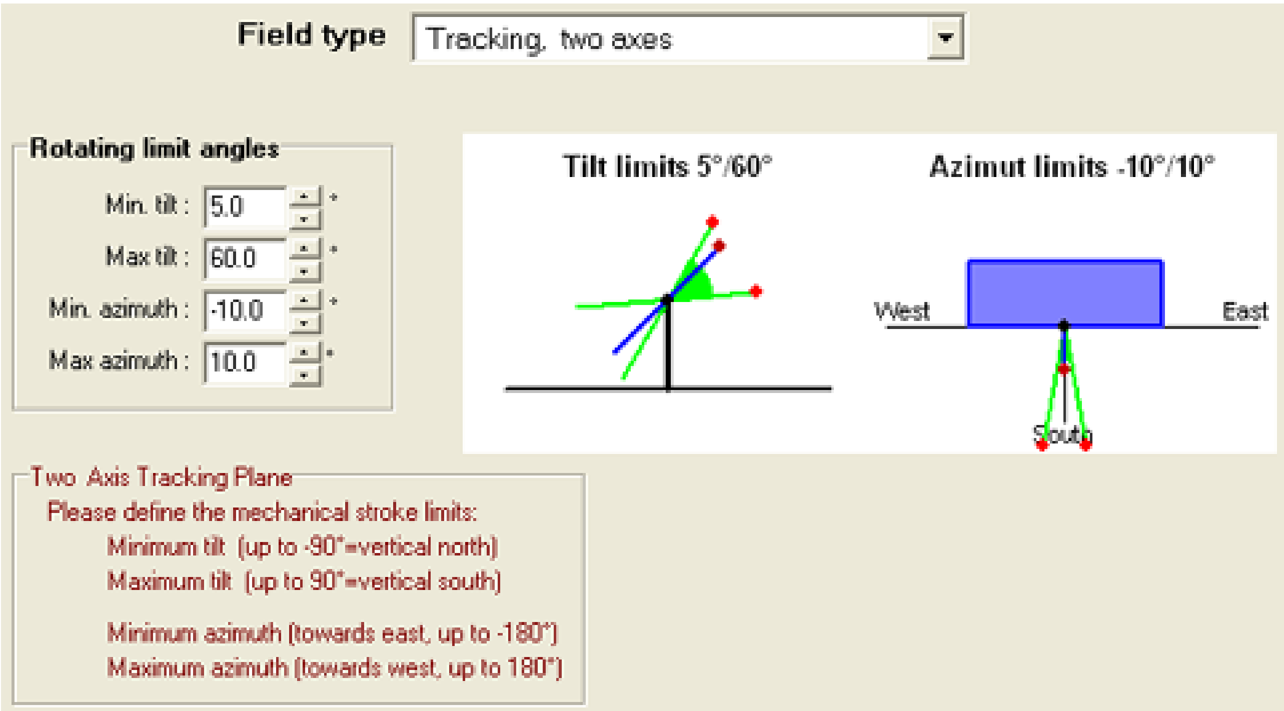


Figure 10-2: PVSyst3.31 2-Axis Self-Tracking Frame, Tilt Angles and Azimuth Input

10.2.5. Geographical Data Definition

The exact location for the HARS in Simikot is (from 9.2).

- 29° 58’ 02” Northern Latitude (29.9670°)
- 81° 49’ 02” Eastern Longitude (81.8170°)
- 3,000 m.a.s.l. (meter above sea level)

Simikot is surrounded by high mountains, which influence the daily availability of sun hours. Therefore the 360° horizon around Simikot has to be taken into account. That is taken care of by providing the PVSyst software with the 360° horizon generated with the NASA-90m-horizon-model by Mr. Jan Remund from METEORNORM.

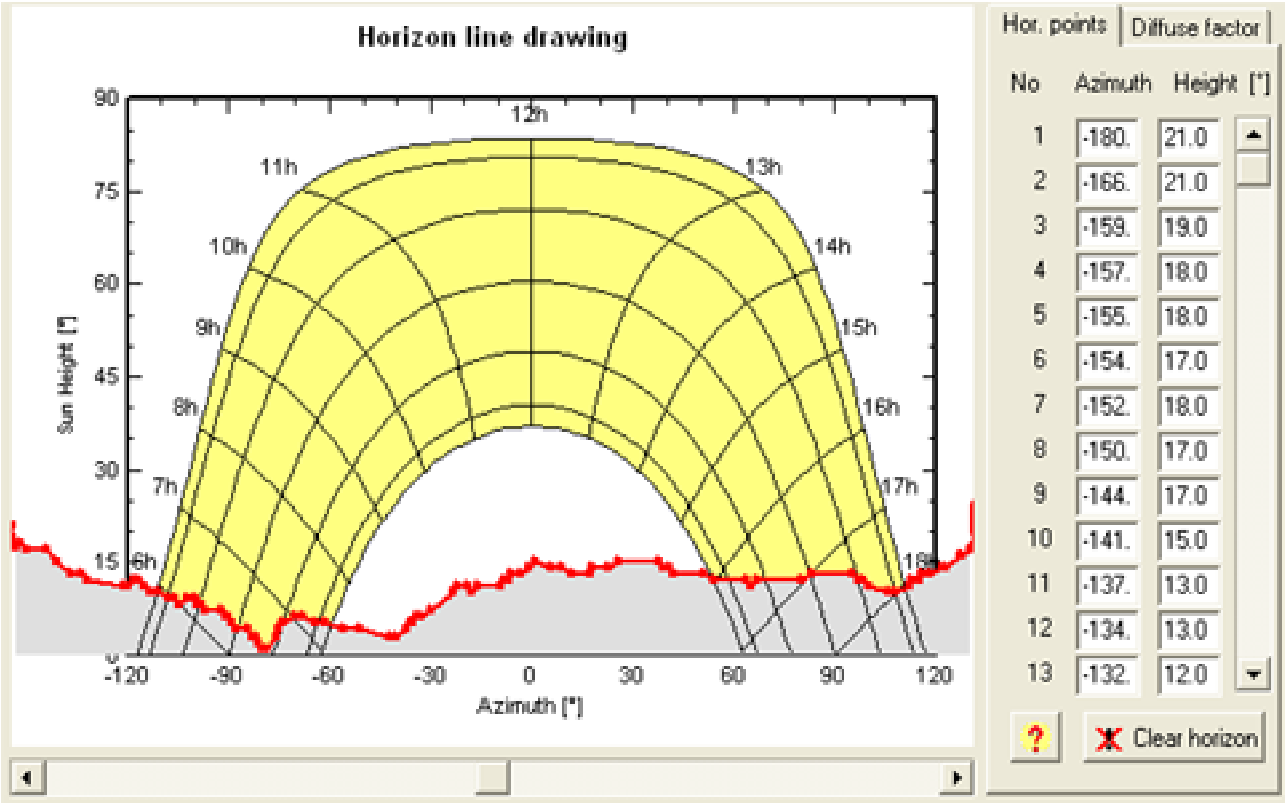


Figure 10-3: PVSyst3.31 Input for Simikot's 360° Horizon

10.2.6. Battery Bank and Solar PV Array Sizing

The battery bank size is defined according to the previously defined amount of days of energy services needed without sunshine (days of autonomy) and the system voltage (24 VDC). The solar PV array size is defined by the defined average daily load demand and the chosen solar PV modules (75W BP275F module).

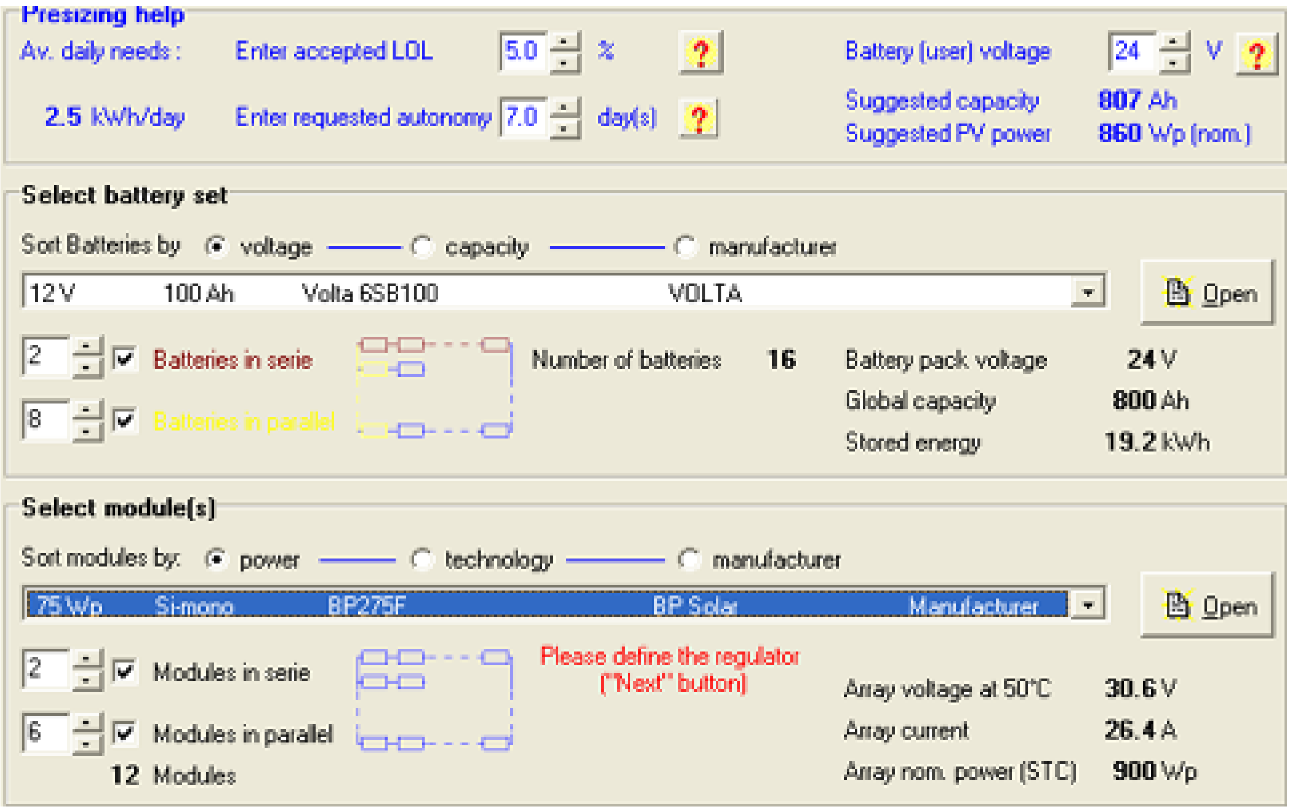


Figure 10-4: PVSyst3.31 Sizing of the Battery Bank and the Solar PV Array

10.2.7. Life Cycle Cost

PVSyst3.31 enables the input all the important economic data needed (costs such as hardware, transport, installation, maintenance, loan payment etc.) to calculate the life cycle cost and thus the final cost of the generated kWh unit (see page 5 of the 5 page simulation report in the Appendix 18.6.1).

10.2.8. Additional Main Parameters

For the PVSyst3.31 to simulate the HARS PV system, some additional parameters are needed such as:

- Albedo values according to the month. These values have been defined for Humla according to the monthly NASA albedo values for Nepal (see Appendix 18.6.1., page 1 of the simulation report).
- Any PV array shadings which may occur during the day, which is not the case for HARS.

- The battery charge regulator.
- Battery bank operation temperature.
- NOCT (Nominal Operation Collector Temperature) of the PV modules, at 800 W/m^2, T_{amb} 20°C, wind speed1 m/s.
- Thermal loss factor, defined by the constant loss factors and the wind loss factor.
- Ohmic loss factors (the wiring ohmic resistance induces losses (RI^2) between the power available from the modules and that at the terminals of the array).
- Voltage drop at STC (Standard Test Conditions, which are: 1,000 Watt/m^2 solar radiation, 25°C PV module temperature, 1.5 AM (air mass crossing in comparison to the vertical air mass at sea level).
- PV module efficiency losses due to mismatch with the manufacturer's specification.
- PV array mismatch losses (losses due to "mismatch" are related to the fact that the real modules in the array do not rigorously present the same I/V characteristics).
- Power loss factor at MPP (maximum power point), or fixed voltage. That allows for the quantification of power loss at the maximum power point, as well as of current loss when working at fixed voltage.
- Costs of all the various equipment, such as the PV modules, the 800 Watt inverter, cabling, financing schemes etc.

10.3. The HARS PV System Simulation Results

With all these parameters and data input into PVSyst3.31 the software simulates the PV system. It provides a 5 page simulation report, which includes, beside all the defined system parameters and conditions, all the needed technical data such as:

- PV array power output (Watt) at operation condition.
- Average yearly energy generation of the PV array.
- Battery bank life expectancy.
- Performance ratio of the system.
- LOL (Loss of load) factor.
- The fraction of energy provided by solar (in case there is a back-up system such as a diesel generator, which is not the case for the HARS system).
- The missing energy which the PV system can not provide due to the available solar energy and the demand of load (this is detailed in a table per month).
- Average horizon height.

Beside the main report a wide range of detailed technical parameters and system performance indicators can be generated through the generation of defined graphs and tables.

The economic side is covered by indicating simulation results such as:

- Listing of the various hardware cost defined for the investment, thus summerising the gross investment cost.
- Financing scheme (VAT, subsidies).
- Maintenance cost, annuities, taxes, insurance and yearly cost to set aside to replace the battery bank in due time.
- Total yearly system cost to be considered over its life time.
- Actual generated energy unit cost (kWh).

The detailed 5 page report with all its results is in the Appendix 18.6.1. For a Figure of the installed HARS solar PV system see Figure 7-26 in Appendix 18.3.10.

10.4. Chauganphaya Village Solar PV System Simulation

The Chauganphaya village PV system has been defined in the same manor and style and simulated with the PVSyst3.31 software tool. The detailed Chauganphaya village PV system definition, and a back of the envelop calculation is presented in chapter 12, and the full PVSyst3.31 simulation results are found in the Appendix 18.8.11.

11. Social Village Survey

11.1. Social Village Survey Questionnaire

Chauganphaya, the village chosen to implement a holistic grass root community development project was selected because of the poverty status of the people and their identified needs. Because of its needs it qualifies for the 2003 – 2004 projects to install light, powered through a solar PV system, smokeless metal stoves, pit latrines and a drinking water system. In order to be able to clearly distinguish the impact that the various projects will have, upon on the life and living conditions of the local people, a detailed survey questionnaire has been developed by four different people, an anthropologist (Dr. Kimber Haddix), a mechanical engineer (Alex Zahnd), the Humla project coordinator (Govinda Nepali), and a medical doctor. Detailed knowledge about the Chauganphaya village, its people and their living conditions was obtained by living and working with the people and by the extensive survey by the team. The survey questionnaire that was developed, with 44 questions, is called: "*Household and Health Improvement with Solar Lights, Smokeless Stoves, Pit Latrines & Drinking Water*. Baseline Questionnaire: Year 1 (2003 - 2004)"[127], of which a copy is attached in the Appendix 18.7.1.

The questionnaire is divided in the following parts:

1. General, questions 1 - 20

The part on general questions, aims to identify the name of the family, marital status (as in this area it is not unusual to have polygamous and polyandrous families), and family size. Their economic status is mainly identified through their animal and land possessions. It goes on to identify their way of cooking, heating, and methods used for light. Also addressed are questions asking if the family use a latrine and if so what kind, and if not how did they handle this problem. The last part of this section of the survey aims to find out the source of drinking water for the family, the time spent to get it, and how it is treated.

2. Demographic, questions 21 - 25

The composition of the family in question, the different age groups in the household according to sex, how many students in the family, female and male, and what school level they are currently at, all go towards the demographic part of the questionnaire.

3. Social / Attitudinal Data, questions 26 - 36

This part of the questionnaire aims at understanding the living habits of the family, and their attitude towards possible development projects in their village and community. Questions such as, the hour of rising in the morning and going to bed at night for both female and male, activities that make up their day, are part of the social data collection. These questions try to find out the household and work responsibilities of each member of the family. It aims to find out more details and reasons as to why e.g. women have a lower life expectancy than men. In the attitudinal part, questions are asked about the 4 proposed projects soon to be started in the village. It aims to find out how much awareness and what expectations the people have, e.g. their attitude to lights, powered by the sun’s energy, soon to be replace the traditional "jharro". The question asked to find out, "..what changes will be brought about in the home with the entry of electric lights..", helps to find out what beliefs people may already have and what additional awareness and training people need in order to understand better the forthcoming new solar PV electrification system. Further, various questions are asked with regard to the smokeless metal stove, in order to assess what, and how much people already know about the benefits of such a stove technology, and the impact it can have on health improvement, saving firewood, and the reduced drudgery of collecting firewood.

4. Health Data, questions 37 - 43

The poor health condition of the people, is the main reason for Humla's low average life expectancy of 54 years[128]. This part of the questionnaire, developed by a medical doctor, aims to ask the major relevant questions to find out the key issues to be addressed. In order to collect relevant information and data, a nurse from the HARS Humla project staff was made responsible to undertake initial and basic examinations of the people.

Questions asked and examination taken such as:

- Number of people in the family with acute respiratory infections.
- People in the family with diarrhea (with identified time periods).
- People in the family with worms.
- Mid-upper arm measurement of children under 5 years of age.
- Various examinations of each women of child bearing age in the household.

Every question distinguishes between male and female and in particular, young children are examined for worms, diarrhea and other infectious diseases.

11.2. Summary of the First Detailed Data Survey in Chauganphaya and neighboring Kholsi Village

In the following, a summary of the first detailed data survey (detailed questionnaire in Appendix 18.7.1.), which took place during the months November 2003 – March 2004, in the two neighboring villages of Chauganphaya (out of which 58 households from 63 took part), and Kholsi (56 households from 56 took part) with a total of 114 households. The following tables provide some of the most important data related to the lighting, cooking, latrine and drinking water conditions of these two villages.

First Village Data Survey Summary:

11.2.1. How do the people make light in their home (Table 11-1)?

What is their Lighting Method before Solar Energy powered WLED Lights			
Answers	*Households*	*Percent*	*Remarks*
"jharro"	113	99.1	Resin soaked pine wood sticks
Solar	1	0.9	10W Solar PV panel powers 1 fluorescent tube 10 W
Total	114	100	

Table 11-1: Lighting Methods before WLED Lights

Explanation:

- "jharro": Resin soaked pine wood sticks which are burned to generate a dim and smoky light inside their room.

11.2.2. Changes do they expect from solar energy powered lights (Table 11-2) ?

Expected Changes from Light through the Solar PV Village System			
Answer	*Households*	*Percent*	*Remarks*
Bright inside the home	25	21.9	
More activities in the evening	9	7.9	For housework and income generation possibilities
Children can study in the evening	3	2.6	
Cleaner air	2	1.8	No “jharro” to burn
Cleaner home	5	35.1	The dirt can be seen more clearly
Healthier inside environment	18	15.8	
“Jharro” free	15	13.2	
Less firewood is used	1	0.9	
Missing	1	0.9	
Total	114	100	

Table 11-2: Expected Changes with Solar powered Lights

11.2.3. How the people cooked before the smokeless metal stove project started (Table 11-3)?

What is their Cooking Method before the Smokeless Metal Stove			
Answers	*Households*	*Percent*	*Remarks*
Non-Jumla-design stove	2	1.8	Smokeless metal stove
Open fire with 3 stones	2	1.8	
Open fire with odhan	109	95.6	With a 3-legged metal ring
Other	1	0.9	
Total	114	100	

Table 11-3: Cooking Methods before the Smokeless Metal Stove

Explanation:

- The Jumla design smokeless metal stove is the stove designed by the writer, during his 4 ½ years of living and working in Jumla, another poor and remote mountain district, neighboring Humla.

- Odhan: A three legged metal ring holding one pot at the time above an open fire (see Figures 4-6, 4-7 and 6-9).

11.2.4. What do they like in their cooking method before the smokeless metal stove was installed (Table 11-4)?

What do they like about their current cooking/heating method			
Answers	*Households*	*Percent*	*Remarks*
Heating	35	30.7	
No Benefit	16	14.0	
Tradition	62	54.4	We have always cooked on open fires
Missing	1	0.9	
Total	114	100	

Table 11-4: What People like about the current Cooking/Heating Method

11.2.5 Why do they want the Smokeless Metal Stove (Table 11-5)?

What do they expect from a Smokeless Metal Stove			
Answers	*Households*	*Percent*	*Remarks*
Cleaner inside the home	1	0.9	No soot on the ceiling
Healthier inside environment	6	5.3	No smoke
No smoke inside the home	16	14.1	
More efficient cooking possible	39	34.2	
Less firewood is used	49	43.0	
Missing	3	2.6	
Total	114	100	

Table 11-5: Expectations of the Smokeless Metal Stove

11.2.6. What do they perceive to be the disadvantages of the smokeless metal stove (Table 11-6)?

Perceived Disadvantages of a Smokeless Metal Stove			
Answers	*Households*	*Percent*	*Remarks*
Cost	18	15.8	NRp 2,500 (~ US$ 35) each family has to pay of the full cost of NRp 6,500 (US$ ~ 95).
No Disadvantages	75	65.8	
Will not heat the house	18	15.8	The smokeless metals stove will not heat the house as good as the open fire
Missing	3	2.6	
Total	114	100	

Table 11-6: Perceived Disadvantages of a Smokeless Metal Stove

11.2.7. How many hours a week do the women and girls collect firewood (Table 11-7) ?

Average amount of Hours per Week the Women to Collect Firewood			
Hours	*Households*	*Percent*	*Remarks*
7	3	2.6	
8	22	19.3	
9	4	3.5	
10	3	2.6	
32	5	4.4	
35	1	0.9	
40	36	31.6	
48	28	24.6	Probably several women per household
64	2	1.8	Several women per household
72	3	2.6	Several women per household
80	2	1.8	Several women per household
112	1	0.9	Several women per household
Missing	4	3.5	
Total	114	100	

Table 11-7: Average Weekly Firewood Collection Time for Women

11.2.8. How many “bari” of firewood do they consume a week (Table 11-8) ?

Average amount of “baris” of Firewood per Week one Families consumes			
“Baris”	*Households*	*Percent*	*Remarks*
4	5	4.4	
5	36	31.6	
6	28	24.6	
7	1	0.9	
8	2	1.8	
9	3	2.6	
10	2	1.8	
14	1	0.9	Probably an extended family with 3 generations
Missing	36	31.6	Shows that firewood has no “actual price tag”, as it is part of the women’s daily chores.
Total	114	100	

Table 11-8: Average amount of “baris” of Firewood Consumption per Family per Week

Explanation:

“bari”: One bari of firewood is a bundle of cut up firewood between 25 – 35 kg.

11.2.8. How many have a pit latrine before the Pit Latrine project (Table 11-9) ?

How many Families had a Pit Latrine before the Pit Latrine Project started			
Answers	*Households*	*Percent*	*Remarks*
Yes	56	50.9	This figure is most probably incorrect, as many must have understood “if a pit latrine is accessible”, or must have felt ashamed to say No, as only 3 pit latrines have been identified during the initial visit and meetings before the project started (see 3.3.2).
No	58	49.1	This figure is most probably as high as 95% for “No pit latrine”.
Total	114	100	

Table 11-9: How many Families hads a Pit Latrine before Project Start

11.2.10. How many boil their drinking water (Table 11-10) ?

How many Families Boil their Water before Drinking			
Answers	*Households*	*Percent*	*Remarks*
Not boiling	109	95.6	People have been drinking unfiltered and un-boiled river water, which is contaminated from villages further upstream
Missing	5	4.4	
Total	114	100	

Table 11-10: How many Boil their Drinking Water

11.2.11. Out of what material is their house built (Table 11-11) ?

With what kind of Material do they build their Homes			
Answers	*Households*	*Percent*	*Remarks*
Stone / Mud	112	98.8	Local stones and mud
Stone / Dry Masonry	2	1.8	No mud used but only well cut stones
Total	114	100	

Table 11-11: Material out of which they Build their Homes

Additional details of the Chauganphaya Village Survey data on the social status of the community, age distribution of men and women, education level, their animals and their daily activities according to sex can be seen in 18.7.2. Appendix to Chapter 11 Additional Chauganphaya Village Survey Data.

11.3. Ongoing Data Collection

The same survey was planned to be carried out a second time in Chauganphaya in September - October 2004. This time each family had been living with 3 WLED lights and a smokeless metal stove in their home, as well as using a pit latrine and with access to drinking water for 8 months. What impact did the implemented project have on the family's health, social life and education of the ones going to school? What changes did the people see and experience both within their family and in the village? These are answers this survey aims to find out with reference to each of the individual projects implemented, as well as the synergetic benefits of the holistic project approach.

Due to the rapidly deteriorating political condition and war like situation in Humla, the second survey could not be carried out in the same way. Instead, Chauganphaya people have been asked to come to the HARS office in Simikot to provide their experience and answers. Chapter 14 looks at the Chauganphaya solar PV system performance and experience in more detail.

12. Chauganphaya Village Solar PV System

12.1. Design Approach

In chapter 3.3.2. it was discussed why the Chauganphaya village has been electrified with a solar PV system. To design an appropriate solar PV system for a remote, impoverished mountain community in the Nepal Himalayas, various types of data must be known. These can be distinguished as essential data, and additional (helpful and informative) data and information. The essential data and information is:

- The number of households in the village.
- Annual growth.
- The lighting levels needed.
- The lighting technology used or needed.
- The daily load (the number of lights per house and hours per day used).
- Numbers of days the load demand has to be met without sunshine (days of independency).

- The solar irradiation available, either hourly irradiation (kWh/m^2), daily irradiation (kWh/m^2 per day), or as monthly irradiation data (kWh/m^2 per month).
- An approximate calculation for the solar PV array and battery bank size.
- The geographical position of the village (latitude, longitude and altitude).
- Solar PV system equipment specifications.
- People's/community's economic capabilities.
- Current prices and delivery times for everything that is to be purchased.
- A formally signed request / invitation letter from the local community for the village's elementary electrification system.

Among the non mandatory data and information are:

- Number of people in each household and overall in the village.
- Numbers of women and men, and number of children under 5.
- Average life expectancy of men and women.
- Present sources of illumination and present cost and time required to maintain/sustain it.
- Positive and negative aspects of the traditional lighting, and its technology.
- People's expectation for future illumination.

12.1.1. Guidelines for Designing the System

The nature of the community in regard to its remoteness, economic capacity and stage of development is crucial in deciding which technologies are appropriate to apply. Decision making was based on the following considerations, derived from the writers practical experience.

- The more remote and difficult to access a community, and the more it is impoverished, the less the technical approach needs to focus on achieving the highest possible efficiency and the more it needs to focus on achieving the highest possible sustainability and appropriateness. Thus equipment that is proven to be reliable, robust and long-lasting must be set at a higher premium than equipment for which these properties are uncertain but which is said to offer apparent efficiency gains.
- The poorer a community is the more a solar PV system needs to focus only on providing elementary electrification services to generate power only for lights in homes. Such lights need to consume as little power as possible while still enabling dwellers to fulfill their basic daily indoor activities (such as cooking, grinding, cleaning, reading and social gatherings).
- The more vulnerable a community is economically, the more reliable and long-lasting the lights installed must be. Therefore lights themselves demand a technology associated with a long life expectancy, comparable with the usual 20 years lifespan of a solar PV system.
- In many developing countries, including Nepal, it cannot be taken for granted that all materials and parts for a solar PV system are always available. Therefore it is important to maintain an up-to-date network or files of preferred equipment, components, ingredients and spare parts providers. Such a network allows for better designing, time planning and component delivery appropriate to the context, as well as accurate budgeting and greater transparency in choices and purchases.

In the following sections the most important data are defined in order to calculate and design the elementary Chauganphaya village solar PV system. Appendix 18.8.1.

– 18.9.9. gives details on acquiring other relevant and important data and information.

12.2. Lighting Level

For the Chauganphaya Solar PV Village System, 189 WLED lights, each consuming 1 Watt, are installed (see Chapter 5). They provide just enough light in order to be able to cook, conduct simple work, read, write and socialize inside the home.

12.3. Daily Load

Chauganphaya village has 63 homes and in each home 3 WLED lights were installed, each light consuming 0.8 – 0.85 Watt (see Figure 6-11, in Appendix 18.2.1.). To accommodate about 20% losses mainly in wiring systems, the consumption is defined as 1Watt per WLED light. It has been discussed and decided with the village community that the lights shall be used for a maximum 4 - 5 hours daily. The village has an approximate annual growth of 2 - 5% (or 1 – 3 homes). That results in approximately 73 homes in 5 years. The maximum and expected daily design load is evaluated as follows:

- Number of lights expected after 5 years = 219
- Maximum daily load = 219 x 3 WLED lights x 1Watt x 4hours = 876Wh
- Expected % of lights in use for 4 hours = 80%
- Maximum likely daily load up to next 5 years = 700Wh

12.4. Days of Independency

Considering the precipitation during the 4 monsoon months (June – September) the solar system must provide from its battery bank the energy to have the daily load met for up to 5 days, with a maximum DoD (depth of discharge) of the battery bank of 30% - 35%, in order not to shorten the battery bank's life expectancy (8 –10 years).

12.5. Solar Irradiation

With the METEONORM software, a PVSyst3.31 software compatible, hourly meteorological file has been created. This indicates that the daily average solar radiation is 4.458 kWh/m^2, or 4.458 Peak Sun Hours (PSH) @ 1 kW/m^2, for a 35° south tilted surface (see chapter 9.7. – 9.9., in Appendix 18.5.7.).

12.6. Chauganphaya Village Solar PV System Approximate Calculation

12.6.1. Solar PV Array Size

***Solar PV array Size*:** $\dfrac{700\ Wh(daily\ load)}{0.8(battery\ bank\ efficiency)} = 875Wh\ per\ day$

In this region of very clear skies, the average temperature of the solar panels is estimated to be 25°C – 35°C above the ambient average temperature (25°C). With an average power output reduction coefficient of – 0.44% (for the BP275F PV module), one 75W BP275F solar panel, generates under "real field conditions" (assuming the higher solar PV module operating temperature), a maximum power output of: (-0.44) x (60°C - 25°C) = - 15.4 % less power output, or 75 x (1 – 0.154) = 63.45W. Thus, the BP275F 75W mono-crystalline solar panel generates daily approximately: 63.45 W x 4.458 PSH = 283Wh.

Thus the needed solar array size must be: 875Wh / 283Wh = 3.1, i.e., 4 solar panels each 75W rated output, to be safe, and in order to have a 24VDC system (enabling a future easier upgrade in regard to current increase in the cabling and charge/ discharge equipment). Thus a total of 4 x 75W solar panels have to be installed as a 24VDC system for the Chauganphaya village.

12.6.2. Battery Bank

Battery Bank size:

$$\frac{5\ Days\ Independency\ from\ the\ Sun\ x\ 0.7\ kWh\,(daily\ load)}{0.35\,(DoD)} = 10\,kWh$$

With a 24VDC battery system that results in: 10kWh / 24 V = 417Ah energy storage capacity in the battery bank to provide the daily load of 700Wh for up to 5 days without sun and without discharging the battery bank more than 35% at a time.

The chosen (best available deep cycle battery in Nepal) is the 12VDC 100Ah (@ 20 hrs) Volta battery[129]. With a 100 hours discharge rate, this battery provides 110Ah. As the current is never expected to exceed ~ 8Amps (average 180 WLED lights even after 5 years) from the whole battery bank, the higher capacity range for this battery can be chosen. Thus with each deep cycle battery capacity of 110Ah that results in: 417Ah / 110Ah = 3.8 batteries, or 4 batteries in parallel, and each serial connected with one other battery, to make up the 24VDC. That means that 8 x 12VDC 100Ah (@ 20 hrs) Volta batteries have to be installed as a 24VDC system.

On a daily level this battery bank, with a daily load of 700Wh, reaches an average daily DoD = (700) / (8 x 110Ah x 12V) x 100 = 6.63 %. After 3 days without sun, the batteries reach a DoD of just under 20%, and after 5 days of no sunshine a DoD of 33 % is reached. Under proper use and maintenance that enables the battery a life of up to 10 years, including a 16% energy demand growth over the first 5 years.

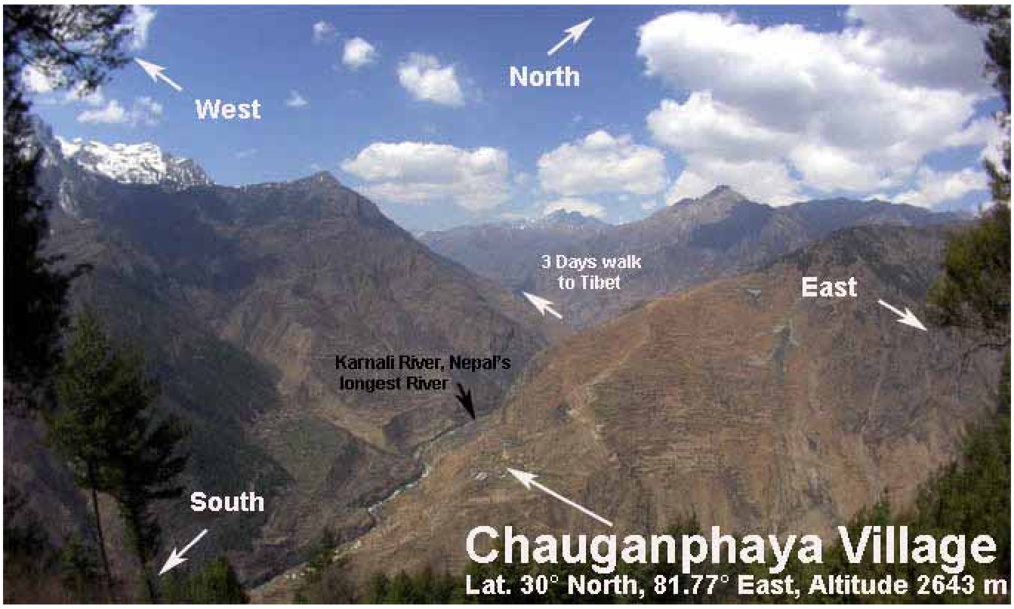
12.7. Geographical Data Definition

The extrapolation of the latitude, longitude, and altitude of Chauganphaya village was first carried out with data which was read from the "Chauganphaya VDC" map[130], with a scale of 1:50,000:

- 30° 00' 32" Northern Latitude (30.005°)
- 81° 46' 09" Eastern Longitude (81.768°)
- 2,600 m.a.s.l. (meter above sea level)

With a detailed wide angle picture from a neighbouring mountain range (see Figure 12-1), Mr. Jan Remund from METEONORM could define the village's location exact with the NASA-90m-horizon-model (as in 9.6.).

- 30° 00' 00" Northern Latitude (30.000°)
- 81° 46' 26" Eastern Longitude (81.774°)
- 2,643 m.a.s.l. (metres above sea level)



Chauganphaya Village in the district of Humla, in the North - West of Nepal. It is surrounded by high mountain ranges, creating a high horizon. This limits the daily solar irradiation value significantly and thus has to be included into the calculation.

Figure 12-1 is taken from the village's eastern high mountain range, some 1.3 km air distance away.

Figure 12-1: Chauganphaya Village Humla

Comparing the results from the extrapolation of the map and the NASA-90m-horizon-model, a very close proximity, within 30" for both latitude and longitude has been achieved. Also the altitude value, which is 43 metres different, is within a reasonable tolerance. Thus for the meteorological data generation (with METEONORM V5) and the solar system size and cost simulation (with PVSyst3.31) the data calculated as per NASA-90m-horizon-model have been used.

12.8. Solar PV System Equipment

12.8.1. Solar PV System Layout Figure 12-2

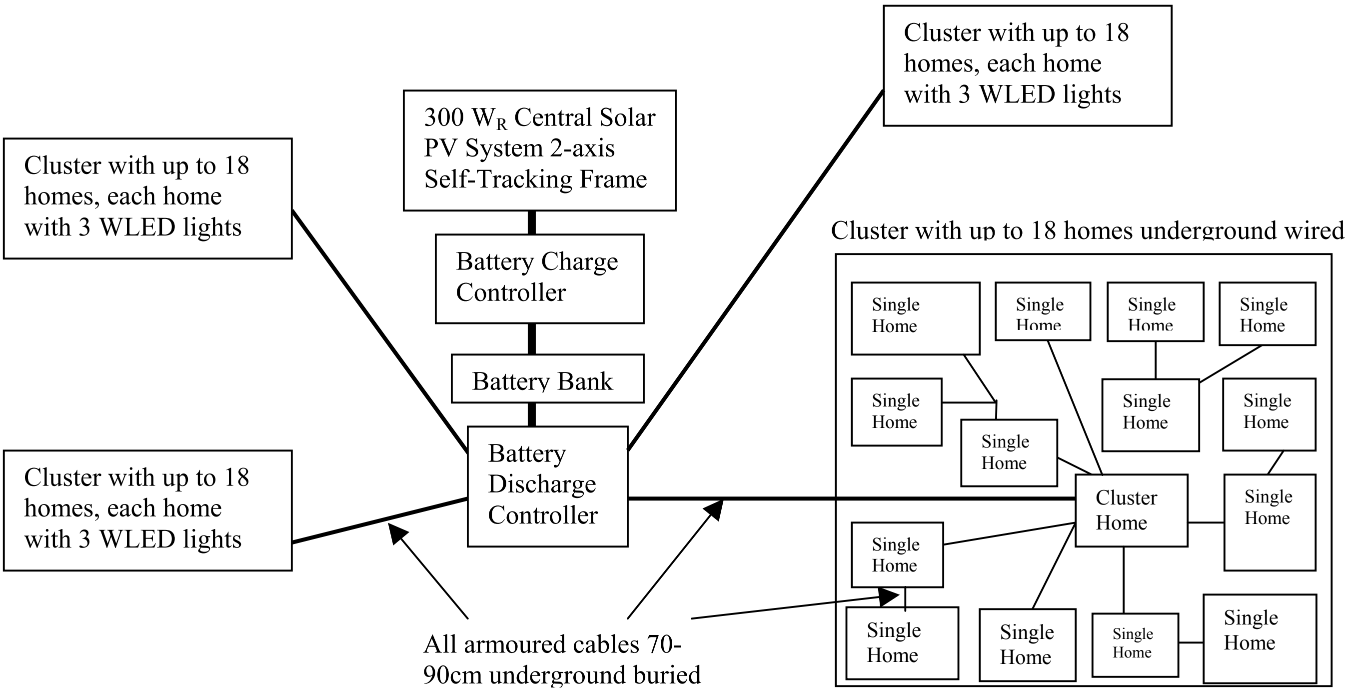


Figure 12-2: Chauganphaya Solar PV System Block Schemata

12.8.2. Solar PV Modules

For both Chauganphaya Village and the HARS in Simikot Solar PV system, the same solar PV modules (BP275F) have been chosen. That enables the solar irradiation and solar PV module power generated data measured and recorded in the HARS in Simikot to be extrapolated for the Chauganphaya village conditions with acceptable accuracy (see Appendix 12.3 for why this PV module has been chosen and technical details).

The main technical specification for the BP275 F solar module can be seen from its label in the following Figure 12-3.

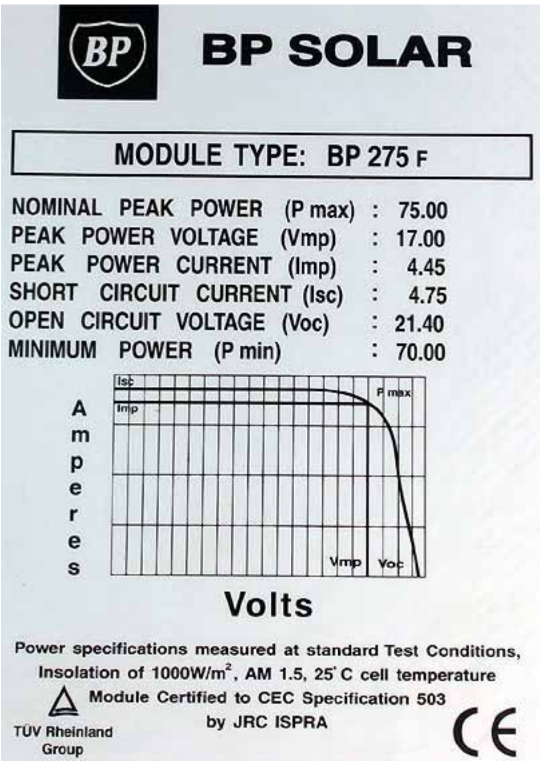


Figure 12-3: BP275F Solar PV Module Characteristics

The BP275F solar PV module label indicates the main module characteristics. With the provided values this module has a good fill factor FF of:

$$\frac{V_{mp}\times I_{mp}}{V_{oc}\times I_{sc}} = \frac{17.00\times 4.45}{21.40\times 4.75} = 0.744 = 74.4\%$$

with that value the solar PV module cell efficiency η can be calculated for standard conditions, 1,000 W/m^2, 1.5AM and 25°C, and a cell area of 156cm^2 and 36 cells per module.

$$\eta = \frac{P_{\max module}}{P_{\inf romthesun}} = \frac{V_{oc}\times I_{sc}\times FF}{1kWm^{-2}\times A_{\mathrm{mod}\,ulecells}} =$$

$$\frac{21.40V\times 4.75A\times FF}{1000Wm^{-2}\times 0.5616m^{2}}\times 100 = 13.47\%$$

13.47% efficiency at the maximum power point on the I-V curve. That matches rather well with the manufacturer's data provided in the PVSyst3.31 software with 13.49 % for the BP275F module cell efficiency.

12.8.3. Two-axis Self-Tracking Solar PV Module Frame

The 2-axis self-tracking frame consists of an aluminum frame, with mountings for 4 x BP275F solar PV modules. In the middle of the East-West turning axis is a gear box with a reduction ratio of 1:100. A small 1.5VDC motor with an internal gear box having a reduction ratio of 1:900 is powered by two 2.5W PV modules (on top of the frame), set at an angle of 30° angle to each other below the sun. As the sun moves one panel's position becomes slightly more directly illuminated than the other, thus generating a slight power excess. This drives the DC motor to rotate the East-West axis towards the more illuminated panel. When the two small solar PV modules' power output is again equalized, the motor stops, and the frame is set perpendicular to the sun. This small DC motor is enough to drive the gear box, which is connected to the North-South axis, turning the whole frame around it from East-West according to the sun path.

Figure 12-4: 2-Axis Self-Tracking Frame 1
2-axis self-tracking frame for 4 x BP275F solar PV modules. This tracker is installed in the Chauganphaya Village solar PV system.

On an average, when the sun shines, every 5 – 6 minutes the frame is adjusting its position after the sun. A strong foot holder, which is covered with stones, holds the frame steadfast on the ground even in strong winds. The HARS solar irradiation measurement with the 80SPC pyranometer mounted on the tracking frame is to find out the increased mean daily solar irradiation received due to the daily tracking for the solar PV modules. The 2-axis self-tracking frame is made in Nepal and costs as much as one 75 W BP275F solar panel.

2 solar PV modules are serial connected, to provide a 24 VDC system, cutting down the current losses, and each 2 are parallel connected. Thus the total power output is 300 W. For the Chauganphaya village the North-South frame angle has to be changed from 54° (with a minimum solar altitude angle between the horizontal and the line to the sun of 36.24° on the 24th December), to 8° (with a maximum solar altitude angle of 82.00°, on the 30th June[131]). The angle is changed approximately twice a month.

The reasons to include a 2-axis self-tracking frame in the solar PV system for Chauganphaya, and more detailed information is provided in the Appendix 18.8.4.

12.8.4. Solar Charge Controller

The local Nepali company PPN (Pico Power Nepal) has built the following charge controller, according to the set specification demands (see Appendix 18.8.5. for more details) with the following technical specifications at 25°C[132]:

• System Voltage	12Volt	24Volt
• Max. Module current	30Amps	30Amps
• Max. Self-consumption current	5.5mA	6mA
• Final Charge cut-out voltage	14.4 Volt	28.8 Volt
• Final Charge re-connection voltage	13.6 Volt	27.2 Volt
• Temperature compensation	3.5mV/ ° C and cell	
• Final gassing (equalization) voltage	15.4 Volt	30.8 Volt
• Ambient temperature	-10°C to + 50°C	

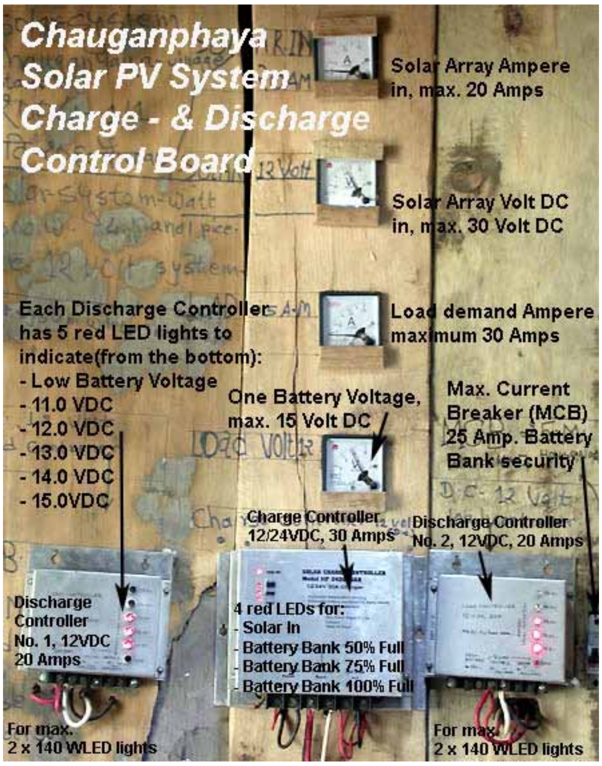


Figure 12-5: Charge- and Discharge Controller
The Chauganphaya Solar PV System Charge- & Discharge Control Board. It enables to have an immediate status of the solar PV system, for the trained maintenance staff in charge, to record the daily data.

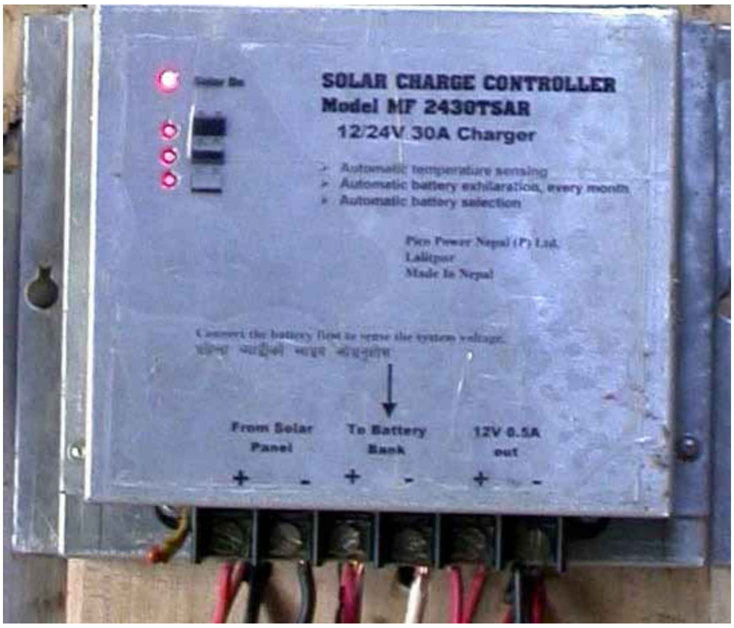


Figure 12-6: Charge Controller
The purpose built Chauganphaya Solar Charge Controller. Beside the + and – connections for the solar array and battery bank, it has a 12 VDC and 0.5 Amps connection for the powerhouse only. At the left side of the wire connection point “From Solar Panel +”, is the external temperature sensor positioned. It measures the ambient temperature in the powerhouse, and charges accordingly the battery bank. The battery bank temperature compensation correction coefficient is 3.5mV/ °C and cell.

12.8.5. Solar Discharge Controller

For the Chauganphaya village solar PV system a special discharge controller, to discharge the Volta deep cycle lead-acid, vented plate batteries, has been built by PPN according to specified demands (see Appendix 18.8.6. for more details).

The Chauganphaya solar PV system powers initially 63 homes, each home with 3 WLED lights. These 63 homes are divided into 4 clusters, each 15 – 18 homes. Each cluster has a separate power line from the powerhouse into their cluster. Within the cluster a mini-grid distribution system connects all the homes of one cluster.

Figure 12-7: Discharge Controller

The two discharge controllers installed, have total 4 outputs, with each output able to provide power for up to 140 WLED lights, consuming each 1 Watt. Each cluster has initially 45 – 60 WLED lights installed. The village has an average growth rate of homes of about 2% - 5% per year. That enables an additional growth per cluster of 100% over at least the next 10 years, without changing, or adding, another discharge controller. Further, if one of the two discharge controllers fails to deliver power to one, or even two, power lines, the other discharge controller is able to provide the full daily load demand for up to two additional clusters.

Each discharge controller has 6 red LED light indicators for the battery bank's status. It represents the batteries' voltage, from low, (under 11.0 VDC, and thus considered empty, cutting the power line), to total fully charged, at 15 VDC, at each 1 VDC voltage steps.

12.8.6. Battery Bank

The battery bank is a central part of a solar PV system. Even more so if the system is designed for and installed in a remote area difficult to access, as this is the case for the Chauganphaya Village solar PV system. Batteries operate under specific conditions which have to be defined as clearly as possible during the design stage (or simulation stage if a software packet is used) of the solar PV system.

The following two pictures (Figures 12-8 and 12-9) show the installed Chauganphaya Solar Village Battery Bank in the powerhouse. The powerhouse has a flat mud roof, on which the solar 2-axis self-tracking frame and the four mounted BP275F solar PV modules are fixed (see Figure 12-18), right above the battery bank.

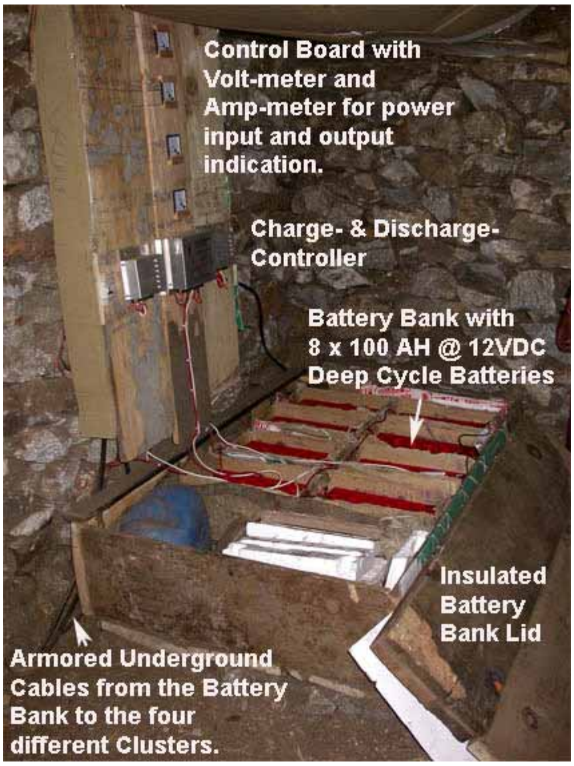


Figure 12-8: Chauganphaya Battery Bank 1
Inside the Chauganphaya solar PV system power house. Volt and Ampere meters indicate the status of the solar PV system and the battery bank at any time.

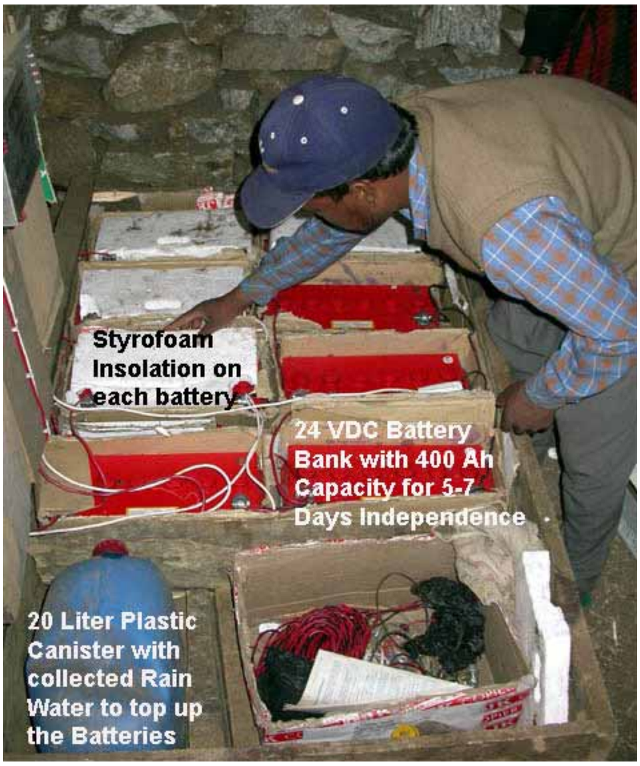


Figure 12-9: Chauganphaya Battery Bank 2
The Chauganphaya solar PV system battery bank, well insolated with a wooden box and Styrofoam.

For more detail information on the defined conditions under which the battery bank is designed to run, and the points considerate for the installation see in the Appendix 18.8.7.

12.8.7. Underground Cables and house wiring

In order to provide save power supply in the future during floods, snow storms and strong winds, all the cables from the central power system to the individual homes are installed 90 cm underground (under the ground freezing level). Further, because of acute local deforestation, and the short (approx. 3-year lifespan) of soft pine wood poles, overhead transmission lines are not considered.

Figure 12-10: Armored Cable 4mm^2, 2.5mm^2, 1.5mm^2
The three different sized armored (with galvanised armored steel wire) copper underground cables used in the Chauganphaya Solar PV System transmission lines. The 2 copper strings are with PVC insulated. Inside and outside is a PVC covering layer, providing additional protection. The cables are manufactured in Nepal.

Figure 12-11: Armored Cable 4mm^2
4mm^2, 2 strings @ 7 copper lids armored cable, able to carry 41 Amp and 1,100 Volt, at up to 70° C conducting temperature. .

For more detailed information and the technical specifications of the armored underground cables see Appendix 18.8.8.

12.8.8. WLED Lights

As explained, such an elementary electrification scheme requires that the lights considered have to be low power consuming, easy available, affordable, long lasting and not easy to damage or break (more in the Appendix 18.8.9.).

Figure 12-12: Nichia WLED Light
The WLED lights are manufactured by PPN in Nepal. One WLED light has 9 individual Nichia NSPW510BS WLEDs with an angle of 50°. The light can be moved around two axis to adjust the light beam inside the home.

Figure 12-13: Installation WLED Light 1
The house wiring and WLED light installation is part of the trainees training. Hands on experience enables the two persons, later on responsible for the solar PV system's running and maintenance, to gain practical experience and trust among the community. The final touch to the position of the WLED light is done together with the house owner, so that he can say where the light has to be focused on.

12.8.9. Fuse Protection

Traditionally glass fuses are used. As the Tangin village SHS experienced affirmed (see chapter 13), owners did not have spare glass fuses for the charge- and discharge-controller, or for the tube lights. They have tended to use metal strips to bridge fuses, jeopardizing the equipment.

For the Chauganphaya Village Solar PV System a new electronic fuse was developed in partnership with PPN. This electronic fuse is able to take the load of 60 WLED lights, i.e., 60 Watt, before tripping. Once tripped, the electronic fuse can be switched on again. The electronic fuse box, one per cluster, is installed in the cluster leader's home. He is responsible for his own clusters, and ensures that nobody uses unauthorized lights, or any other electric equipment, consuming higher power.

12.8.10. Lightning Protection

During the months of March and April, the spring season in Nepal, there are frequent electrical storms. Therefore the solar PV system in Chauganphaya is installed with lightning protection, with a spiky copper head on the roof of the powerhouse, and a rectangular copper plate, connected by a 10mm copper cable, buried ~1.5m under the ground, with salt and charcoal mixed soil on top of the plate. This lightning protection will be installed as soon as the unstable political situation in the region permits it.

Figure 12-14 depicts the similar spiky copper head installed on the roof top of the HARS Solar PV system at Simikot. Salt pieces (red bag) are prepared, and a 1.5m – 2m deep hole to bury the copper plate is dug in a place where the soil remains moist. Figure 12-15 shows the essence of the "spike-protection" system: a whole sack of charcoal, mixed with salt pieces is laid at the bottom of a hole. On top of that lies the square copper plate, which the 10mm copper cable connects to the spiky copper head on the roof. Then the hole is closed again with mud. In this way a good, moist and conductive area is provided, ideal for a spike protection.

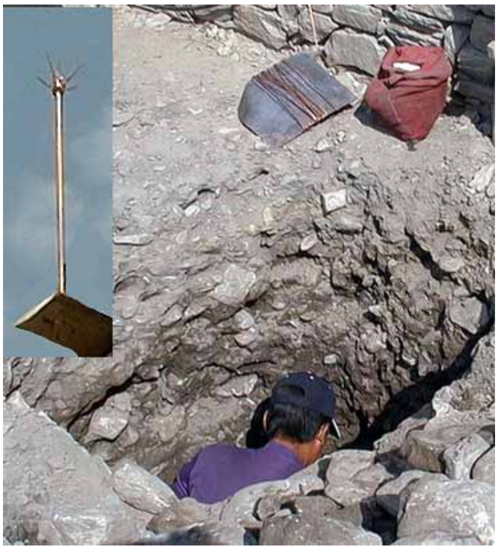


Figure 12-14: Lightning Protection 1
Spiky copper head, copper, salt

Figure 12-15: Lightning Protection 2
Charcoal mixed with salt provides good conduct.

12.9. Chauganphaya Village Solar PV System Mini-Grid

There are two options to reach the Chauganphaya village, either through a 16 day walk from the next road head in Surkhet, or catching a small airplane from Nepalgunj, in the south of Nepal, flying for one hour to Simikot, and then walking for one day, being the far more expensive alternative and for many not affordable.

The national electricity grid will not reach this village and all the neighboring villages for decades to come, if ever. Therefore solutions have to be found to enable local, or embedded, power generation. Therefore a mini-grid approach, defined by the village's size and location, is necessary. RAPS systems with a local mini-grid provide a good solution for such places. The 300 W solar PV system for the Chauganphaya village aims to be such a system.

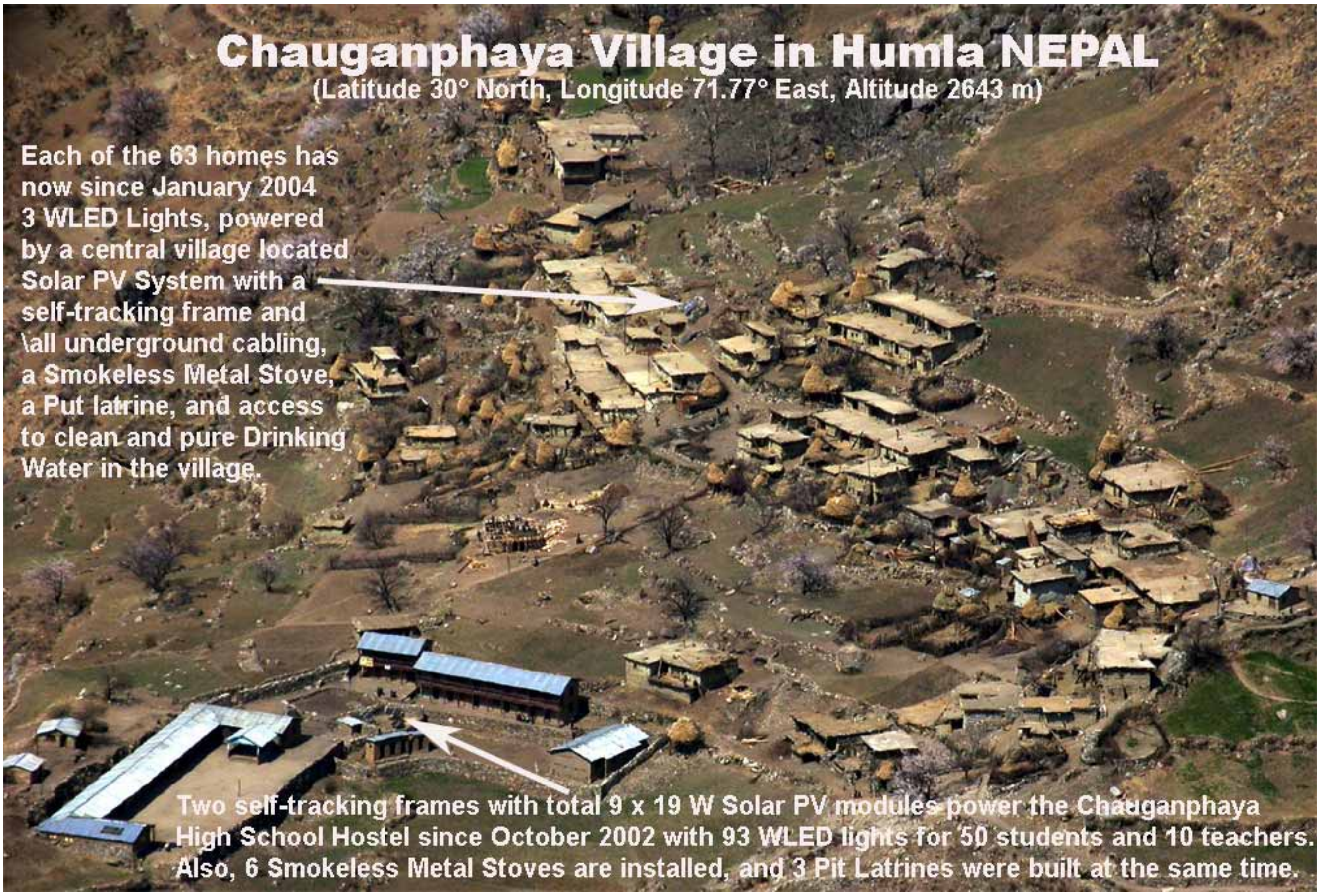


Figure 12-16: Chauganphaya Village, from its Eastern high Hill Range (pictured from an air distance of 1.3 km).

The electricity distribution arrangement explained above (see 12.8.7.) is safe against all anticipated problems, and it is environmentally sound. The buried transmission cables are sized such that the next 10 years' load demand growth, which may bring a doubled load, are accommodated. That can occur if the community recognises the long-term advantages that follow once light is in their homes, in regard to health, education, income generation potential, improved conditions under which in particular the women and children live, as well as their overall improved social activities.

To accommodate for this potential load growth is an important feature of a solar PV system which is designed with a life expectancy of 20 years. And for this community it is their very first experience of electricity and home lighting, thus they may learn fast and will desire increased access to electricity in some years.

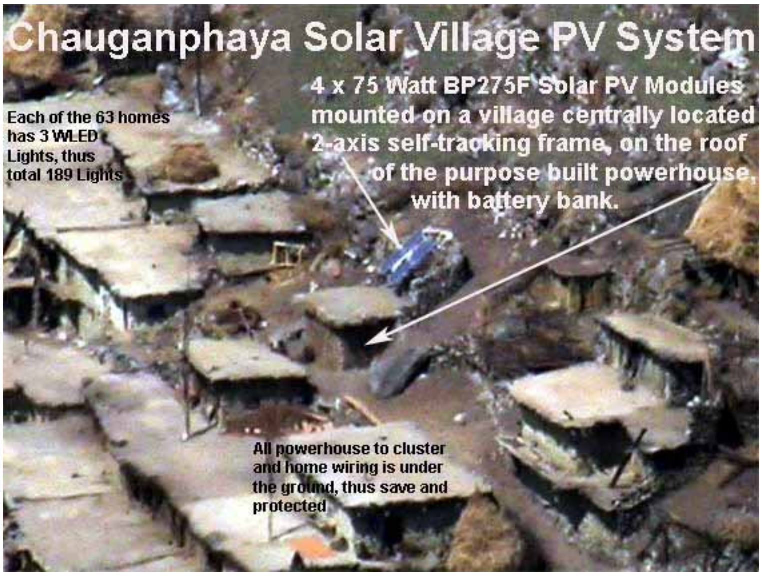


Figure 12-17: Chauganphaya Village Solar PV Power System
Chauganphaya Village solar PV 2-axis self-tracking frame and powerhouse. This picture is taken from an air distance of 1.3 km away on the high eastern side of Chauganphaya (see horizon line Figure 9-3, or Appendix 18.8.11. report page 2). As it is typical for this area, people build their homes very close to each other and on top of each other. That saves precious land for their agriculture land, which is their only means to grow food. The various wooden poles seen in the Figure on the flat mud roof tops are not for the transmission line, but are an indication that a shaman (a witch doctor) lives in that home.

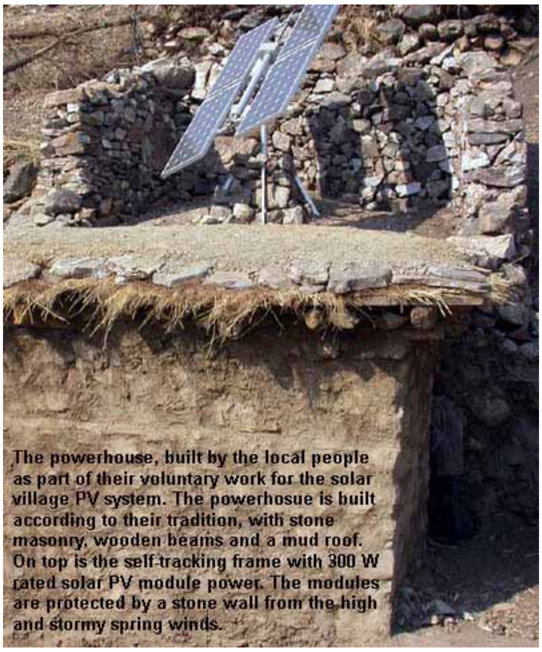


Figure 12-18: Solar PV Power House
Chauganphaya powerhouse with the 2-axis self-tracking Frame and four BP275F solar PV modules. The powerhouse has a flat mud roof, insulated with additional local available materials such as pine tree needles, and silver perch tree bark. At the edge around the roof, heavy slates are protecting the mud from being washed away.

12.10. Chauganphaya Village Solar PV System Installation

Due to the intense and difficult political situation in Nepal since 1996, it is very difficult to plan, organise and implement any work in the remote areas. The planning and designing of the Chauganphaya Village Solar PV System started in spring 2003, followed by various meetings with the village community, the eldership and the various political parties active in the region, in order to involve everybody from the beginning. Thus great care and caution was needed to make the beneficiaries aware of what changes the intended solar PV system and WLED lights will bring to their village and homes, and what they might expect. It was crucial that the people have a realistic expectation of what light in their homes might mean, with all its limits and benefits. They also needed to understand from the beginning that their participation was needed, in regard to positioning the powerhouse, providing land and local available materials for the building of the powerhouse. Further, their voluntary work in building the powerhouse, digging the trenches for the underground cables etc., as well as undergoing the maintenance training, and paying the monthly fee for the lights and for maintaining the whole system, is discussed and agreed upon.

Once the local people agreed to the conditions, a sponsor was searched. The manufacturing and purchasing of all the specified equipment started in June 2003, and from October 2003 onwards the equipment was transported by truck from Kathmandu to Nepalgunj and from there by aircraft to Simikot, in Humla. The local people carried all the equipment to the village.

Over the winter (November until February) a week-long solar PV installation and maintenance training course was given for 2 local people, as no digging for the underground cabling can take place.

The actual solar PV system installation work began in the first week of January 2004, despite a late snow fall. The two local trainees took part in the whole installation of the solar PV system, including house wiring and underground cable laying. Throughout the two weeks of installation at least one person from each family participated in the work.

Eventually on the 15th January 2004, for the first time in its history, electricity came to Chauganphaya. That night no thick smoke from burning “jharro” filled the houses, but small WLED lights shone dimly in the village darkness, and people gasped at the new clean lighting.

12.11. Solar PV System Performance and Cost Calculation

The Chauganphaya solar PV system performance and cost simulation has been carried out with two tools:

1. The PVSyst3.31 software packet containing the meteorological data file, generated with the METEONORM V5 software in a compatible output form.
2. With a designed Excel spreadsheet, Life Cycle Cost Analysis, (based on Markvart's chapter "Life Cycle Costing"[133]) which can be consulted through the following link:

Chauganphaya Excel Simulation

The PVSyst3.31 is a software packet in which all the above chosen and defined equipment, its technical parameters and individual costs, can be input in great detail. A final summary report provides the main simulation data for the technical characteristics and performance of the solar PV system, the overall solar PV system costs, the generated energy cost, and maintenance cost. Also a fullness of information can be extracted from the simulation results through the generation of user defined tables and graphs. The main result undoubtedly is the kWh unit costs of the generated energy, which is 200 NRp/kWh, or approx. US$ 2.86/kWh. For the 5 page summary report of the simulation see Appendix Chapter 12.11: *PVSyst3.31 Chauganphaya Village PV System Simulation Report*.

The comparable main result from the Excel simulation for the generated energy kWh unit costs, with an excess inflation rate of 2% and a discount rate of 5%, is 212 NRp/kWh (a 6% difference).

Page 3 of Appendix Chapter 18.8.12: *Excel Spreadsheet Chauganphaya Village PV System Cost Simulation,* shows that the final kWh unit price depends rather strongly on the excess inflation rate, and discount rate assumptions. But with realistic rates the difference between the *PVSyst3.3.1.* and the *Excel spreadsheet* varies between –3% and +20%, which is still within an acceptable range. The monthly needed payment of 72 NRp per household, based on a 20 years life cycle cost calculation, is also included.

12.12. Solar PV System Maintenance

Two local people have undergone a week long training in how to maintain the Chauganphaya Village Solar PV System. They have further been trained to recognise any deviation from the normal conditions, such as low battery voltage over extended time, or low battery electrolyte level in the batteries. They are able to solve some problems, such as topping up the batteries with collected rain water, and they are trained to write down and report others to the HARS in Simikot.

They have the tools they need most, including a multimeter, screw drivers, pliers, hygrometer and Excel sheets on which they record battery bank voltage, and daily check ups and data recording. At any time the maintenance person has to have 5 spare fuses at hand for the battery bank charge and discharge controller, and about 5 new WLED lights, in case one or more have a defect and have to be sent to Kathmandu for repair (which can easily take one to two months). One roll of simple house wiring cable is part of the maintenance equipment, in case a reconstruction of an existing house, or a newly built house, has to be added to the mini-grid.

During the one week solar PV systems Installation, Operation and Maintenance training program, the following topics were addressed in very elementary ways:

- Solar PV Module: what is a solar PV module, how to keep it clean (twice weekly before sunrise or after sunset), and how to check whether it is in the right direction under the sun.
- Battery: what is a battery, and how to measure and record the battery voltage. How the battery bank is kept well insulated, clean and free from mice. How to check each batteries' electrolyte level, and how to top it up with rain water. How to collect and store rain water for topping up the batteries.
- Wiring: checking the connections of the underground cabling to the discharge controller, the solar PV modules to the charge controller and the charge controller to the battery bank.
- House wiring: How to measure DC + and -, how to connect a WLED light, a light switch, and how to insulate a wire connection.
- Protection: How to change the glass fuse in the charge and discharge controllers and how to switch a tripped electronic fuse on again.
- Collection of the monthly fee to be paid by each family (which was initially defined by the community to be 10 NRp/month), and how to open a bank account and keep accounts. How to keep a list of all the maintenance work and the spare parts exchanged and bought.
- How to contact with the project staff in case an unforeseen problem arises.

12.13. Fee Payment

In order to have a solar PV system fully sustained and operated over its entire expected life time (usually 20 years), it needs to be maintained and repaired. That needs manpower and some materials, which both have a cost. As every family has 3

WLED lights it is assumed that during the course of a month, every family consumes about the same amount of energy. Thus there is no need to install unit counters. The monthly fee which needs to be paid has been calculated with the Excel spreadsheet, including all the recurring costs such as battery bank renewal after about 8-10 years (the old batteries need to be brought to our HARS office in Simikot in order that we can get the batteries recycled), solar charge and discharge renewal after 10 years, etc.

These costs, including the yearly amortisation cost for the whole solar PV system, amount for each family to 72 NRp/month (see chapter 18.8.12., Excel Life Cycle Costs). The same cost calculation done in PVSyst3.3.1, amounts to 64 NRp/month, or 12.5% less, despite the same input data. The calculation thus suggests that each household should raise about 70 NRp/month to make the solar PV system sustainable. As this amount is far too high for all of the 63 families according to the interviews and committee meetings, the monthly fee payment has been calculated without the initial investment costs, as the needed investment funds have been raised through a donor organisation. Thus it is assumed that beyond the life expectancy of the solar PV system, a donor agency will be again willing to provide the hardware cost of a new solar PV system for the village.

Further, the major recurring cost is the battery bank, which has to be renewed after 8 - 10 years (see Appendix 18.8.11., page 5 provision for battery replacement after 9.6 years). If assumed that a sponsor can be found to come up with this one time cost throughout the project's 20 years life expectancy, the needed amount to be raised from within the community becomes much more reasonable. As a trained person has been put in charge of the solar PV system, this person is expected to be paid a minimum monthly wage, of about 300 NRp/month (4.3 US$). With these above stated assumptions, the actual monthly fee payment limits itself just to the recurring costs of solar charger and discharge controller, the broken switches, and the maintenance person's monthly salary, throughout the project's life. That amounts to about 8,600 NRp/year. That means for each household a monthly fee for the electricity of about 11 NRp (0.15 US$), which is the maximum economic capability of most of the households in Chauganphaya (as the committee members also defined). That monthly fee for the electricity for the 3 WLED lights in each home is collected by the trained maintenance personal. The funds are put into a bank account in Simikot (a one day's walk away) from which all the above mentioned expenditures are going to be covered (i.e., except for the basic solar PV System and battery bank replacements).

A long-term follow-up schedule agreement with the local community is integrated into the whole project. This provides a high degree of proper maintenance of the solar PV system for the first 2 - 3 years until the new technology has its firm place within the community, and those maintaining it have gained the local people's trust and are fully capable of caring for this elementary solar village PV electrification system.

One can say, that for a place like Chauganphaya, a solar PV electric lighting project is not sustainable without considerable initial subsidy for the hardware, the installation and to some extent also for the maintenance and replacement of some equipment. The elementary Chauganphaya solar PV village system is one of the first projects of its kind in such a context, and there remains a lot of work to be done in keeping track of how the system performs and how the people learn to live with the lights and the other implemented projects alongside (stove, pit latrines and drinking water). Only after some years will it be possible to have this detailed and realistic knowledge, with all the shortcomings and benefits.

But now is the time to begin thinking how the availability of local electricity and lighting inside their homes can be a springboard for potential new income generation, in order to earn the (maybe more complete) monthly fee payments, as well as more income for the running of households, the education of children, and health care.

12.14. Holistic Project Approach

The solar village PV system described in this chapter is part of a more holistic ongoing (long-term grass-root) community development project in Chauganphaya. Light in homes, though of prime concern, is only one aspect of a holistic community development project and does not stand in isolation. There are four integral parts of this whole project, each supporting the other, and the other three components are:

- Smokeless Metal Stove
- Pit Latrine
- Drinking Water

These 4 projects have to be seen as a very close integrated part, supporting each others' long-term benefit multi times over. For more details on these three integrated protects, with Figures see in the Appendix 18.8.10.

12.15. Community Participation

It is important that not just any outside party or organization comes to a village, intending to start a project according to their strategy and donor interest, which are mostly pre-determined opinions of what the local communities need. It is crucial to involve the local people in every step, from the initial meeting, where ideas are exchanged, to the defining of where tap stands are going to be built, how many lights are needed in each home, to where the pit latrines are going to be built.

Further, in order to create a strong project ownership feeling among the local community, they have to participate in each project with some cash as well as sweat work, as part of the overall budget. Thus in the holistic community development project with the Chauganphaya village community, the local people paid 2,500 NRp towards the smokeless metal stove, carried all the materials for all projects, and dug all the trenches for the underground cabling.

Further, at least one person per household had to participate in the 3 days pit latrine training, beside organizing all the local materials for the pit latrine, as well as building the pit latrine under the project's supervision and advise. Two people were trained in the solar PV system maintenance and monthly fee collection.

All-in-all the Chauganphaya community participated in the overall project value (actual costs plus calculated labour cost) with around 35 %. That makes them proud to have achieved in partnership with a project significant changes in their own village. They feel that they are now the owners of their village solar PV system, their stoves, pit latrines and drinking water system.

However, that is by far no guarantee for a 100 % successful project, especially over a long-term period of one to two generations (which is 10 – 20 years in this area), but this approach presents important steps towards higher appropriateness and sustainability.

13. Case Study of the Tangin Solar PV Home System Project

Just a 3 hours walk away from the Chauganphaya village in Humla, lies the Tangin village, which was visited in October 2002, shortly after solar home systems (SHS) were installed in most of their homes. This chapter highlights an interview, with one of the owners of a SHS in Tangin, 1 ½ years after the installation, in order to get relevant feedback.

13.1. Tangin Solar PV Home System Equipment and Project Implementation

In August 2002 (Saun 2058 according to the Nepali calendar), a private solar PV company from Kathmandu had been given the contract to install SHSs for the Tangin village in Humla. Each SHS received a Government subsidy (from the DDC, VDC and HMG) of NRp 21,000 (or 87.5% of the total SHS price). In total, 38 homes out of 40 homes, were installed with a SHS in Tangin under this project.

"The aim of the SHSs, from the subsidy providers and solar PV company point of view, was to provide electricity for lights only", said Mr. Sonam Lama, an owner of one of the SHSs in Tangin village.

Each SHS cost NRp 24,000 (343 US$) at the time, which was paid for in the following way:

- Each family had to participate with NRp 3,000 (43 US$).
- The Governmental institution DDC (District Development Committee) paid NRp 4,500 (64 US$).
- The Governmental institution VDC (The Village Development Committee) paid NRp 4,500.
- The HMG supported SHS subsidy program paid NRp 12,000 (171 US$).

The following equipment is used for each home:

- A 20 Watt solar PV module, (some are a-Si Siemens and some are 20 Watt multi-crystalline modules) mounted on a fixed frame at 30° - 45° south oriented.
- A solar charge and discharge controller.
- A 40 Ah deep cycle Gel battery from Trojan.
- Three 15 Watt fluorescent tube lights, each with a on-off switch.
- Normal house wiring cables.

(see Figure 13-1 in the Appendix 18.9.1., which was taken in October 2002, some 3 months after the installation).

13.2. Interview about the Tangin Solar PV Home System 1 ½ years after its Implementation

In March 2004, a bit more than 1 ½ years after the initial installation, a visit was planned to Tangin village, in order to investigate the SHSs conditions, and to interview roughly 10 families, arbitrarily chosen, asking them 10 questions, under the following categories:

- ***Performance of the SHS***
- ***Maintenance and management of the SHS***
- ***Experience and suggestions***

Unfortunately, due to the politically unstable situation in Humla at the time, and raising tension in the relations between the Government troops and the Maoists, an actual visit to Tangin village was not possible. The next possible solution was to meet Mr. Sonam Lama, a young man from Tangin, right in Simikot. He kindly agreed to an interview with the writer (Alex Zahnd) and Govinda Nepali (the Humla project staff manager), to answer all the questions. The interview was held in Nepali language and translated by the writer into English. In the following summary the main points of the interview are highlighted, while the full interview, the 10 questions and all the detailed answers provided by Mr. Sonam Lama, are added in the Appendix 18.9.1.

A. Performance of the SHS

- No problems faced with the solar modules.
- Outdoor wires have cracked insulations.
- Too short life span of the fluorescent tube lights.
- Charge controllers broke with no spare parts available.
- Batteries showed clear decline in their capacity.

B. Maintenance and management of the SHS

- No follow-up since the installation by the installed or subsidy provider.
- No training of local people for maintenance has been provided.
- There is an inactive SHS committee.
- No monthly fee is raised for a maintenance fund.
- No life expectancy or performance of the SHS has been provided initially.
- No spare parts are available.

C. Experience and suggestions

- The evenings in particular have become much more meaningful with light in the home.
- Basically, people are satisfied, though their expectations were different.
- There is a request for training and some basic tools for maintenance.

13.3. Other SHS Installation Experiences

The answers from Mr. Lama from Tangin are very similar to the investigation WLG (Wisdom Light Group) and WECS (Water and Energy Commission Secretariat, Kathmandu) undertook in 1995, and Ganesh Ram Shrestha, from Centre for Rural Technology (CRT) published on the Internet in the form of a paper called: *Some Experiences With Practical Implementation of Photovoltaics Solar From Nepal*, [134] The paper mentions that the main benefit perceived by the households were related to improved health and sanitation (in the sense of generally improved hygiene) as well as increased study time for the children. Shresta also indicated some technical and institutional barriers, which exist related to the dissemination and market expansion of SHSs. The main constraints as indicated by him, are the high initial capital cost for a SHS, and poor promotional strategies. Listed below are the main technical hold backs, observed by Ganesh Shresta. As is clear, they are parallel to the Tangin SHS project's experience.

Technical

- High initial financial investment required to own a SHS.
- Failure of lights and charge controllers are common problems.
- Inadequate network of technical back up services for timely repair and maintenance/replacement of components.
- Technical limitations (low power conversion efficiency, climatic uncertainty, difficulty for transfer in remote location).
- Lack of "trained" technicians and promoters specially in the potential districts.

13.4. Conclusion and Recommendation

During the initial visit to Tangin village in October 2002, the SHS installation were looked at, including the quality of the used materials. This field visit and Mr. Lama's answers provide several important points to be considered for a project in a remote location in general and for a SHS project in particular. They are summarised in the following list.

The issues to be address and the recommendations given are:

No.	Problem Realised / Identified	Possible Approach / Solution
1	The local community and the other stakeholders (in the Tangin village case the DDC, VDC, HMG and implementing solar PV company) do not really know each other. The local people are not aware of the scope of the solar PV project / SHSs, and the other stakeholders do not know what the local community expects.	The benefiting community has to be involved from the very early beginning, by stating their intention to have a solar PV system (or SHSs) installed in their village and their willingness to participate in the overall budget as well as work implementation. This request has to be in written form and signed by each house owner or head of each family of the village. (This is one of the most important steps, as this shows their intention and willingness, and gives the local people from the start a proper ownership feeling over the whole project, as it has initially "started" in their mind!)
2	A lack of ownership feeling for the solar PV system / SHSs.	In an initial meeting with the village eldership (the main body of the social and political village leadership), the actual formalities and project procedures have to be discussed. Interest groups can be formed to increase the local people's participation and responsibility. This enables the local people to participate and input their ideas, formulate their expectations and apply their expertise right from the start.
3	The local people cannot fathom how much light and for how many hours a day the SHSs will provide light, so expectations are unrealistic.	During the initial meeting the actual lights are demonstrated to the people, in order to show them what light services will be provided in terms of light output, numbers of lights and amount of hours a day. It will be defined what the solar PV system can provide, its life expectancy, and need for ongoing maintenance.
4	The solar PV modules are shaded, installed at different angles and in different directions.	The solar PV module(s) have to be properly positioned, able to bear any possible storm. PV modules have to be cleaned 2 - 3 times a week before sunrise or after sunset (part of the training), as a rule of thumb PV modules are installed inclined according to the latitide + 5° - 10°.
5	Batteries are installed in a cold place. Many batteries are not providing the initial capacity after the first winter months.	The battery bank is installed in the kitchen in a locally made wooden box with a lid and insulated with the original packing material (carton box and styrofoam cover) as well as local available insulation materials such as silver perch tree bark and pine tree needles. With an approximate kitchen room temperature (in these remote high altitude areas) between 10°C and 25°C throughout the year, this keeps the battery temperature range within an acceptable limit of approximately 15°C - 20°C, which is a good temperature range for a good performance of a battery.

6	Broken fuses are not replaced, or instead metal strips are installed.	Some spare fuses and some new lights, for immediate exchange in case of failures, need to be at hand at any time. Electronic fuses provide be an appropriate alternative.
7	Tube lights turned dark at the edges within a few months, and many lights can only be run for half the time after a few months. Tube lights break easily.	Consider installing only high quality lights for remote areas. Consider installing low power consuming lights. Consider installing lights which are affordable, and not easy to damage or break.
8	The cabling from the solar PV module to the battery are free hanging through the air, and after 1 year the wire mantle insulation started to crack, so that the copper wires are visible.	UV stabilized cabling (though very difficult to get in Nepal). Underground wiring, or in HDP pipe protected cabling. Or one solar PV system per house. One roll simple house wiring cable has to be part of the maintenance kit, for repair, or in case a reconstruction of an existing house, or an additional new building which has gone up has to be electrified.
9	No maintenance is done on the SHSs.	The village community chooses 2 – 4 people (from both gender) from their village to be trained (through a formal training) in the implementation and maintenance of the solar PV systems. They have to participate in the actual implementation of the project in their village. That gives them first hand on the job experience and additional knowledge of the local conditions. Further, it establishes an important relationship between them and the local community. They will be respected as the ones to carry the responsibility to maintain the solar PV system, and collect the monthly fee.
10	No tools are available to maintain and repair the SHSs.	The trainees are provided with the needed tools as part of their skill training. The tool box can include e.g.: A multimeter, a screw driver set, a fixed spanner set, a pliers and insulation tap to repair any small wiring problem, a 20 liter plastic canister with a funnel and a big plastic washing basin, to collect pure rain water to top up the battery bank periodically, spare fuses for the charge controller. Prepared worksheets, to input the battery bank voltage periodical (best daily), can additional bring great benefit for the long-term performance evaluation as well increased interest of the people in their SHS.
11	There are no funds available for maintenance or repair, after the initial installation.	A monthly fee (with the actual amount decided by the established village based solar PV group) for the electricity consumption of each home, is collected by the trained maintenance personal. The funds are put into a bank account. With these funds the maintenance, any repair or battery exchange, and salary cost for the trained maintenance person has to be covered.
12	The SHSs are not sustainable.	A long-term follow-up schedule, mutually decided by the local community and the implementer, is planned into the whole project.

Table 13-1: Issues to address and Recommendations for Solar Home Systems

14. Chauganphaya Village Solar PV System Performance and Experience

On the evening of the 15th January 2004 the Chauganphaya village community had for the first time in its history electric light inside their homes! In March and April the whole system was checked and the people were interviewed regarding the whole system's performance, and the success or otherwise of the WLED lights. In July a second visit was planned, with additional interviews and data gathering. But sadly it has not proved possible to visit Chauganphaya village since April 2004 due to the intensified war situation between Government troops and the Maoists.

Nevertheless is was essential to evaluate the whole project: the performance of the solar PV system, the local people's experiences with 5 hours of home illumination per day, the smoke-free rooms, the pit latrines and the new access to drinking water. Not knowing how the political situation would deteriorate, it had been intended to discover as much as possible about the lifestyle changes that were occurring in the village, and the impact of the projects. Therefore, eight months after the solar PV system had been installed and the linked projects were completed, various people from the village were asked to travel (sometimes under life-threatening conditions) to the HARS office in Simikot to relate their experiences and to share their comments and suggestions about the ambitious improvements.

The following two sub-chapters summarise the important point-by-point issues that the Chauganphaya village people, including our own two "technicians", shared in regard to various suggestions concerning the new solar PV system and all its associated parts, and the impact it had on their lives over the previous 8 months.

14.1. Chauganphaya Village Solar PV System Experience after 8 Months

1. One of the four clusters, which had been planned to be maximum 200 meters away from the powerhouse, ended up being about 350 meters away. That was partly because of the local geography and partly due to unforeseen changes during the installation phase to the wiring plan. That resulted in a too high a voltage drop of 4VDC at the 4th cluster main house, giving it a supply voltage of only 9VDC. The armored underground cable (4mm^2 sectional area) has 4.8Ω/km specific resistance. Over 350m that results in 1.68Ω resistance.

   If approximately 30 WLED lights are in use in the cluster, with each lights consuming 1 Watt, that results in a current flow of:

   - 30 x 1/12.8 = 2.34A, where 12.8V is the mean battery voltage.

   Therefore the voltage loss V = I x R is:

   - 2.34A x 1.68 Ω = 3.94VDC.

   Therefore the resulting line voltage is approximately:

   - 12.8VDC - 3.94VDC = 8.9VDC.

   That is not enough to provide the 18 homes in that cluster with total 54 WLED lights with enough voltage to bring forth the WLED lights' full illumination. There are two potential remedies which can be applied on returning to the village.

   a) Reinstall this cluster line connection with a more direct, maximum length of 200 metres from the main power house. Then the voltage drop will be about 2 to 2.5VDC, or 11 - 11.5VDC, just right for the WLED lights, as the lights comprise 9 diodes, 3 are in series and 3 series circuits are in parallel, so each group of 9 diodes needs 3 x 3.6VDC = 10.8V.

   b) Or, install a second underground cable of the same 4 mm^2 section, to run parallel to the existing one, so doubling the section and halving the losses.

2. Two WLED lights had to be replaced due to loose wire connection between diodes and the circuit board. These were returned to Kathmandu for repair and sent back to the HARS in Simikot as spare parts.

3. Several families (exact number is not defined), from the 4^{th} cluster with the low voltage and thus the reduced WLED light output, requested for brighter WLED lights.

4. All the other 3 clusters and WLED lights are working well and the families are satisfied. No "jharro" is used anymore for lighting purpose.

5. The WLED lights are in use daily during 06:00 – 09:00 AM in the morning and during 18:00 – 20:00 PM in the evening, thus for approximate 5 hours a day. One of the two trainees is switching the main lines to the clusters on and off for these times. If an expected 75% of the WLED lights are on during these 5 hours, a total daily load of about 709 Wh is consumed.

$$189\, WLED\, lights \times 5\, hours\ per\ day \times 0.75 = 709\, Wh$$

which is slightly higher (1.3 %) than initially designed (700 Wh average daily load). But that is still within the expected daily load range the whole solar PV system is able to cope with.

6. The battery bank inside the power house has been throughout the first 8 months (out of which 4 months were during the monsoon) between 13.5 VDC maximum, and 12.3 VDC minimum.

7. The 2-axis self-tracking frame with the 4 x 75W solar modules mounted has worked well during the 3 seasons, winter (January - March, with snow fall), the spring (with the sudden gusts and thunderstorms) and the summer (June – September, with the monsoon's sometimes day long rain falls).

8. Each of the 63 households is participating in the periodical (usually monthly) maintenance fee of NRp 10 (0.14 US$) from March 2004 onwards. By the end of August NRp 3,500 (US$ 50) have been collected and put in the newly opened bank account, in the bank in Simikot, a one day walk away.

14.2. Main Impact and Changes experienced in the Chauganphaya Village Community

1. Each day the children in most of the homes study now for about 2 hours more. The local school teacher said that he could see already after 6 months a clear difference in the students academic achievements and interest, due to their increased evening reading and ability to do their homework.

2. The people can cut now the fire wood also in the evening inside the home, and they consider that as an advantage.

3. People have more social gatherings in the evenings. This is considered as a positive impact as more village issues can be discussed in depth.

4. The awareness-raising program about pit latrines has not yet had the full impact that was expected. People are not finding it convenient to wash after using the pit latrines. This could perhaps be rectified by installing another water outlet and providing more awareness and "how to use" training.

5. The smokeless metal stove is popular and appreciated for the preparation of their daily food, as it cooks their staple food (rice, lentils and one vegetable curry dish) all in one go. It takes all the smoke, previously remaining inside the home due to open fire place cooking and heating, outside the home. That improves the health conditions, in particular giving respite from respiratory chest diseases. Children are safer and are no longer burned by open fires. People have suggested to overlap the edges of the top metal stove plate by about 20 – 30 mm to have slightly more top surface for the pots and pans.

15. Striving for Appropriateness and Sustainability

15.1. Introduction

For projects in such remote and impoverished areas it is crucial that they are designed and installed with a long-term view. This implies that the local communities have to be involved as the key stakeholders from beginning to end. It also means that the technologies applied have to be appropriate and sustainable for the context.

“Appropriate” and “Sustainable” are two very important words that unfortunately often are used too loosely in the context of development work. They are not mere words but rather stand for whole concepts and ways of how one can approach projects such as the Chauganphaya Village Solar PV system. I suggest we take a closer look at these concepts.

15.2. What then is "Appropriate Technology"?

Coming out of experience, the following are some short definitions of what appropriate technology means in the context of development of remote and impoverished communities.

1. ***Technology, which is suitable, fitting and apt for a particular situation, and for a particular people group.***

   Example**: Rural electrification of a remote village**. In remote mountain areas, with no access to roads for days on end, it is unlikely that a diesel generator will be appropriate to provide energy services to a community. Rather, a survey is conducted to assess what energy sources are available in a given community, what resources have already been tapped into thus far, and based on that experience and confidence look into possibilities of tapping into hitherto untapped energy resources. Naturally, the locally available renewable energy resources such as water, sun and wind, provide good, reliable and long-term energy resources for the community.

2. ***Technology has to be contextualised, since it is the COMMUNITY and not the TECHNOLOGY that is the main focus.***

   Example: **A stove project for a village.** As we have seen in Chauganphaya, the people cook on open fireplaces (see Figures 4-6, and 4-6), resulting in a house full of smoke leading on to inevitable lung problems. The need for a smokeless stove becomes apparent, but instead of installing just any kind of smokeless stove available on the market, it is important to have one that is appropriate for the context. For this we take a closer look at the given community to understand the local people's food and eating habits and what is locally available. Further, it is important to look into the possibility of other functions the stove has to fulfill, such as providing heat in the winter and hot water for washing and drinking. Such issues are better understood by living, and discussing, with the local people. With the information gathered, an appropriate smokeless stove is designed and the engineering task begun, to develop a stove to fit the needs of that community. This approach was followed in the case of the smokeless metal stove installed in the Chauganphaya village (see Figures 12-27 and 12-28 in Appendix 18.8.10.) alongside with the solar PV system for lights. The stove now serves, both as a cooking and as a heating facility. It has been so designed that the local people can cook their traditional food the way they like it, have hot water to wash and drink, and all these services with 40% - 50% less fire wood consumption.

3. ***Appropriate technology aims for better living conditions, to raise the living standard of people.***

   Example**: A holistic community project in a remote village**. The key to a successful community development project lies in understanding what the community actually thinks they need. In order to do this one needs to live in the community and initiate healthy discussions and exchange of thought (see Figure 15-1). Thus, it becomes clear as to what the community considers to be their most urgent needs, rather than being dominated by an organisation's schedule or plans.

In this way, the collaboration of the local peoples can be taken for granted, as it was they, who have defined their needs in consultancy with the project/organization. Only through such a process can a realistic project plan and approach be worked out. In this way the local people are in the center of the project's interest, and the technology applied is to serve them.

Figure 15-1: People are in the Center of a Project's Interest and the Technology applied is to Serve Them. Village elders meet with project staff to discuss their most urgent needs, and project staff share their capacity and ability. In this way mutual understanding is established through dialogue right from the start.

15.3. Striving for Sustainability

Projects, which inspire and motivate other communities, after they recognised that their neighbors are living in changed and improved conditions, and projects which can be replicable, are on the right track towards sustainability. For most, though in particular for rural electrification projects, a detailed community and household level survey must be conducted. Through such a survey the right balance between the community's needs, their desire and the market price for energy services can be determined. This enables one to start out on a realistic basis, that is both affordable and manageable for the community and therefore will be more sustainable.

Four categories of sustainability have to be considered:

1.Technical and Operational Sustainability

- Reliable components and systems.
- Sound design of system configuration.
- Local capability for O & M services.

2.Economic and Financial Sustainability

- Least-cost preferred systems.
- Services that match consumer ability to pay.
- Revenue collection and control system.

3.Social and Institutional Sustainability

- Equity participation by stakeholders.
- Training of consumers in system use, safety and maintenance.
- Cultural acceptance by end user.

4.Environmental Sustainability

- No ecological impact through installation and operation.
- Removal/recycling of batteries, lubricants.

15.4. Obstacles to Sustainable Projects

Each project aiming to serve the marginalized and poor communities faces potential downsides and disappointments for all the stakeholders involved. To know these areas ahead of time, enables one to raise awareness in time, and strengthen the base on which the partnership is built upon. Some identified potential obstacles are:

- Based on false understanding there is an expectation that energy services must be delivered free of cost by the project.
- The high capital and transport cost, especially if the community is in a remote and difficult to access area.
- Deep-rooted poverty.
- Minimal and poor education/knowledge of the local community in regard to the solutions/technologies, which can meet their needs.
- Lack of an institution or local group to install, service and maintain (e.g. through raising periodical payment collection from the end users) the project.

15.5. Need for Capacity Building

Being able to do a defined job in appropriate and satisfactory ways as part of a whole project is crucial for each stakeholder. As the jobs to be done demand different skills, it is important to recognise that the right capacity must be built in, for the right person or organisation.

For instance, the implementation of a community solar PV village system should be undertaken in close partnership with technical and managerial experts such as a suitably qualified NGO or an entity, who has the necessary skills and experience to install the system professionally. The local people appointed by their community to look after and maintain the project, need to be properly trained to do so. They must be able to check the batteries, wire system, clean the lights, and advise the consumers as to how they can use the energy services. They also need to know where they have to go to for advise when a new problem arises. On the other side of the spectrum, a Government department dealing with the implementation of a SHSs program for a country needs to be able to develop suitable and applicable policies on how such a program can be implemented. That includes setting policies and regulations on the scope, time frame, and the ways as to how such a program can be financed through subsidies and loans. They have to be skilled in knowing how to enforce these policies and to make sure all the stakeholders in that program adhere to it. They should not be considered as suitable entities for the implementation of projects. All involved at one stage or the other in a project, need to be able to succeed in their job and responsibility, to the satisfaction of all stakeholders. In order to achieve that, each one needs to have the capacity to be successful.

Capacity building can be defined as:

> "The development of an organisation's or individual's core knowledge, skills and capabilities in order to build and enhance the organisation's or the individual's effectiveness and sustainability. It is the process of assisting an individual or group to identify and address issues and gain the insights, knowledge and experience needed to perform effectively." [135]

Capacity building can be facilitated through the provision of:

- Awareness raising, education and training (formal and on-the-job).
- Technical support activities.
- Specific technical assistance and periodical follow-up.
- Resource networking and sharing of experience.

Capacity building is recognised as being a long-term, continuing process, in which all stakeholders participate. Capacity building is required across many sectors, organisations and groups. The capacity building that is required is diverse and the actual requirements vary according to a country's context and people group.

An approach to capacity building e.g. required for a country wide village electrification program through renewable energy technologies, aiming to provide appropriate and sustainable energy services to remote communities, include developing skills and knowledge in the following areas:

- Awareness raising.
- Understanding the existing policies and regulations, and if needed to motivate and start new regulations initiatives.
- Assessing the locally available renewable energy resources.
- Evaluation and selection of technology options.
- Preparation of business plans.
- Development of financial schemes (subsidies, loans, credits).
- Skill resource assessments.
- Investment promotion and donor relationship.
- Project financial accounting.
- Technical advisory service networking.
- Product development and testing.
- Establishment of community based user groups.
- Set tariff structures.
- Develop reporting and presenting skills.

15.6. Characteristics of Successful Appropriate Technology Projects

Through practical experience and observation of other implemented appropriate technology projects, a range of issues and approaches have come up again and again, which are seen as crucial for the support of long-term success and sustainability of such projects. They are:

1. The needs of all stakeholders must be met. Stakeholders are the end user/consumer, the installer, the financing parties/donors, the equipment dealer, operator, service and maintenance provider.
2. Strive for the best mix of: Least-cost, preferred by the community, appropriate, and sustainable.
3. The local community participates from the start to the end, and beyond the project. Thus they are involved right from the planning stage, decision making, to building, to installation, commissioning and on to operating and maintaining (technical as well as financial).
4. There is always an appropriate O & M, as well as a basic accountancy training for local people included, to enable them competence in operation and maintenance (technical and financial) of the installed projects.
5. The local community/end users defines the "Rules of the Game". They are made responsible to define, implement and keep a check upon the rules and regulations that they themselves set in place as to how to run the projects both before and after the commissioning has taken place. In that way they feel responsible and are capable within their means to give, both the needed time and finances to keep the projects running long-term.
6. There needs to be effective cost recovery systems, such as through periodical payments/fees, in place, in order to have a win-win situation for all stakeholders, especially the consumers.
7. Sustainability has to be considered before efficiency. There is little use of a highly efficient piece of equipment e.g. in a rural electrification system, if it fails after several months due to the harsh conditions it is exposed to.

8. New activities and opportunities are created within the community through an implemented project. Such as, income generation possibilities, evening non-formal education classes for adults, community gatherings to discuss development issues etc.

9. Successful projects are designed to reduce dependence on foreign agents for supplying equipment and fuel. Technology transfer components must be built into each project, ranging from local manufacturing, marketing, and distribution, to effective training for O & M services.

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[1], http://www.nepalinformation.com/, http://www.indexmundi.com/g/g.aspx?c=np&v=79

[2] The statistics for the remote areas are from the writer's own survey data over a 8 years' time span (1996-2004) working in the remotest parts of Nepal.

[3] E. Mills, *The $230-billion Global Lighting Energy Bill"*, Lawrence Berkeley National Laboratory, 2002

[4] IEA, *World Energy Outlook 2002*, chap. 13, page 373

[5] IEA, *World Energy Outlook 2002*, chap. 13, page 365

[6] IEA, *World Energy Outlook 2002*, chap. 13, page 365

[7] IEA, *World Energy Outlook 2002*, chap. 13, page 372

[8] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 13

[9] IEA, *World Energy Outlook 2002*, chap. 13, page 366

[10] ; *Smoke, The Killer in the Kitchen,* Indoor Air Pollution in Developing Countries, Hugh Warwick & Alison Doig, ITDG Publishing, ISBN 1 85339 5588 9, page 6

[11] The World Bank, International Monetary Fund, in their *Millennium Development Goals,* September 2000, http://www.developementgoals.org

[12] The World Bank, International Monetary Fund, in their *Millennium Development Goals,* September 2000, http://www.developementgoals.org

[13] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 13

[14] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 13-14

[15] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 14

[16] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 23

[17] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 23

[18] This relates in particular to poor communities which are accessible by road or vehicle transport, where diesel generators can be installed relatively easy and quick, and where the diesel fuel is available. Diesel fuel in many countries enjoys still a heavy subsidy, thus distorting the actual final price of installed kW and generated kWh. In comparison, just the solar PV modules still cost around US$ 5 per Watt output power, in addition to the BOS (balance of system) and installation cost. Installed micro-hydro power plant cost between US$ 1,500 – 6,000, the former a more international price, the latter the average installation cost of micro-hydro power plants in Nepal during the years 1980 - 1995.

[19] The Chauganphaya elementary electrification system is laid out in such a way that it can be doubled in size over the next 5-10 years, once the peoples have understood the benefits of having lights in their

homes and are willing to raise the funds to extend the system for additional electricity consumption such as a radio or battery charger, or increased electricity consumers.

[20] *Energy, Poverty, and Gender,* A Review of the Evidence and case Studies in Rural China, The Institute of Development Studies, The University of Sussex, UK, page 27

[21] Again, the Chauganphaya elementary village electrification is not yet aiming for income generation through the installed system, but to provide just basic lighting inside the home as a very first step out of the trap of utter poverty, partly caused due to the hazardous indoor health conditions the people are permanently exposed to.

[22] *Governance in the Karnali, an Exploratory Study,* August 2002, Karnali Integrated rural Development and Research center, Jumla, page 4

[23] *Governance in the Karnali, an Exploratory Study,* August 2002, Karnali Integrated rural Development and Research center, Jumla, page 4

[24] *Governance in the Karnali, an Exploratory Study,* August 2002, Karnali Integrated rural Development and Research center, Jumla, pages 4 - 5

[25] *Governance in the Karnali Exploratory Study* , by Karnali Research Group Jumla, 2000, page 52

[25] *World Energy Outlook 2002,*IEA, 2002

[26] *Governance in the Karnali Exploratory Study* , by Karnali Research Group Jumla, 2000, page 52

[27] *World Energy Outlook 2002,*IEA, 2002, page 37

[28] E. Mills, *The $230-billion Global Lighting Energy Bill"*, Lawrence Berkeley National Laboratory, 2002

[29] IEA, *World Energy Outlook 2002*, chap. 13, page 373

[30] E. Mills and S. Johnson, "A Dramatic Opportunity for Technology Leapfrogging in the developing World", Lawrence Berkeley National Laboratory, 2002

[31] *The Rational Path To The Age Of Renewable Energy*, Richard J. Hunwick, Hunwick Consultants Ptv. Ltd, August 2002,

[32] IEA, *World Energy Outlook 2002*, chap. 13, page 375

[33] More details in *Smoke-the Killer in the Kitchen,* Hugh Warwick et al, ITDG Publishing 2004, ISBN 1 85339 5889

[34] Energy Information Administration, *Nepal*, www.eia.doe.gov

[35] CEN (Clean Energy Nepal) 2002, *Kathmandu's Air Quality,* CEN Fact Sheet # 1, Kathmandu's Air Quality, Clean Energy Nepal, June 2002, Kathmandu

[36] *Energy Country Analysis Brief: Nepal,* February 2002 http://www.sari-energy.org/Publications/eia/Nepal.pdf , page 14

[37] *Energy Country Analysis Brief: Nepal,* February 2002, page 14, http://www.sari-energy.org/Publications/eia/Nepal.pdf

[38] see in the Appendix: *Theoretical Power Potential,* Nepal Electricity Authority, 2004

[39]Theoretically Possible of 83.290 MW, Technically Feasible of 44.600 MW, and Economically Feasible of 42.133 MW, *Theoretical Power Potential,* Nepal Electricity Authority, 2004

[40] unpublished figure provided by Nepal Electricity Authority, 2003

[41] Through research and interviews, the writer was not able to extract a possible hydro power generation extension scenario, through new power plants and upgrades over the next 10 years. Too many contradicting answers have been gathered. This reflects in general Nepal's handicapped and paralised economy, unable to make any realistic future planning or forecasting.

[42]Hydro Power Stations Planned and under construction, P > 10 MW, Nepal Electricity Authority, 2004.

[43] *Some Experiences With Practical Implementation of Photovoltaics Solar From Nepal*, Paper for the Conference on Solar Photovoltaic Power -The Power Supply of Tomorrow, 31 August - 2 September, 1998, Copenhagen Ganesh Ram Shresta Shrestha, Centre for Rural Technology (CRT), http://www.panasia.org.sg/nepalnet/crt/pvsystems.htm

[44] see in the Appendix 8.3, Average 30º towards Equator Tilted Solar Irradiation from 1983 –1993 for Nepal, and Average Horizontal Solar Irradiation from 1983 – 1993 for Nepal for each Month

[45] This information has been gathered by Alex Zahnd through interviewing the personal in charge of the Government owned, and run solar PV arrays systems in Simikot Humla, and Gamghadi Mugu.

[46] http://www.aepcnepal.org/intro/index.php

[47] http://www.aepcnepal.org/esap/index.php

[48] http://www.aepcnepal.org/sp/se.php

[49] http://www.aepcnepal.org/pmis/solardata.php

[50] http://www.aepcnepal.org/esap/solarnepal.php?ii=28

[51] *Governance in the Karnali, An Exploratory Study*, Karnali Integrated Rural Development and Research Center, Jumla, August 2002, page 4

[52] During 1996-2000 the writer lived in the remote mountain area of Jumla, where initially 23 micro-hydro power plants have been installed over the course of a decade. Out of these 23 power plant only

3 were functional, providing the local communities with light, all others were not operational due to technical and socio-economical problems.

[53] Open fire use create PM_{10} levels ≥ 20,000µg/m^3. US-EPA 24 hrs average is not to exceed 150µg/m^3 more than 3 times a year. Annual average not exceeding 50µg/m^3, *Smoke, Health and Household Energy,* ITDG, September 2002

[54] IEA, *World Energy Outlook 2002*, chap. 13, page 367-8

[55] *Smoke health and household energy,* Issues paper for DFID, Liz Bates, ITDG Answer to Poverty ,September 2003, page 3

[56] *Smoke health and household energy,* Issues paper for DFID, Liz Bates, ITDG Answer to Poverty ,September 2003, page 3

[57] *Smoke-the Killer in the Kitchen, Indoor Pollution in Developing Countries,* Hugh Warwick & Alison Doig, ITDG Publishing 2004, ISBN 1 85339588 9, page 6

[58] *Saving Energy through Lighting Management,* Energy Management Advisory Booklet, Energy Programs and Fisheries Division Department for Primary Industries and Energy, Australian Government Publishing Service Canberra, June 1994, page 3

[59] Australian Standard AS1680-1990 for Interior Lighting, Part 1: General principles and recommendations, *Saving Energy through Lighting Management,* Energy Management Advisory Booklet, Energy Programs and Fisheries Division Department for Primary Industries and Energy, Australian Government Publishing Service Canberra, June 1994, pages 4-6

[60] Lux is the luminous flux on a surface per unit area. The unit is the lux (lx), with symbol E. 1 lx = 1 lm/m^2, *Saving Energy through Lighting Management,* page 42. www.lightsearch.com, Light Guide: Useful Formulas. Lux = Total Lumens ÷ Area in Square Meters; 1 Lux (lx) = 1 Footcandle (fc) x 10.76; and a Footcandles (fc) = Total Lumens (lm) ÷ Area in Square Feet.

[61] *Saving Energy through Lighting Management,* Energy Management Advisory Booklet, Energy Programs and Fisheries Division Department for Primary Industries and Energy, Australian Government Publishing Service Canberra, June 1994, page 3

[62] The power factor characterizes the difference of phase between current and voltage in altering current supply. If the load includes components that are capacitive or inductive, the peak current does not occur simultaneously with the peak voltage. The more out of phase the current and voltage, the smaller the power factor and the greater the power loss in the transmission/distribution lines concerned. *Rural Lighting,* Intermediate Technology Publications, Jean-Paul Louineau, Modibo Dicko, Peter Fraenkel, Roy Barlow,and Varis Bokalders, The Stockholm Environment Institute 1994, page 143

[63] *A Dictionary of Science,* E.B. Uvarov et al., Penguin Reference Books, 4th Edition, 1973, page 61

[64] Luminous flux is the time rate of flow of light. The unit of measure is the Lumen. One lumen may be defined as the light flux emitted in one unit solid angle by a one-candela uniform-point source. The lumen differs from the candela in that it is a measure of light flux irrespective of direction. The lumen is used to express a quantity of light flux: total output of a source, output within a specific angular zone, amount of absorbed light, etc.

[65] Illumination is the density of luminous flux on a surface This parameter shows how "bright" the surface point appears to the human eye. The appropriate units of measure are Footcandle and Lux. One footcandle is the illumination produced by one lumen uniformly distributed over one square foot of a surface, or conversely this is the illumination at the point of a surface which is one foot from, and perpendicular to, a uniform point source of one candela. So, footcandles incident on a surface = Lumens/Area (sq.feet). Lux is used in the International System. Both have a similar objective, but meters are used for Lux and feet are used for Candelas. Therefore, one lux=0.0929 footcandles. Or, approximately, 1 Fc=10 Lux.

[66] http://home.howstuffworks.com/question236.htm/printable

[67]Light Bulbs: Fluorescent vs. Incandescent: Efficiency: http://www.saintmarys.edu/~rtarara/ENERGY_PROJECT/EFFICIENCY.htm;

[68] Ultralamp company: http://www.ultralamp.com/english_company.htm

[69] http://www.energyoutlet.com/res/lighting/cfl_info.html

[70] http://tristate.apogee.net/lite/bltinca.asp

[71] *Comparison of Performance of Electric Lighting Systems for Rural Nepal,* P. Freere & A. Poudyal, S. Shrestha, Department of Electrical and Electronic Engineering, Kathmandu University, Nepal

[72] Basic LED Radiation Diagram from: *LEDs Are Still Popular (and Improving) After All These Years*, February 2003, http://www.maxim-ic.com/appnotes.cfm/appnote_number/1883/ln/en

[73] Pico Hydro Power Seminar Butwal 14th January 2003, Alex Zahnd, Kathmandu University, page 8

[74] http://www.energyoutlet.com/res/lighting/cfl_info.html

[75] *Beacon Light Program*, http://www.ulct.org/bountiful/power/beacon.html

[76] *Beacon Light Program*, http://www.ulct.org/bountiful/power/beacon.html

[77] http://www.public.iastate.edu/~envr_stu_324/compacts.htm

[78] Cree is a company that develops and manufactures semiconductor materials and devices based on silicon carbide (SiC), gallium nitride (GaN), silicon (Si) and related compounds. http://www.cree.com/
[79] *Revised LED lighting page,* http://www.otherpower.com/cgi-bin/webbbs/webbbs_config.pl?noframes;read=249
[80] *Christmas Lights*, http://www.xmas-village.com/christmas-lights/led-christmas-lights.html
[81] http://www.cyberium.co.uk/ledlighting.htm, and http://www.reactual.com/lighting.html
[82] *Efficient Lightning*, http://otherpower.com/otherpower_lighting.html
[83] *Sandia Power Point Presentation,*
[84] "0.1 Watt WLEDs Lumen Efficacy Comparison (Average values from 10 samples driven at 20 mA)", Light Up The World, Lumen/Watt Laboratory test of 10 different WLED brands, August 25th, 2004
[85] Steward A. Craine, November 2003, *Technical and economic optimization of village electrification systems,* chapter 3.1.2: "Lighting Options", page 29
[86] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 6
[87] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 9
[88] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 10
[89] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 6
[90] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 6
[91] C. Donald Ahrens, *Meteorology Today,* 7th Edition Brooks/Cole, 2003, page 45
[92] Thomas Markvart, *Solar Electricity,* UNESCO Energy Engineering Series, Wiley 1994, page 7
[93] Roger G. Barry et. al., *Atmosphere, weather and climate,*7th Edition, Routledge, New York 1998, pages 20 – 21
[94] Martin A. Green, *Solar Cells,* National Library Australia, Prentice-Hall 1992, page 6
[95] Thomas Markvart, *Solar Electricity,* UNESCO Energy Engineering Series, Wiley 1994, page 8; Martin A. Green, *Solar Cells,* National Library Australia, Prentice-Hall 1992, pages 1-5;
[96] John W. Twidell & Anthony D. Weir, *Renewable Energy Resources,* chapter 4 Solar Radiation, page 66, E & FN Spon, Great Britain 1997
[97] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 46
[98] John W. Twidell & Anthony D. Weir, *Renewable Energy Resources,* chapter 4 Solar Radiation, page 82, Table 4.1., E & FN Spon, Great Britain 1997
[99] John A. Duffie & W. A. Beckman, *Solar Engineering of Thermal Processes,* Second Edition John Wiley & Sons, New York, 1991, page 61
[100] Kamal Rijal, *Water Nepal* Vol. 3, No.: 1, July 1992, pages 192 - 196
[101] *METEONORM* Global Meteorological Database for Engineers, Planners and Education, Version 5.0, METEOTEST, April 2003, www.meteonorm.com
[102] Kamal Rijal, *Water Nepal* Vol. 3, No.: 1, July 1992, page 192
[103] Kamal Rijal, *Water Nepal* Vol. 3, No.: 1, July 1992, pages 195
[104] Kamal Rijal, *Water Nepal* Vol. 3, No.: 1, July 1992, pages 196
[105] Kamal Rijal, *Water Nepal* Vol. 3, No.: 1, July 1992, pages 196
[106] For more details and a comparative calibration curve with a high quality thermopile detector pyranometer such as the Kipp-Zonen pyranometer CM21, see Appendix 18.3.1., Comparative curve of a 80SPC and Kipp-Zonen CM21 Pyranometer.
[107] C. Donald Ahrens, *Meteorology Today,* 7th Edition Brooks/Cole, 2003, page 148-149
[108] The minimum value is quite obvious, as when there is no light at all, there cannot be any solar radiation, neither beam, diffuse nor any albedo value. But the question may arise as to why the value of 1,500 W/m^2 has been defined as the maximum value, higher than the solar constant? The reason for this, higher value than the solar constant, is that the edges of this small, snow white, dense cloud, are reflecting and thus amplifying the sharply incoming solar radiation, once the direct visual connection between the sun and the pyranometer is again suddenly established. Thus the measured value, "jumps" for an instant, to a very high radiation value.
[109] *Chauganphaya,* map sheet No. 3081 16, Scale 1:50,000, His Majesty's Government of Nepal, Survey Department, January 2000, and *Simikot,* map sheet No. 2981 04, Scale 1:50,000, His Majesty's Government of Nepal, Survey Department, January 2000.
[110] *METEONORM*, Global Meteorological Database for Engineers, Planners and Education, Version 5.0, *Introduction Main Form,* April 2003; www.meteonorm.com

[111] Calculated with the SunPlot 3D software tool from Maui Solar Energy Software Corporation, www.mauisolarsoftware.com
[112] Simikot VDC (Village Development Community) map, sheet No. 2981 04, scale 1:50,000, His Majesty's Government of Nepal, First edition 2001
[113] This model creates a detailed relief of the horizon (360°) of a defined location (latitude, longitude and altitude). This model is not yet commercially available, but through the METEONORM software developer, Mr. Jan Remund, it was possible to create a detailed horizon relief for both, the Simikot HARS and the Chauganphaya village.
[114] The NASA Graph are from *Average Horizontal Solar Irradiation from 1983 – 1993 for Nepal for each Month*, in chapter 18.4.1., and *Average 30º towards Equator Tilted Solar Irradiation from 1983 –1993 for Nepal,* in chapter 8.3.
[115] The NASA Satellite Data are from *Irradiation on horizontal surface (kWh/m^2/day),* in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[116] *Peak Sun Hours radiation for equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day),* in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[117] From *Radiation on equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day)*, in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[118] From *Radiation on equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day),* providing the average maximum solar irradiation at an optimum monthly tilt angle towards south, in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[119] The optimum average monthly tilt angle towards south which provides the monthly averaged maximum radiation. From *Data from Radiation on equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day)*, in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[120] Chauganphaya VDC (Village Development Community) map, sheet No. 3081 16, scale 1:50,000, His Majesty's Government of Nepal, First edition 2001
[121] The NASA Satellite Data are from *Irradiation on horizontal surface (kWh/m^2/day),* in chapter 18.4.1. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / ,2643 m.a.s.l.), in Humla, Nepal
[122] *Peak Sun Hours radiation for equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day),* in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[123] From *Radiation on equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day)*, in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[124] From *Radiation on equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day),* providing the average maximum solar irradiation at an optimum monthly tilt angle towards south, in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[125] The optimum average monthly tilt angle towards south which provides the monthly averaged maximum radiation. From *Data from Radiation on equator-pointed tilted surfaces / Perez/Erbs et al. method (kW/m^2/day)*, in chapter 18.4.5. NASA Data for the Simikot HARS Solar PV System (Lat. 29.967º N / Long. 81.817º E / 3,000 m.a.s.l.) and the Chauganphaya Village Solar PV System (Lat. 30.000º N / Long. 81.774º E / 2,643 m.a.s.l.), in Humla, Nepal
[126] PVSYST V3.31 is a PC software package for the study, sizing and data analysis of complete PV systems, designed by Andre Mermoud. GAP/CUEPE, Université de Genève, Switzerland.
[127] *Household and Health Improvement with Solar Lights, Smokeless Stoves, Pit Latrines & Drinking Water,* Baseline Questionnaire: Year 1 (2003-2004), Kathmandu University and The ISIS Foundation Humla Projects, Dr. Kimber Haddix University of Montana, USA, and Alex Zahnd, Kathmandu University, Nepal, and Govinda Nepali, KU-ISIS Humla Project, Nepal, June 2003

[128] *Governance in the Karnali, An Exploratory Study*, Karnali Integrated Rural Development and Research Center, Jumla, August 2002, page 5

[129] The 12VDC 100Ah @20hrs Volta deep cycle battery life cycle performance is provided by the manufacturer with 20% DoD 2,500 cycles, 50% DoD 1,200 cycles, 80% DoD 250 cycles. With an average of ~ 15% DoD this battery should be able to last between 4,000 – 5,000 cycles according to the diagram, which is approx. 12 – 13 years. Thus 10 years with a DoD of around 10%, as in the case of the Chauganphaya battery bank, is a realistic assumption.

[130] Chauganphaya VDC (Village Development Community) map, sheet No. 3081 16, scale 1:50,000, His Majesty's Government of Nepal, First edition 2001.

[131] SunPlo3Dt Version 1.1, as part of the Solar Design Studio v5.0a CD, Maui Solar Energy Software, www. Mauisoalrsoftware.com

[132] *CHARGE AND DISCHARGE CONTROLLER FOR SHS,* Charge Controller features, Muni Raj Upadhaya, PPN, Kathmandu, Nepal, April 2004

[133] *Life Cycle Costing,* Solar Electricity, Markvart, chapter 5.2.2, pages 120 - 126

[134] *Some Experiences With Practical Implementation of Photovoltaics Solar From Nepal*, Ganesh Ram Shrestha, from Centre for Rural Technology (CRT), Kathmandu, Nepal, 1995, (http://www.panasia.org.sg/nepalnet/crt/pvsystems.htm

[135] IEA PVPS International Energy Agency, Implementing Agreement on Photovoltaic Power Systems, Task 9, Deployment of Photovoltaic Technologies: Co-operation with Developing Countries PV for Rural Electrification in Developing Countries. – A Guide to Capacity Building Requirements March 2003.