Solar Photovoltaic Installation in Chaurikharka Secondary School & Energy Study for Lukla Primary School, Nepal

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I am heartily thankful to my mother, Marie-Claire, my brother, Arnaud, and my girlfriend, Céline, who supported me during the completion of this thesis. Finally, I would like to give my respects to my late father, Morris, without whom none of this would have been possible.

List of abbreviations

AC	alternative current
AM	air mass coefficient
BSP	battery status processor
BTS	battery temperature sensor
CSP	concentrating solar power
DC	direct current
DoD	depth of discharge
ESD	emergency shutdown device
GHI	global horizontal irradiance
Imax	maximum current
Isc	short-circuit current
IT	information technology
LOL	loss-of-load probability
MF-VRLA	maintenance free valve regulated lead–acid battery
MHPP	micro-hydro power plant
MPPT	maximum power point tracker
NGO	non-governmental organization
PHPP	pico-hydro power plants
Pmax	maximum power
PV	photovoltaic
RCC	remote control center
SD	secure digital
SHC	solar thermal collectors for heating and cooling
SoC	state of charge
STC	standard test conditions
TILT	flat-plate tilted at latitude
UPS	uninterruptible power supply
VA	volt-ampere
Vmax	maximum voltage
Vmp	voltage at maximum power
Voc	open circuit voltage
VRLA	valve regulated lead–acid battery
Wp	watt-peak

Chapter 1
Introduction

1.1. Sherpa people

Although the original homeland of the Sherpa people has yet to be confirmed, a number of historic hypotheses were formulated thanks to the discovery of significant documents during a German research project (1). These hypotheses concur with the oral traditions of the Sherpa and with their name ("eastern people", from *shar* "east" and *pa* "people") (2).

It is believed that the Sherpa ancestors came from a district called Salmo Gang in the eastern Tibetan province of Kham. A migration of four clans – Serwa, Minyagpa, Thimmi, and Chakpa – took place at the turn of the 15th to the 16th century to escape the turmoil of war carried on by the Mongols. According to the above-mentioned documents the initial clans established themselves for a few decades in the Tinkye area, in south-central Tibet. But they were forced to abandon their homes once again due to rumors of an invasion from the west. They crossed a high pass called Nangpa La (5,716 m.) and finally settled down in the Solukhumbu district of Nepal (1 pp. 143-144). Sherpa folklore suggests that these lands had already been accidently discovered and were seldom used for meditation retreats by lone Tibetan hermits (3 p. 26).

The descendants of these fours clans are considered today as pure Sherpa and their traditions have remained more or less intact depending on the regions. Newer clans of Tibetan immigrants have integrated Sherpa society throughout the years and are also acknowledged as such even though they do not have any scriptural tradition concerning their genesis and descent (1 pp. 144-145).

Figure 1: A porter carrying a heavy load, 13th of October 2011 (4).

The Sherpa people are best known for their mountaineering skills as guides and porters but it wasn't until the first British expeditions in the 1920s that they became involved in climbing. In 1953, Sir Edmund HILLARY from New-Zealand and Tenzing Norgay SHERPA were the first to reach the summit of the tallest mountain in the world, Mount Everest (8,848 m.), on the Nepal-Tibet border (5). From that point on, mountaineering became part of the Sherpa culture from which the people earned a reputation as reliable, loyal, and honest workers (Figure 1).

1.2. Description of the project

Although the Swiss association Lukla-Chaurikharka, LUKLASS, was founded in 2008, its members have been active in the Khumbu valley of Nepal, and more precisely in the Lukla-Chaurikharka area (Figure 2), since 1984 by promoting and supporting children's education as well as sustainable development. The association provides teachers' salaries and has participated in the construction of several buildings for the primary school of Lukla and secondary school of Chaurikharka. In collaboration with the United Kingdom charity Classrooms in the Clouds, a new objective recently emerged: equipping both schools with brand new computers in order to improve the quality of the education provided. Reliable power sources are paramount in both schools for there to be an optimal utilization of the computers.

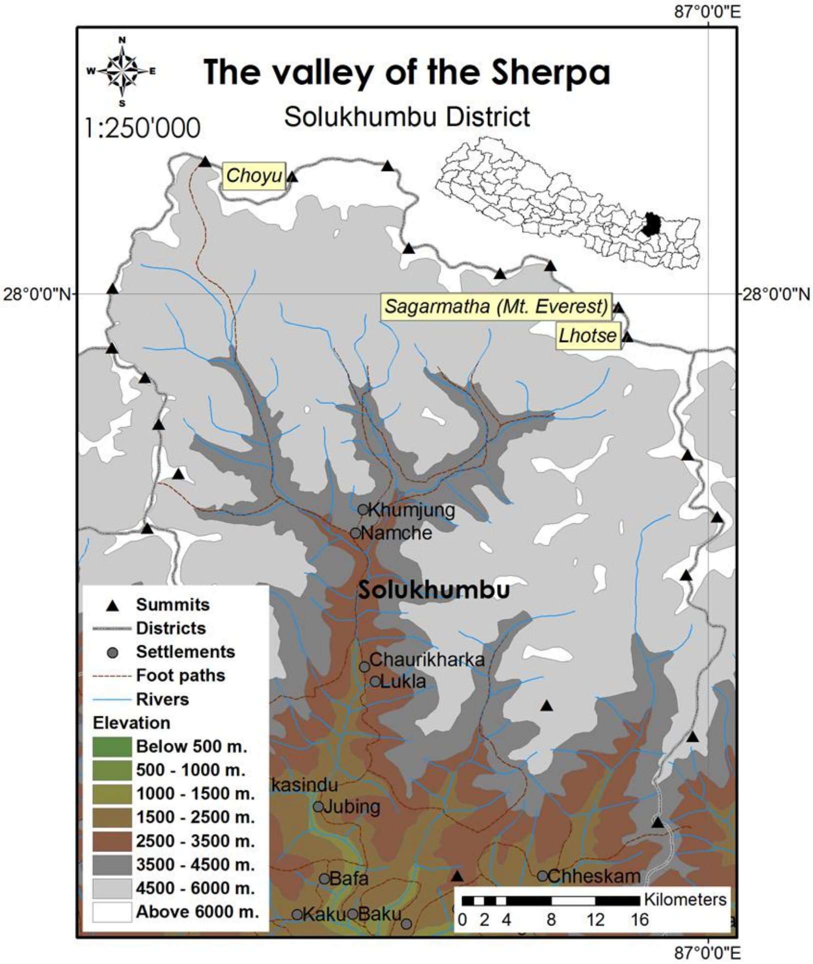


Figure 2: Map of the Solukhumbu district (6).

Currently, the 100kW Bom Khola micro-hydro power plant (MHPP) and a few privately owned pico-hydro power plants (PHPP) provide the town of Lukla with electricity. Power shortages and overload problems occur frequently due to the current excess of demand and lack of supply, especially during the period of low water (dry season). As for the village of Chaurikharka, it has only a few pico-hydro power plants owned by private individuals.

Considering the issues at hand and certain matters of urgency the following objectives were determined:

- Install a “pilot” photovoltaic (PV) system in the secondary school of Chaurikharka to contend the lack of power and provide electricity in the classrooms. To accomplish this mission, the Swiss association Lukla-Chaurikharka called upon two volunteers, Bernard MAGNIN and Nicolas COSANDEY. A training for the school personnel is also required to guarantee the maintenance and the monitoring of the system over the long-term;
- Evaluate the above-mentioned PV system in order to use it as a reference to better size the future solar installation in the primary school of Lukla;
- Conduct an energy study and design a solar installation for the primary school of Lukla by collecting and analyzing meteorological data, by estimating its electricity consumption, and by running hourly production simulations using the PVsyst software (7);
- Ensure the subsequent replication of the above-mentioned method of designing solar projects for the other schools and public infrastructures of the Khumbu valley such as the Pasang Lhamu-Nicole Niquille Hospital in Lukla.

1.3. Thesis guidelines

The thesis is organized as follows:

Chapter 1 sets the project’s environment, goals, and challenges. An assessment on the current energy status in Lukla is described in Chapter 2, as well as the measures that are to be applied in a short-, medium-, and long-term.

In Chapter 3, the solar potential in Nepal, and more precisely in the Khumbu valley, is demonstrated using results produced by state-of-the-art methods with the best-known satellite data. These results are then confirmed with ground measurements obtained for the following sites: Lukla-Chaurikharka, Namche, Pheriche, and Lobuche.

Chapter 4 presents the secondary school of Chaurikharka as well as the work that was accomplished on the above-mentioned PV system and its evaluation. As for Chapter 5, it proposes the energy study and the solar installation design for the primary school of Lukla based on the estimation of its electricity consumption and the hourly production simulations obtained with the PVsyst software.

Chapter 6 focuses on the guidelines to replicating the above-mentioned method of designing solar projects. Finally, conclusions and perspectives are synthesized in Chapter 7.

Chapter 2

Energy status in Lukla

2.1. Context

Commissioned on 6th of June 2008, the 100kW Bom Khola micro-hydro power plant (Figure 3) is a joint venture of the Alternative Energy Promotion Center of the Government of Nepal, the UNDP Rural Energy Development Programme, REDP, the World Bank, and the local community. It provides electricity to approximately 200 households, of which about 150 have been converted into hotels and lodges, and has significantly contributed to the economy and lives of the local people whose main source of income is tourism:

"A quick short walk in the Lukla market can lure a person to stay for some extra days. Electricity has enabled people to run restaurants, bakery with internet and email facilities, retail shops, tailoring centres, ironing centres, coffee houses and pubs with little disco theatres and even a movie house besides the general lighting and heating. The hot cakes and apple pies coming out of the microwaves and big ovens give warmth to the place and a different ambience that holds one in the place for quite a while and the shining coffee machines have expanded the choices of coffee for the visitors (8)".

Figure 3: General view of the 100kW Bom Khola micro-hydro power plant (9).

The Pasang Lhamu-Nicole Niquille Hospital has its own 25kW micro-hydro power plant but needs a stronger additional supply for the use of its radiographic equipment (X-ray). A connection point was established between the hospital and the town network that can be triggered manually when needed. Unfortunately, a number of concerns have risen recently about the current excess of demand and lack of supply as power shortages and overload problems occur frequently. Several hotels and lodges have even installed their own pico-hydro power plants, while others are currently looking into alternative energy sources such as solar photovoltaic. Having all this in mind, the town officials of Lukla and the members of the direction of the hospital called upon a volunteer engineer, Henri BUTTICAZ, to execute a brief project appraisal. The goal of the study was to define the current state of the 100kW Bom Khola micro-hydro power plant as well as its adequacy to the needs of the town and eventually to those of the hospital. This chapter is based on the report he did during his stay in Lukla in October 2011 (9).

2.2. Current issues at hand

The runner is the piece of the turbine, consisting of curved vanes, blades, or buckets on a wheel or a hub, that is turned by the pressure of high velocity water and thus transforms falling water energy into rotating mechanical energy. The Pelton runner originally supplied with the 100kW Bom Khola micro-hydro power plant was destroyed after only six months of operation, as shown in Figure 4. It had to be replaced by a new one that was delivered by a local supplier. Unfortunately, this new runner cannot reach the expected nominal power of 100kW but only 65kW, causing the power plant to be already overloaded by about 12% and thus to work under very poor conditions of load and frequency. The needs of the town and the hospital are no longer guaranteed, especially during the day when all the hotels and lodges consume electricity at the same time, and during the period of low water that generally starts in November and ends around April or May.

Figure 4: Pelton runner (spheroidal cast iron) destroyed after approximately after 4,000 working hours (9).

In addition, the solenoid coil of the emergency shutdown device (ESD) was also burned, causing the Pelton unit to work without any protection. In the case of a load rejection due to an electrical failure, it could operate during an extended time period at the runaway speed, which is approximately 2'700 rpm (1.8 times the nominal speed). This could be extremely dangerous for the Pelton unit as well as the operator and his family who live next to the power house.

Hence, the effective power capacity of the Bom Khola micro-hydro power plant is already too small to respond to the ever-growing electrical demand of the town of Lukla, let alone the hospital. Problems due to overload occur frequently. These situations can be very critical as the voltage and frequency decrease drastically, causing the current of each phase to increase proportionally. A significant increase in temperature in the transport and distribution cables can then be observed (especially in those that have been under-dimensioned), as shown in Figure 5.

Figure 5: Detailed view of a distribution cubicle, the red cable was burned (9).

2.3. Measures to be applied

At short-term, it is crucial to acquire the main spare parts that are currently missing, such as the solenoid coil for the emergency shutdown device as well as an extra set of ball bearings! An inventory on the real power installed and connected to the power grid should be made and act as a control measure. A load shedding programme for the consumers needs to become effective rapidly in order to reduce the variations in energy consumption and thus optimize the distribution of the daily load (and avoid the actual high peaks).

At medium-term, the electrical demand for heating water in the hotels and lodges must be significantly reduced. The hot water used by the local people and the tourists for cooking and taking showers can be produced with high efficiency by solar thermal installations and then stocked in specific tanks.

Finally, at long-term, the generating capacity of the power plant should be restored to its initial state by replacing the existing runner by a new one with a higher performance.

Chapter 3
Solar potential

3.1. Energy resource

Solar energy is the most abundant energy resource on earth. Every hour the earth's surface receives as radiant light an amount of energy that is about the same than that consumed by all human activities in a year. The low energy density and intermittency of sunlight, however, make it difficult and expensive to exploit on a large scale. Today, photovoltaic installations provide only 0.1% of total global electricity generation but are expanding very rapidly due to effective supporting policies and recent dramatic cost reductions. Photovoltaic technology is one of the three main solar active technologies along with concentrating solar power (CSP) and solar thermal collectors for heating and cooling (SHC) (10 p. 5).

As illustrated in Figure 6, some parts of the earth receive more solar radiation than others, the areas at or near the equator generally receive the most. As a result, subtropical regions offer a better resource than the more temperate latitudes.

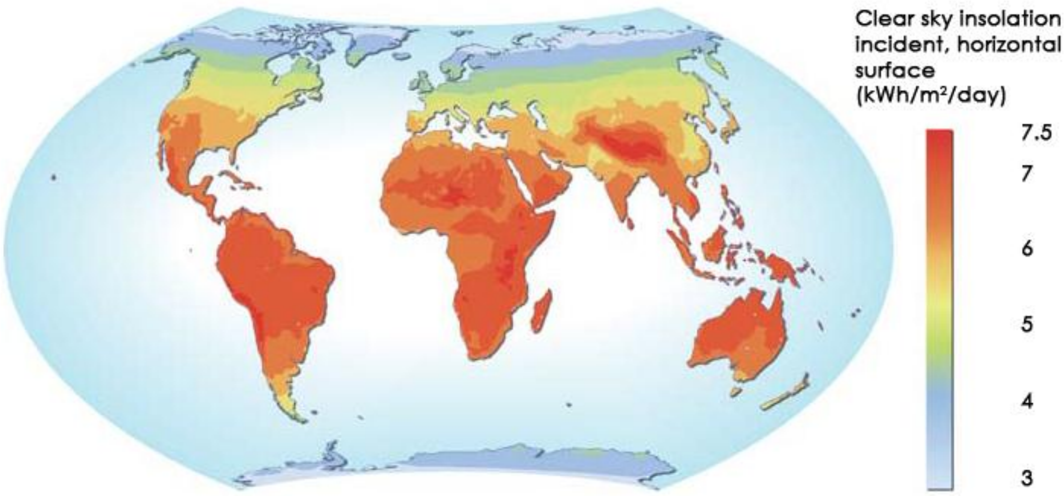


Figure 6: Global horizontal irradiance at one-degree resolution between 1983 and 2005 in the world, expressed in pluriannual daily mean values (11 p. 2).

The solar potential in Nepal, and more precisely in the Khumbu valley, will be demonstrated in the following subchapter using data developed by the UNEP Solar and Wind Energy Resource Assessment programme, SWERA (12). The data derives from two distinct models, global horizontal irradiance (GHI) and flat-plate tilted at latitude (TILT), incorporating geostationary satellite images and global weather observations. The results were validated against ground measurements when available but do not contain any site-specific measurement information (13 p. 14). Both models correspond to a specific orientation of the panels, or collectors, and thus take into account solar radiation differently.

Global horizontal irradiance represents the solar resource available to a flat-plate collector oriented horizontal to the earth's surface, the usable solar radiation includes the direct and diffuse components. Flat-plate tilted at latitude irradiance represents the solar resource available to a flat-plate collector oriented towards the equator at an angle from horizontal equal to the latitude of the collector's location (which is typical practice for photovoltaic installations). In this case, the usable solar radiation includes the direct, diffuse, and ground-reflected components (13 pp. 15-16). Both models are depicted in Figure 7.

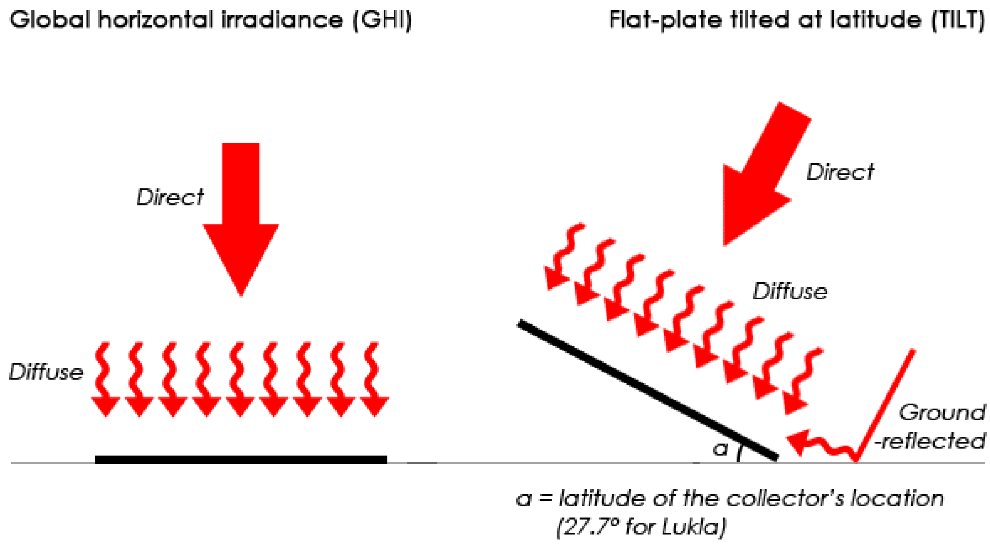


Figure 7: Flat-plate collector orientations and resulting usable solar radiation (4).

Indeed, as solar radiation reaches the earth's surface, it is partially absorbed and diffused by the atmosphere. Several components can be distinguished:

- Direct solar radiation is the portion of radiant energy received directly from the sun excluding the diffusion caused by the atmosphere;
- Diffuse solar radiation is the portion of radiant energy that has been scattered by molecules and particles in the atmosphere. It can vary a lot depending on the weather conditions and is said to be isotropic on a cloudy day, meaning it comes equally from all directions;
- Ground-reflected solar radiation, also known as albedo, is the portion of radiant energy that is reflected by the earth's surface and depends on the surrounding environment (14 p. 21).

3.2. Solar potential in Nepal

Solar resource maps illustrating global horizontal irradiance and flat-plate tilted at latitude irradiance in Nepal are respectively shown in Figure 8 and Figure 9. The following observations can be made:

- The solar energy resource is extremely abundant in Nepal;
- Collectors with a latitude tilt as opposed to a horizontal orientation present higher levels of solar radiation (due to the radiation components at hand);
- The highest values can be seen in the northwestern region of Nepal, going up to 7.0 kWh/m²/day for TILT;

– Levels of solar radiation are in average higher in the western part of the country, 5.0 to 6.0 for GHI and 5.5 to 6.5 kWh/m²/day for TILT, than the eastern part, 4.5 to 5.0 for GHI and 5.0 to 5.5 kWh/m²/day for TILT.

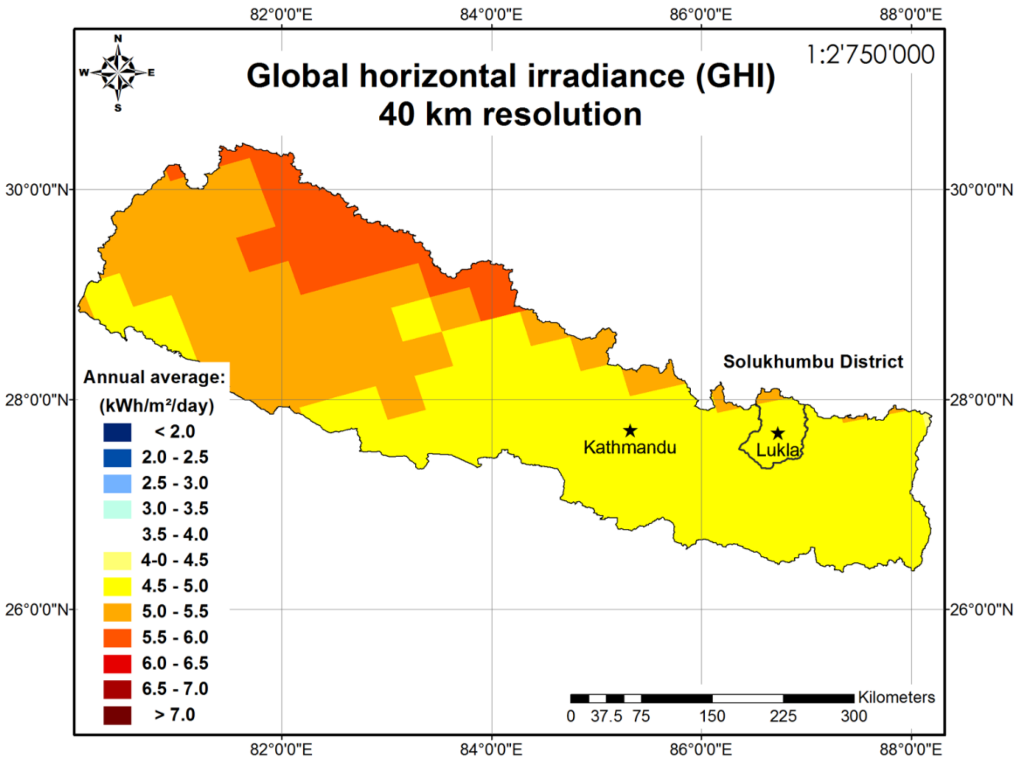


Figure 8: Global horizontal irradiance at 40 km. resolution between 1985 and 1991 in Nepal, expressed in pluriannual daily mean values (15).

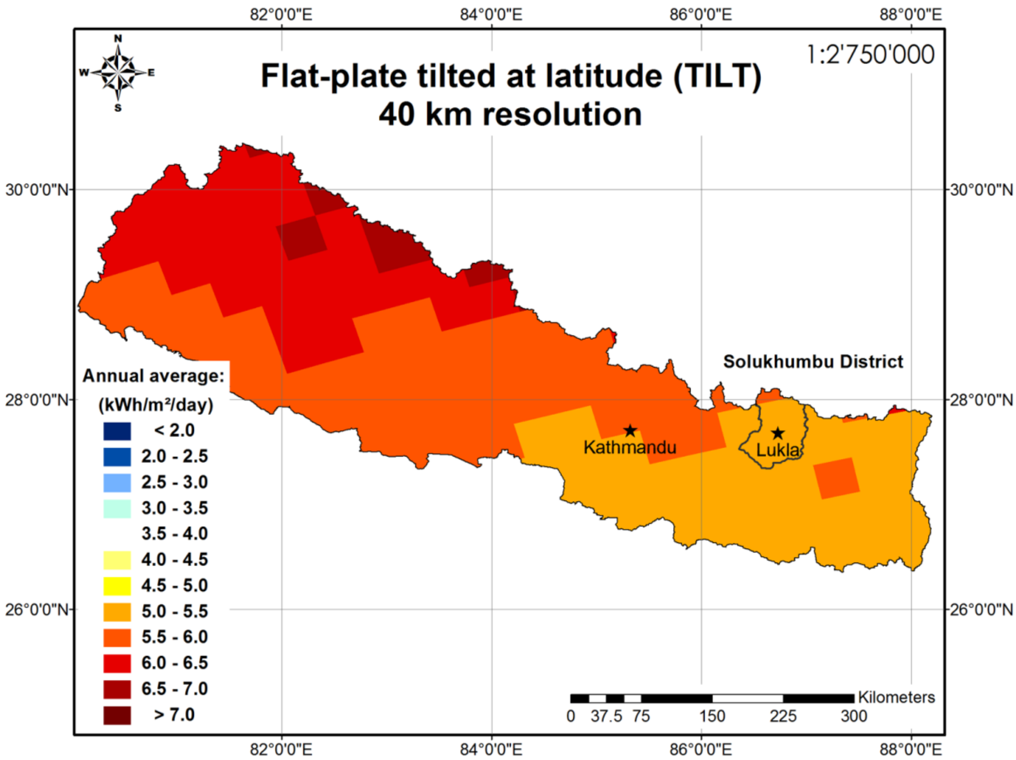


Figure 9: Flat-plate tilted at latitude irradiance at 40 km. resolution between 1985 and 1991 in Nepal, expressed in pluriannual daily mean values (15).

In comparison, the solar potential in Europe, illustrated in Figure 10 and Figure 11, is rather weak with values in Switzerland going from 3.0 to 4.0 for GHI and 3.5 to 4.0 kWh/m²/day for TILT.

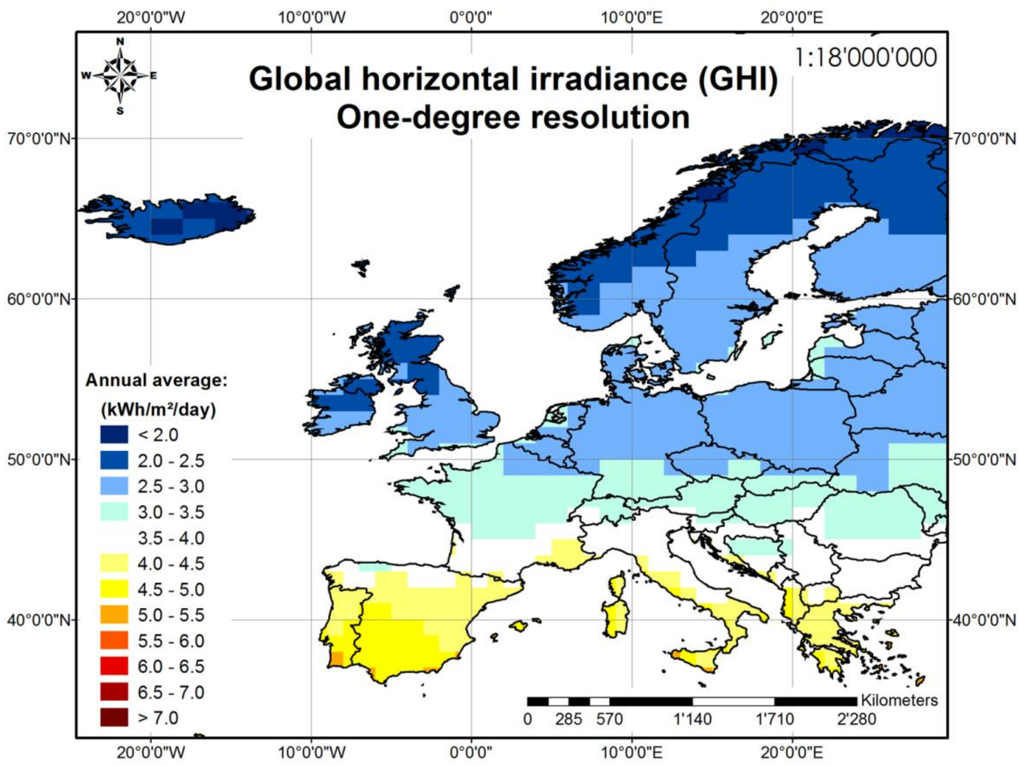


Figure 10: Global horizontal irradiance at one-degree resolution between 1983 and 2005 in Europe, expressed in pluriannual daily mean values (16).

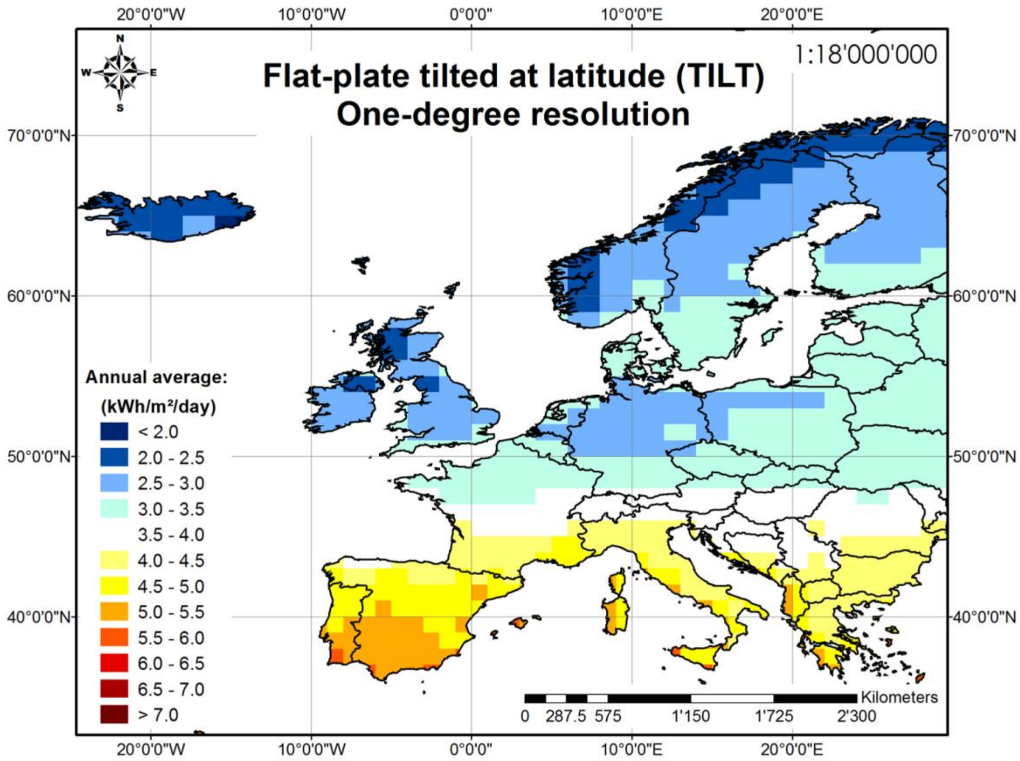


Figure 11: Flat-plate tilted at latitude irradiance at one-degree resolution between 1983 and 2005 in Europe, expressed in pluriannual daily mean values (16).

3.3. Solar potential in the Khumbu valley

Although the Khumbu valley is situated in the eastern part of the country, it still has a considerable solar energy resource that rivals many other regions in the world and which remains to be exploited. As shown in Figure 12, levels of solar radiation for global horizontal irradiance in Lukla, Chaurikharka, Namche, Pheriche, and Lobuche range from 4.5 to 5.0 kWh/m²/day in average for the first four and from 5.0 to 5.5 kWh/m²/day for the latter. Even higher values can be expected with collectors oriented with a latitude tilt.

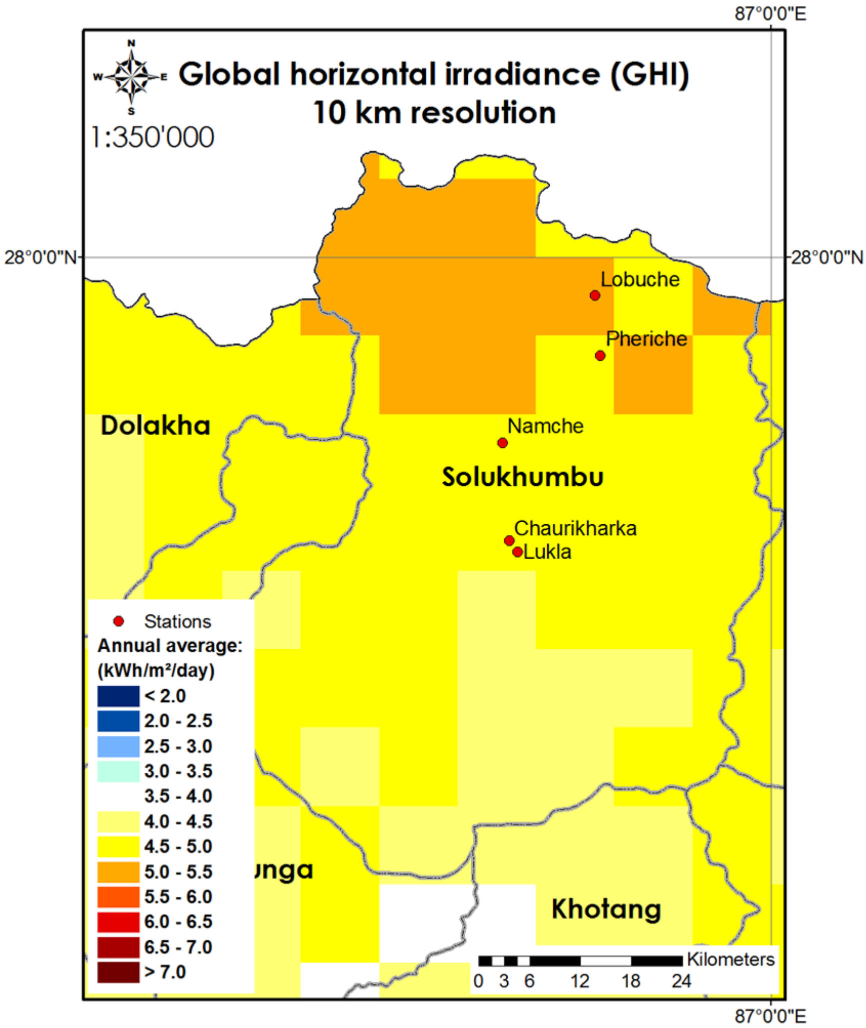


Figure 12: Global horizontal irradiance at 10 km. resolution for the year 2003 in the Solukhumbu district, expressed in annual daily mean values (17).

The data developed by the GHI model at 10 km. resolution will be confirmed later on in this chapter with a series of ground measurements collected in several sites. Analytical results on the seasonal (monthly), annual, and spatial variations of the global solar irradiance will also be reported in order to fully assess the solar potential in the Khumbu valley.

3.4. Meteorological data

Stations at High Altitude for Research on the Environment, SHARE, is an integrated project for environmental monitoring and research in the mountain areas of Europe, Asia, Africa and South America that responds to an international call for information on the effects of climate change. It is promoted by the Ev-K2-CNR Committee with the support of the Italian National Research Council, the Italian Ministry of Foreign Affairs, and the United Nations Environment Programme, UNEP. The SHARE network currently counts 15 sites in four different countries including Nepal with weather stations that are functioning continuously (Table 1), collecting data on various standard meteorological parameters (18).

Station	Altitude (m)	Climate	Latitude (°)	Longitude (°)
Lukla-Chaurikharka	2'660	High alpine	27° 41' 24" N	86° 43' 12" E
Namche	3'560	High alpine	27° 48' 00" N	86° 42' 36" E
Pheriche	4'258	High alpine	27° 53' 24" N	86° 49' 12" E
Lobuche	5'079	High alpine	27° 56' 60" N	86° 49' 12" E
Kala Patthar	5'600	High alpine	27° 59' 24" N	86° 49' 48" E
Changri Nup	5'700	High alpine	27° 58' 56" N	86° 45' 53" E
Mount Everest, South Col	8'000	High alpine	27° 55' 48" N	86° 55' 48" E

Table 1: Automatic weather stations installed in Nepal (18).

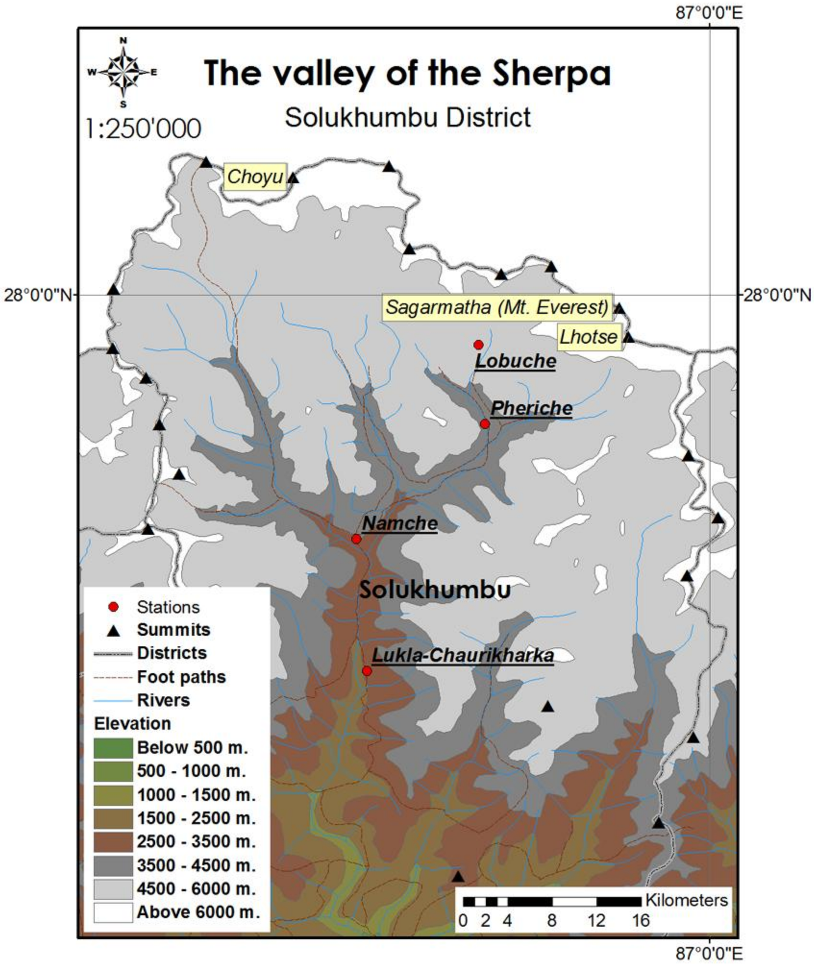


Figure 13: Location of the four automatic weather stations installed in the Khumbu valley that provided the meteorological data used in this thesis (6) (18).

The Ev-K2-CNR Committee provided meteorological data collected between the 1st of October 2002 and the 31st of December 2009 in the four automatic weather stations installed in Lukla-Chaurikharka, Namche, Pheriche, and Lobuche (Figure 13). The data consists of hourly values of air temperature, relative humidity, atmospheric pressure, and global solar radiation. The latter was measured using Kipp & Zonen pyranometers oriented horizontal to the earth's surface, meaning the direct and diffuse solar radiation components are included and that the comparison with global horizontal irradiance can be done directly.

The hourly values of global solar radiation were summed up to daily values from which a pluriannual average was calculated for each day of the year. For instance, the pluriannual average for the 1st of January was obtained by taking the average of the daily values for that same day and for each year between 2003 and 2009. The missing data was either replaced with the monthly mean (in the case of one or several days) or not counted for (in the case of an extended time period). All the ground measurements made on the 29th of February in 2004 and 2008 were neglected. The pluriannual daily averages were then used to calculate a mean value over a time period of ±4 days for each day of the year, meaning the value for the 5th of January was obtained by taking the mean of the pluriannual daily averages between the 1st and the 9th of January. Hence, the resulting curve is flatter due to the averaging of short-term peaks with intervening smaller values during that time period. In addition, a theoretical curve was obtained using a sixth-degree polynomial regression. Both curves for each of the four above-mentioned automatic weather stations are displayed in Figure 14, Figure 16, Figure 18, and Figure 20. They can be used as such to illustrate the seasonal (monthly), annual, and spatial variations of global solar irradiance over the year.

The term cumulated frequency of occurrence is often used in this field of study as it gives an indication of the repartition for each level of radiation (19 p. 10). Indeed, this type of analysis takes a different approach in characterizing solar irradiance by deriving the relationship between the magnitude and the frequency from the record of ground measurements. Instead of plotting the global solar irradiance as a time series, the cumulated frequency of occurrence shows the percentage of time that a given level of radiation is equalled or exceeded. In order to do so, the above-mentioned pluriannual daily mean values (i.e. those that were obtained by taking the pluriannual average and the mean over a time period of ±4 days for each day of the year) were sorted out in decreasing order. A theoretical curve displayed in percentage was then obtained using either a fourth-, fifth-, or sixth-degree polynomial regression. The same approach was applied to the daily values of the minimum and maximum years from which only the mean was taken over a time period of ±4 days for each day of the year. All three curves representing the theoretical cumulated frequency of occurrence of the global solar irradiance for the above-mentioned automatic weather stations are displayed in Figure 15, Figure 17, Figure 19, and Figure 21. The bias (i.e. the difference between the theoretical and measured data) is shown as well and is expressed in absolute percentage error.

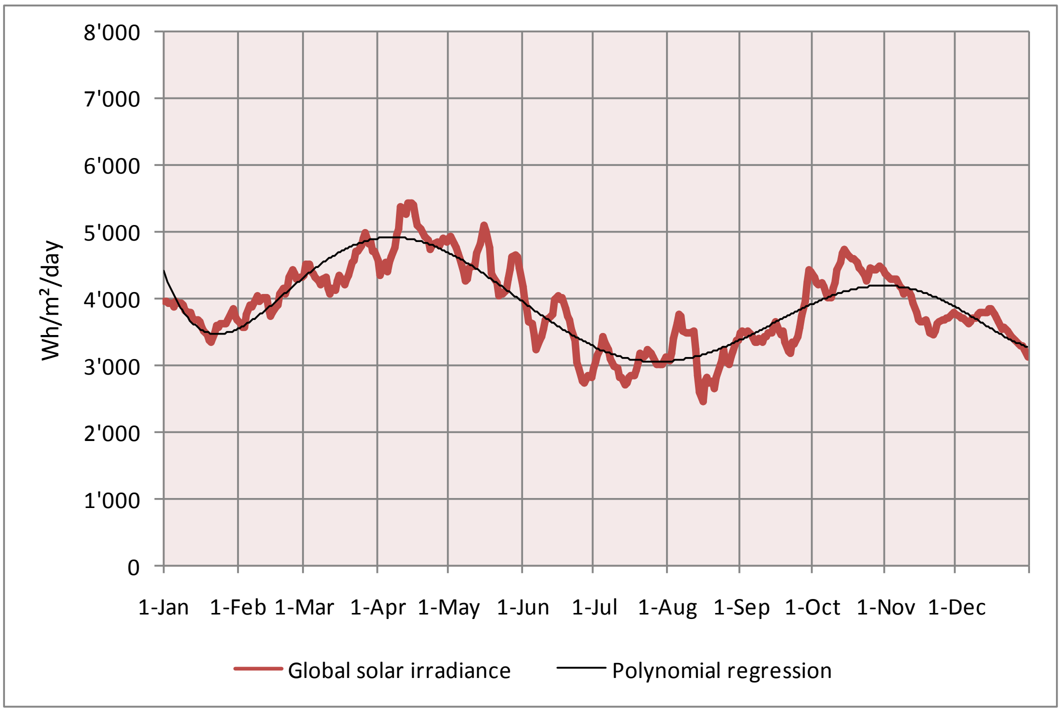


Figure 14: Global solar irradiance measured over the year in the station of Lukla-Chaurikharka, expressed in pluriannual daily mean values (20).

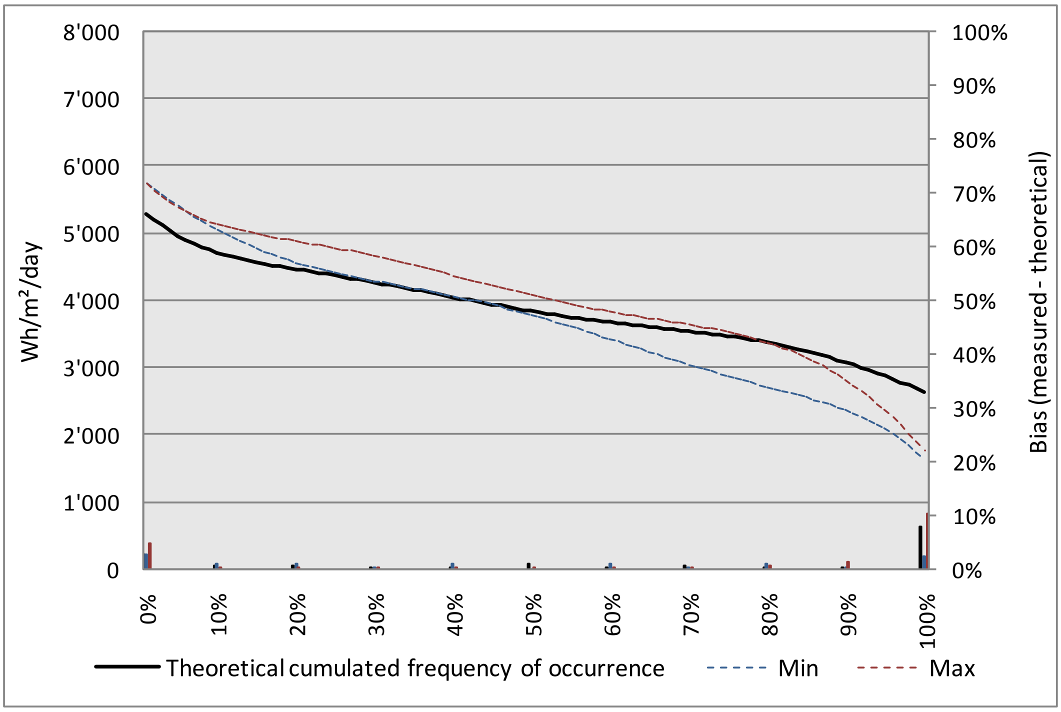


Figure 15: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka, expressed in daily mean values and absolute percentage error (20).

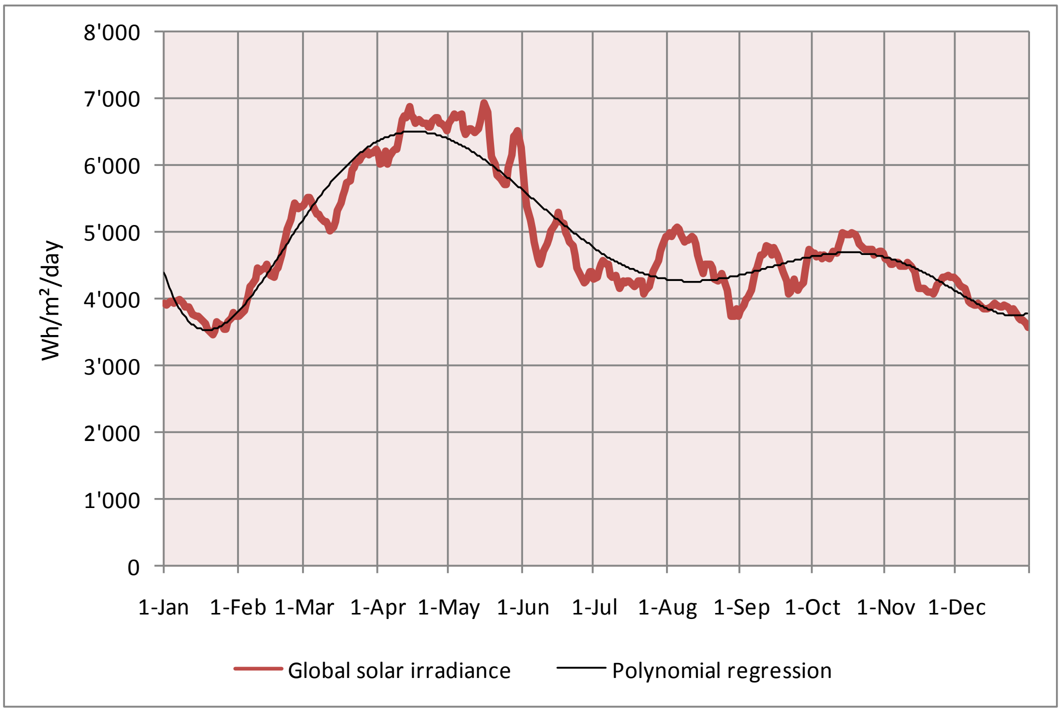


Figure 16: Global solar irradiance measured over the year in the station of Namche, expressed in pluriannual daily mean values (20).

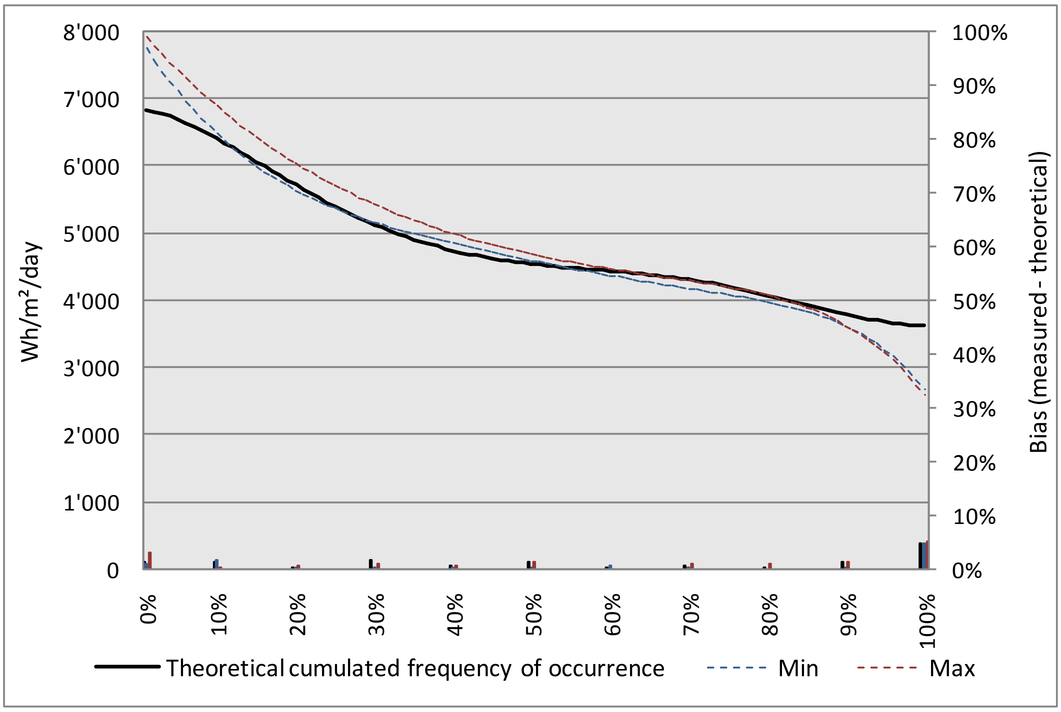


Figure 17: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Namche, expressed in daily mean values and absolute percentage error (20).

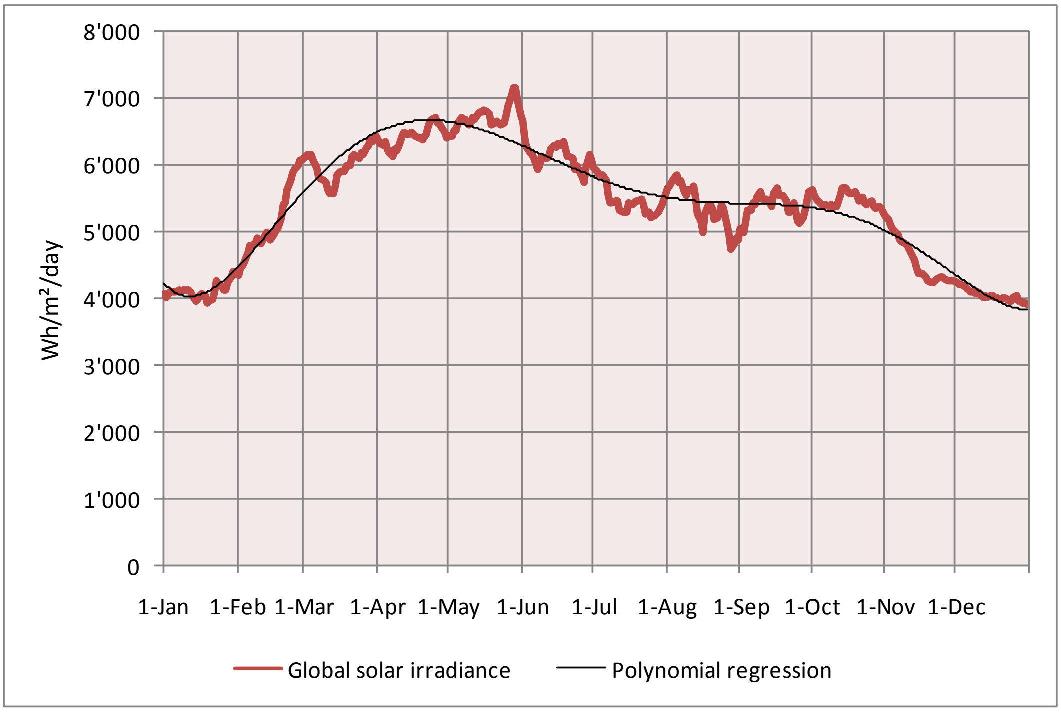


Figure 18: Global solar irradiance measured over the year in the station of Pheriche, expressed in pluriannual daily mean values (20).

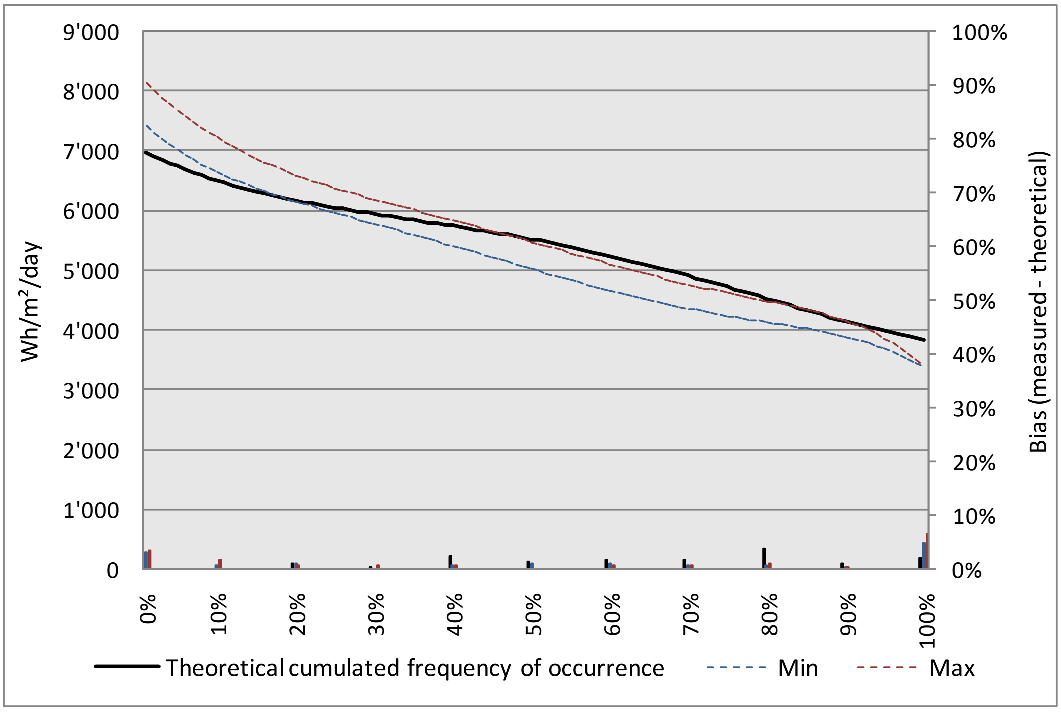


Figure 19: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Pheriche, expressed in daily mean values and absolute percentage error (20).

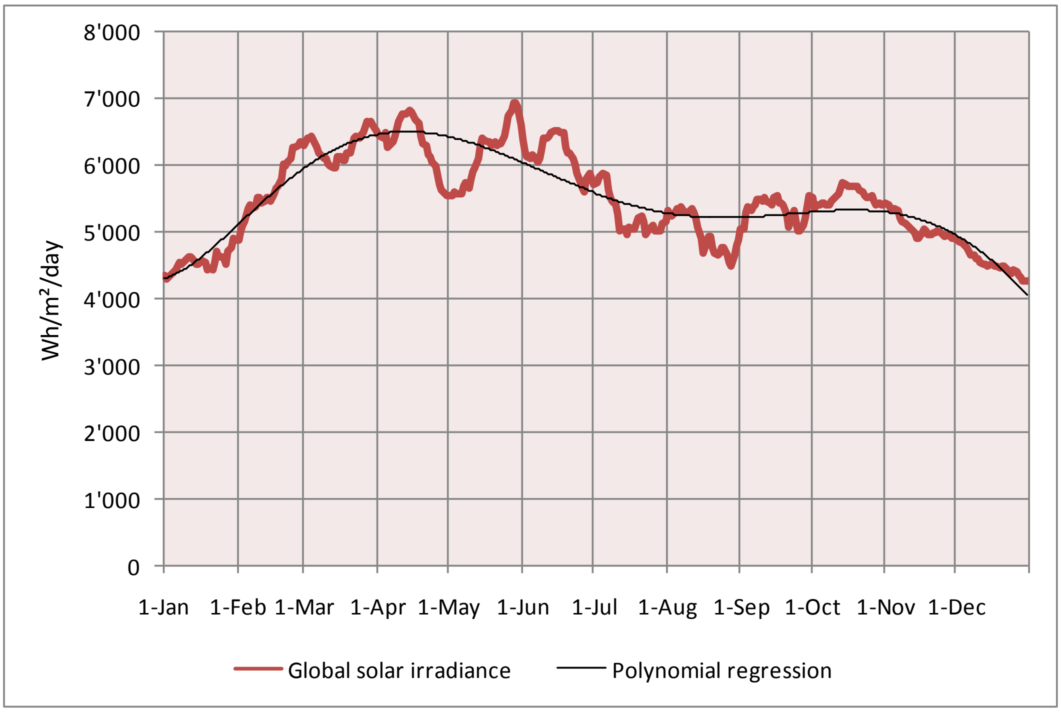


Figure 20: Global solar irradiance measured over the year in the station of Lobuche, expressed in pluriannual daily mean values (20).

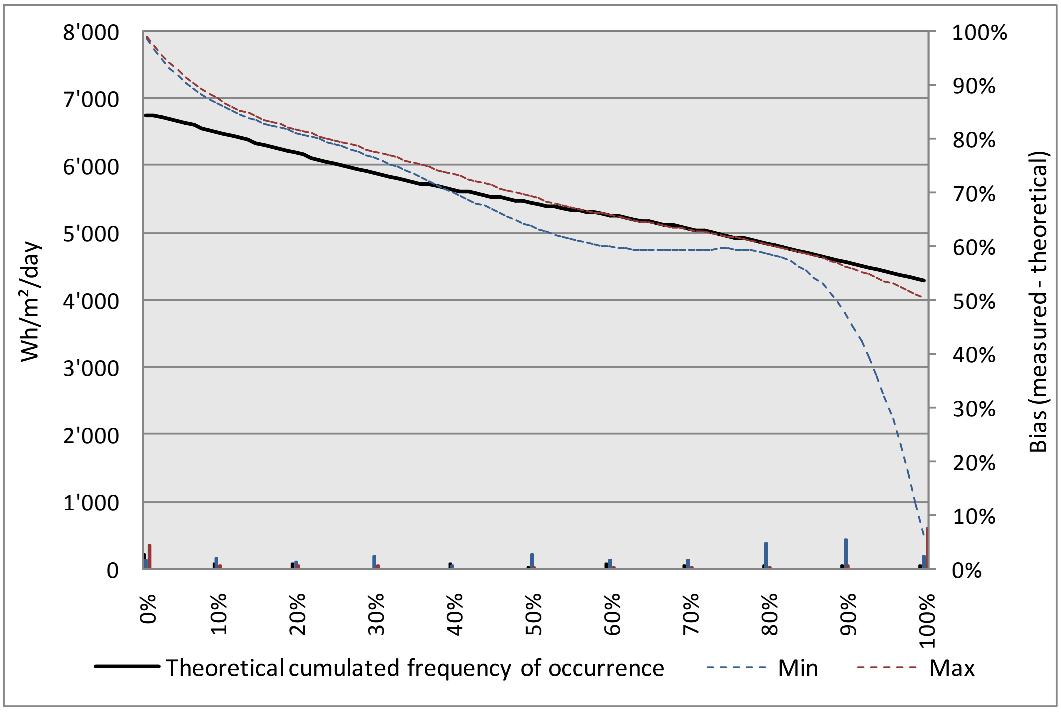


Figure 21: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lobuche, expressed in daily mean values and absolute percentage error (20).

Finally, in order to have more precise information on the Lukla-Chaurikharka area, the theoretical cumulated frequency of occurrence of the global solar irradiance was determined on a monthly scale for the automatic weather station installed there. The resulting curves and biases, in addition to those for the minimum and maximum months for each month of the year, are available in the Appendix A (Figure 65 to Figure 76).

3.5. Comparison

As stated previously, the ground measurements were then used to confirm the area estimations derived from the GHI model at 10 km. resolution. While the former were taken between the 1st of October 2002 and the 31st of December 2009, the latter were generated for the years 2000, 2002, and 2003. It is unfortunate the respective time periods do not overlap well and that the precision of the GHI models at 40 km. and 1° degree resolution is not sufficient for comparing specific sites at such a local scale. Nonetheless, the comparison was done using the first model on the monthly daily mean values and on the average over the year 2003 for the stations in Lukla-Chaurikharka, Namche, Pheriche, and Lobuche, as shown in Table 2. The bias (i.e. the difference between the collected and generated data) is shown as well and is expressed in percentage error.

$Wh/m^2/day$	Lukla-Chaurikharka	GHI 10km	Bias	Namche	GHI 10km	Bias
January	3'893	4'001	*3%*	3'983	3'984	*0%*
February	3'857	3'852	*0%*	4'498	3'776	*-16%*
March	4'220	4'231	*0%*	5'814	4'376	*-25%*
April	5'066	4'530	*-11%*	6'740	4'594	*-32%*
May	5'198	6'209	*19%*	7'366	6'637	*-10%*
June	3'665	5'785	*58%*	4'985	6'182	*24%*
July	2'980	5'269	*77%*	4'305	5'495	*28%*
August	3'541	5'234	*48%*	4'729	5'227	*11%*
September	3'402	4'792	*41%*	4'281	4'806	*12%*
October	4'432	4'318	*-3%*	5'070	4'543	*-10%*
November	3'829	3'970	*4%*	4'454	4'119	*-8%*
December	3'337	3'236	*-3%*	3'489	3'210	*-8%*
Annual average	**3'952**	**4'624**	***17%***	**4'978**	**4'752**	***-5%***

$Wh/m^2/day$	Pheriche	GHI 10km	Bias	Lobuche	GHI 10km	Bias
January	4'197	4'000	*-5%*	4'692	3'955	*-16%*
February	4'981	3'836	*-23%*	5'473	3'965	*-28%*
March	6'077	4'414	*-27%*	6'128	4'669	*-24%*
April	6'907	4'674	*-32%*	6'290	4'931	*-22%*
May	7'837	6'912	*-12%*	6'886	7'017	*2%*
June	6'098	6'860	*12%*	5'259	7'002	*33%*
July	5'131	5'765	*12%*	4'953	5'701	*15%*
August	5'434	5'562	*2%*	4'627	5'952	*29%*
September	5'533	4'922	*-11%*	4'757	5'043	*6%*
October	5'647	4'598	*-19%*	5'684	4'851	*-15%*
November	4'876	4'334	*-11%*	5'283	4'391	*-17%*
December	3'996	3'316	*-17%*	4'409	3'320	*-25%*
Annual average	**5'561**	**4'939**	***-11%***	**5'369**	**5'072**	***-6%***

Table 2: Comparison between the ground measurements and area estimations over the year 2003, expressed in pluriannual daily mean values and percentage error (17) (20).

Based on the collected and generated data at hand, the following observations can be made:

- If the annual averages are in relatively good accordance with biases going from -11% to +17% in percentage error, the area estimations on a monthly scale are less accurate (especially for the station of Lukla-Chaurikharka with a bias going up to +77%). This means that the seasonal evolution of the global solar irradiance is not correctly taken into account by the model;
- Except for the months between June and September, the model has a tendency to underestimate the global solar irradiance all year round (the station of Lukla-Chaurikharka is excluded). This suggests a seasonal effect as the time period corresponds perfectly to the raining season when the hours of sunlight are diminished;
- A site dependence can be pointed out in the station of Lukla-Chaurikharka explaining the model's high inaccuracy and strong tendency to overestimate the global solar irradiance during the raining season. The reasons for this dependence are detailed in the following subchapter.

Therefore, the area estimations derived from the GHI model at 10 km. resolution can be used to demonstrate the solar potential in Nepal and in the Khumbu valley but certain precautions must be taken for the evaluation of specific sites. The model is not reliable for the Lukla-Chaurikharka area during the raining season although it does indicate lower levels of solar radiation in the adjacent area to the south (Figure 12). It is important to add that these observations were made after comparing data over a limited time period meaning additional time series need to be generated in order for them to be fully validated. Nonetheless, models incorporating geostationary satellite images and global weather observations become increasingly performing and give often better estimation of the global solar irradiance than ground measurements, especially if the station is not situated in the near vicinity of the application (21).

3.6. Seasonal, annual & spatial variation

In order to fully assess the solar potential in the Khumbu valley, and more precisely in the Lukla-Chaurikharka area, it is crucial to analyze the inter-annual and inter-month variability of the global solar irradiance as well as its spatial variation. All the ground measurements collected between the 1st of October 2002 and the 31st of December 2009 in the four automatic weather stations installed in Lukla-Chaurikharka, Namche, Pheriche, and Lobuche were included. The reference annual average for each site was determined by the pluriannual daily mean value over the entire time period. It was then used as normalization for the annual and monthly averages, respectively expressed in annual daily mean values and pluriannual monthly daily mean values. All values are given in Table 3 and Table 4, except for the annual averages with an extended time period of missing data that were neglected. The deviation (i.e. the difference between the reference annual average and the annual and monthly averages) is shown as well and is expressed in percentage.

Wh/m²/day	Lukla-Chaurikharka	Deviation	Namche	Deviation
2002	-	-	-	-
2003	3'952	1%	4'978	3%
2004	-	-	-	-
2005	4'008	3%	4'956	2%
2006	-	-	-	-
2007	3'700	-5%	-	-
2008	-	-	4'808	-1%
2009	4'056	4%	-	-
Annual average	**3'895**		**4'837**	

Wh/m²/day	Pheriche	Deviation	Lobuche	Deviation
2002	-	-	-	-
2003	5'561	3%	5'369	-2%
2004	-	-	-	-
2005	5'306	-2%	5'503	0%
2006	5'320	-2%	5'678	3%
2007	5'142	-5%	5'276	-4%
2008	-	-	5'537	1%
2009	-	-	5'644	3%
Annual average	**5'408**		**5'497**	

Table 3: Inter-annual variability of the global solar irradiance and deviation from the reference annual average, expressed in annual daily mean values and percentage (20).

Wh/m²/day	Lukla-Chaurikharka	Deviation	Namche	Deviation
January	3'711	-5%	3'738	-23%
February	4'011	3%	4'603	-5%
March	4'484	15%	5'622	16%
April	4'870	25%	6'488	34%
May	4'556	17%	6'406	32%
June	3'488	-10%	4'854	0%
July	3'021	-22%	4'351	-10%
August	3'184	-18%	4'570	-6%
September	3'505	-10%	4'369	-10%
October	4'423	14%	4'951	2%
November	3'900	0%	4'359	-10%
December	3'600	-8%	3'890	-20%
Annual average	**3'895**		**4'837**	

Wh/m²/day	Pheriche	Deviation	Lobuche	Deviation
January	4'097	-24%	4'518	-18%
February	5'164	-5%	5'706	4%
March	6'002	11%	6'314	15%
April	6'447	19%	6'349	16%
May	6'736	25%	6'179	12%
June	6'120	13%	6'160	12%
July	5'449	1%	5'275	-4%
August	5'418	0%	5'006	-9%
September	5'354	-1%	5'312	-3%
October	5'466	1%	5'540	1%
November	4'567	-16%	5'082	-8%
December	4'041	-25%	4'532	-18%
Annual average	**5'408**		**5'497**	

Table 4: Inter-month variability of the global solar irradiance and deviation from the reference annual average, expressed in pluriannual monthly daily mean values and percentage (20).

Based on the series of ground measurements at hand, the following observations can be made:

- The inter-annual variability of the global solar irradiance remains low and does not exceed 5% of the reference annual average of the site in absolute percentage in any of the four automatic weather stations;
- The inter-month variability of the global solar irradiance is relatively high going up to 34% for the station of Namche, 25% for the stations of Lukla-Chaurikharka and Pheriche, and 18% for the station of Lobuche;
- The seasonal evolution of the global solar irradiance follows a similar pattern in all four automatic weather stations with strong positive deviations during several months around April and May and then weaker ones in October;
- In the stations of Namche, Pheriche, and Lobuche, the strongest negative deviations can be noted in December and in January, while the effects of the raining season on the global solar irradiance remain relatively low between June and September. As for the station of Lukla-Chaurikharka, it stands once more as an exception with the strongest negative deviations during the raining season and weaker ones in December and in January. This could explain the model's high inaccuracy and strong tendency to overestimate the global solar irradiance all year round and especially during the raining season, as shown in Table 2;
- Although the data sets of all four automatic weather stations have relatively similar tendencies, significant differences can be seen when comparing the amount of global solar irradiance in absolute values. For instance, the reference annual averages for the stations of Lukla-Chaurikharka, Namche, Pheriche, and Lobuche are respectively 3,895, 4,837, 5,408, and 5,497 Wh/m²/day and thus indicate a strong spatial variation.

Therefore, the inter-annual variability of the global solar irradiance can be easily accounted for knowing it does not exceed 5% of the reference annual average of the site. As for the inter-month variability, it rarely exceeds 25% and can be neglected or only partially accounted for depending on the consumption profile of the user and its distribution over the year. For instance, the consumption in the schools is greatly reduced during the summer and winter holidays that happen to be the periods with lower levels of solar radiation. It is also important to note that solar and hydro energy can be complementary. The levels of solar radiation are significantly diminished in the Lukla-Chaurikharka area during the raining season but the precipitations are at their highest, favoring the hydro resource. Conversely, the period of low water in the Bom Khola micro-hydro power plant generally starts in November and ends around April or May during which the hours of available sunlight are amply sufficient. This can be very convenient in the case of a grid-connected solar electric system.

The crucial point in all this is estimating the spatial variation when determining the solar potential of a location that is not situated in the near vicinity of a measuring station. Significant differences can be seen when comparing the absolute amount of global solar irradiance in each site. Several factors can explain these differences starting with the variation in altitude and thus in atmospheric pressure and in air mass. Indeed, as solar radiation reaches the earth's surface, it is partially absorbed and diffused by the atmosphere. The air mass coefficient (AM) represents the quantity of atmosphere the solar radiation travels through to reach the earth's surface and defines the available solar spectrum. Regions located near the equator and at high altitudes generally offer a better solar resource than the more temperate latitudes and lower altitudes because the quantity of atmosphere to penetrate is smaller. The stations in Lukla-Chaurikharka, Namche, Pheriche, and Lobuche are respectively located at 2,660 m., 3,560 m., 4,258 m., and 5,079 m., suggesting different air mass coefficients.

The surrounding topography has also an important effect on the solar radiation received in a given location. On-site observations state that cloud formations generally arrive in the Khumbu valley in the middle of the day. Knowing that the sun rises in the east and sets in the west, an eastern solar exposure will generally offer more hours of sunlight than the opposite. The different zones of elevation in Figure 13 give a rough indication on the surrounding mountains and what type of exposure to expect; the station of Lukla-Chaurikharka has a western solar exposure that competes poorly with the south-eastern solar exposure of Namche and Pheriche.

Finally, the last and probably most important factor is the local weather conditions. The Lukla-Chaurikharka area clearly has a climate that differs from the other sites. It is the combination of factors such as the lower altitude, the western solar exposure, and the microclimate of the area that cause the absolute amount and seasonal evolution of global solar irradiance to be so different. It also explains the differences in the curves displaying the global solar irradiance and the related theoretical cumulated frequency of occurrence (Figure 14 to Figure 21). For instance, it is not uncommon the Tenzing-Hillary Airport in Lukla has to cancel all flights for an extended time period due to extreme fog although the weather conditions in Namche, Pheriche, and Lobuche are good. Hence, when sizing solar installations in the Khumbu valley, it is absolutely crucial to take into account the local weather observations provided by the local people. The accumulated experience of farmers, porters, mountain guides, as well as airplane and helicopter pilots in the region can be used as reference and as reliable indicators. The inaccuracy of the GHI model at 10 km. resolution for the Lukla-Chaurikharka area during the raining season stands as proof that results produced by state-of-the-art methods with the best-known satellite data are not always sufficient.

Despite the relatively strong monthly and spatial variations, the Khumbu valley has a prime solar energy resource which remains to be exploited. The annual averages of global solar irradiance measured in the four automatic weather stations mentioned previously were compared with those of other sites in Switzerland, Southern Europe and Northern Africa. They were determined by the pluriannual daily mean values over different time periods. Table 5 shows extremely high annual averages in the stations of Namche, Pheriche, and Lobuche, surpassed only by the values measured in station of Tamanrasset in Algeria. The station of Lukla-Chaurikharka remains a good site as well for exploiting solar energy with relatively high annual averages (compared to Switzerland for instance). The fact that solar panels are also more efficient in cold climates goes to the advantage to the sites located in the Khumbu valley where there are ample hours of sunlight and the temperatures remain generally low.

Station	Altitude (m)	Climate	Latitude (°)	Longitude (°)	Period	Annual average (Wh/m^2/day)	Operated by
Lukla-Chaurikharka	2'660	High alpine	27.70	86.72	2002-2009	3'895	Ev-K2-CNR Committee
Namche	3'560		27.80	86.71		4'837	
Pheriche	4'258		27.90	86.82		5'408	
Lobuche	5'079		27.96	86.81		5'497	
Zürich Kloten (Switzerland)	558	Temperate atlantic	47.38	8.57	1999-2006	3'107	ANETZ - Météo Suisse
Geneva (Switzerland)	420	Semi-continental	46.20	6.13		3'477	CIE - UNIGE
Davos Dorf (Switzerland)	1'610	Semi-continental alpin	46.81	9.84		3'682	WRDC - Met Office
Sion (Switzerland)	489	Dry alpine	46.22	7.33		3'712	ANETZ - Météo Suisse
Carpentras (France)	100	Mediterranean	44.08	5.06		4'332	BSRN - Météo France
Thessaloniki (Greece)	60	Mediterranean temperate	40.63	22.97		4'329	WRDC - Met Office
El Saler (Spain)	10	Semi arid	39.35	-0.32		4'526	FluxNet
Tamanrasset (Algeria)	1'400	Hot, dry desert	22.78	5.52		6'447	BSRN - Met Office

Table 5: Comparison between the ground measurements in different sites, expressed in pluriannual daily mean values (20) (22).

Finally, the curves displaying the theoretical cumulated frequency of occurrence of the global solar irradiance show that a level of radiation of 4.0 kWh/m²/day is equalled or exceeded approximately 80% of the time in station of Namche (Figure 17) and 90% of the time in the stations of Pheriche (Figure 19) and Lobuche (Figure 21). As for the station of Lukla-Chaurikharka (Figure 15), a level of radiation of 3.0 kWh/m²/day is equalled or exceeded approximately 90% of the time. These values provide an excellent indication on the amount of global solar irradiance that can be expected in each site over the year.

Chapter 4
"Pilot" PV system in Chaurikharka

4.1. Context

To complete successfully the objective of equipping both schools with brand new computers, reliable power sources are required as much in the primary school of Lukla than in the secondary school of Chaurikharka. The electrical system of the former infrastructure, although faulty and subject to strong power shortages, is connected to the Lukla power grid. A computer room was built in 2009 and the school was provided with 12 desktops by the United Kingdom charity Classrooms in the Clouds. As for the secondary school of Chaurikharka, being supplied by only a few pico-hydro power plants owned by private individuals, it could not support such a load and building a computer room without planning a new energy source was out of the question. The eventual possibility of connecting the school to the Lukla power grid was rejected by the town officials due to the number of concerns already raised about the excess of demand and current lack of supply. In addition, this solution would have proven to be suboptimal due to the expected losses while transmitting electricity over the distance separating the micro-hydro power plants of Lukla and the school of Chaurikharka using a 400V, three-phase power line (being compliant to the local standards).

Having all this in mind, the Swiss association Lukla-Chaurikharka considered the situation in the secondary school of Chaurikharka as a matter of urgency and searched for an alternative energy source. A stand-alone solar electric system proved rapidly to be the best solution. In this chapter, the school and the work that was accomplished on the "pilot" PV system as well as its complete evaluation will be presented.

4.2. School information

Mahendra Jyoti Higher Secondary School Chaurikharka (referred to in this thesis as the secondary school of Chaurikharka for reading purposes) was founded in 1958 by Sir Edmund HILLARY. Statistical data, including the number of students and teachers per year, was collected on the school for over a decade. It is available in the Appendix B (Table 10) (Table 11), from which the following observations can be made:

- Between 1999 and today, the number of students has increased by 46%, from 226 to 329 in total, and the number of teachers by 50%, from 12 to 18 in total. This suggests that the balance between the number of students and teachers has been maintained throughout the years;
- New classes for grades eleven and twelve started to be administered in 2009 and 2010, increasing the population of the school by 17 students in 2009, 25 in 2010, and 33 in 2011;

– The gender ratio is defined by the proportion of boys to girls that attend the school; if it is equal to 1 there is a perfect balance in boy and girl attendance, if it is greater than 1 there is a gender imbalance in favor of boys, and if it is less than 1 the imbalance is in favor of girls. The evolution of the gender ratio between 1999 and today is given in Figure 22. The average over the entire time period is 1.07 and the linear regression indicates that the ratio of boys to girls is slightly increasing with the years;

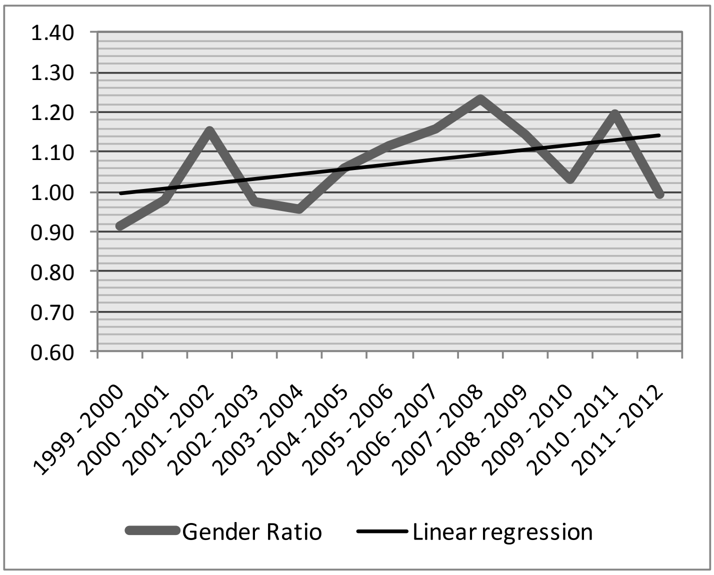


Figure 22: Evolution of the gender ratio in the secondary school of Chaurikharka between 1999 and today (4).

– The number of students per class varies significantly from one grade and from one year to the next. For instance, there were 48 students in grade one in 2001-2002 and then only 9 in grade two the following year, meaning the population of the class decreased by 81%. Another example is that there were 12 students in grade five in 2003-2004 and then 53 in grade six the following year, meaning the population of the class increased by 342%. The average variations from one grade to the next between 1999 and today is given in Table 6. The strong negative value in **a)** can be explained by the fact that the students in grade one also include the smaller children that repeat one year or more before entering grade two. The primary school of Lukla did not administer classes for grades six and seven until 2010 and 2011, meaning the students had to change schools once they completed grade five. This explains the extremely strong positive value in **b)**.

G1-2	G2-3	G3-4	G4-5	G5-6	G6-7	G7-8	G8-9	G9-10
-55%	-12%	-11%	13%	161%	-7%	10%	3%	-27%
a)				b)				

Table 6: Average variations in the number of students from one grade to the next in the secondary school of Chaurikharka between 1999 and today, expressed in percentage (4).

In a more general manner, there are several external factors that can explain the relatively strong positive and negative variations in the number of students from one grade and from one year to the next. Education in Nepal is strongly recommended but is not compulsory. It is not uncommon that the children have to work on the fields in order to help out their families and therefore do not attend school for an extended time period. There is also a strong fluctuation of families moving in and out of the Khumbu valley with their children depending on the work opportunities there are in the area. Finally, both the primary school in Lukla and the secondary school in Chaurikharka administer classes from grades one to seven and their attendance boundaries overlap, causing the students to often change from one school to the other along the way. Despite the constant turnover of students, the school has developed at a relatively fast pace, as shown in Figure 23.

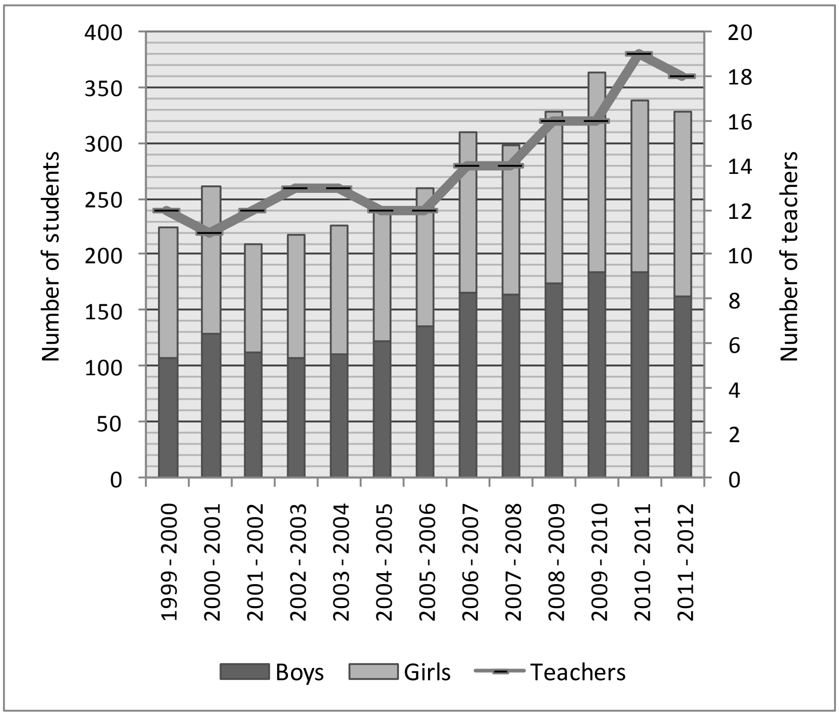


Figure 23: Number of students and teachers per year in secondary school of Chaurikharka between 1999 and today (4).

Such a development was made possible with the involvement and support of diverse organizations such as associations, non-governmental organizations (NGO), foundations, and other financial institutions. For instance, the Swiss association Lukla-Chaurikharka provides two-thirds of the teachers' salaries for the higher secondary level (i.e. grades eleven and twelve) while the school covers the remaining third with tuition fees. The infrastructure (Figure 24) has also known considerable improvements throughout the years thanks to the following sponsors and partners:

- Himalayan Trust, Nepal, 1958 – Building A;
- Rotary Club of Lausanne[1], Switzerland, 1991 – Building B;
- Shizen Wo Aisuru Kai, Japan, 2003 – Building C;
- Ced-Népal, France, 2009 – Building D;
- Swiss association Lukla-Chaurikharka, Switzerland, 2011 – Building E.

[1] The sponsor was approached by Denis BERTHOLET on behalf of the school.

The other buildings were sponsored by private individuals or public entities from different countries at different times. Additional information on the secondary school of Chaurikharka, such as the names of the teachers and committee members for the year 2011-2012 as well as the student population projections, can be found in the Appendix B (Table 14) (Figure 77).

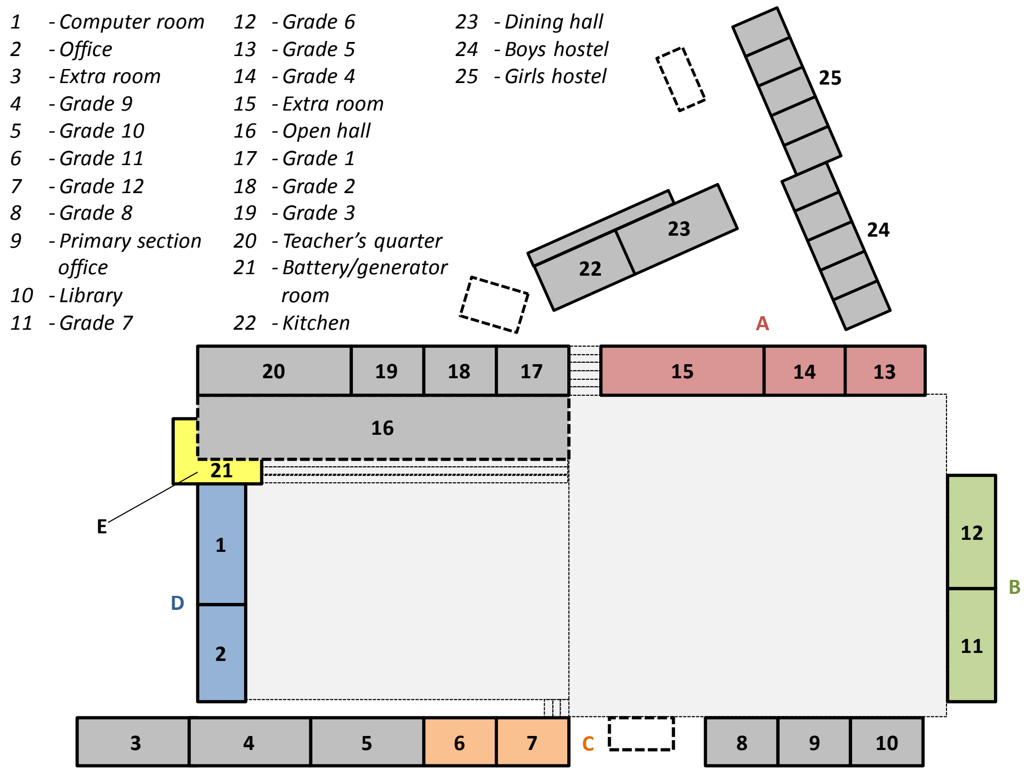


Figure 24: Plan of the secondary school of Chaurikharka (4).

4.3. Solar installation

In 2011, the Swiss association Lukla-Chaurikharka was approved financial support from the Délégation Genève Ville Solidaire to provide the secondary school of Chaurikharka with a stand-alone solar electric system. Two volunteers, Bernard MAGNIN and Nicolas COSANDEY, were called upon to accomplish this mission with the help of Denis BERTHOLET, René GREINER, Marco VUADENS, Henri BUTTICAZ, and myself. Many local people participated as well including Phurba Gyaltzen SHERPA, Jangbhu SHERPA, Purnima SHERPA, and Dawa Tshiring SHERPA. The sizing of the "pilot" PV system was based on the calculations made by Bernard MAGNIN and on his substantial experience in the matter as an electrician. The solar panels and battery cells were purchased from Solar Solutions Pvt. Ltd. in Kathmandu, Nepal, while the rest of the equipment was shipped by plane from Studer Innotec SA in Sion, Switzerland. A budget report of the installation is available in the Appendix C (Table 16). All the material was transported to the school by helicopter between the 7th and the 9th of October 2011 thanks to the implication of Lhakpa Gyalzen SHERPA. The following photographs illustrate step by step the work that was accomplished on the "pilot" PV system until its completion on the 19th of October 2011.

Figure 25: Unloading the helicopter, 7th of October 2011 (4).

Figure 26: Nicolas and Bernard carrying an 80kg battery cell, 7th of October 2011 (4).

Figure 27: Two locals and Phurba digging a trench for the electric cables, 8th of October 2011 (4).

Figure 28: Helicopter transporting more material to the school, 9th of October 2011 (4).

Figure 29: Me and Jangbhu carrying another 80kg battery cell, 9th of October 2011 (4).

Figure 30: Denis and Marco opening up the ceilings in the classrooms, 9th of October 2011 (4).

Figure 31: Nicolas and Bernard fixing a rack on the roof, 9th of October 2011 (4).

Figure 32: Me and Henri connecting the battery cells, 9th of October 2011 (4).

Figure 33: Bernard and Purnima mounting the solar panels on a rack, 10th of October 2011 (4).

Figure 34: René and Phurba preparing the neon armatures, 11th of October 2011 (4).

Figure 35: Me and Bernard connecting the solar panels, 11th of October 2011 (4).

Figure 36: Computer room serving as a workshop and depot, 12th of October 2011 (4).

Figure 37: Dawa, Denis, and Phurba consulting each other, 12th of October 2011 (4).

Figure 38: Nicolas pulling wires to the classrooms, 12th of October 2011 (4).

Figure 39: Me setting up all the switches, 12th of October 2011 (4).

Figure 40: Nicolas and Bernard checking the switchboard, 12th of October 2011 (4).

Figure 41: Jangbhu, Nicolas, and Marco pulling wires to the other buildings, 14th of October 2011 (4).

Figure 42: "Pilot" PV system completed, 19th of October 2011 (4).

In order to assemble a stand-alone solar electric system that has 4.3 kWp of solar power and 60 kWh of battery supply, the entire electrical system of the school was renovated and the following components were installed:

- 24 Suntech STP180S-24/Ad 180W monocrystalline solar panels;
- 2 TriStar Maximum Power Point Tracker (MPPT) 60A 12-48V regulators;
- Amara Raja Maintenance Free Valve Regulated Lead–Acid (MF-VRLA) 48V-1275Ah battery (24 cells of 2.30V);
- Studer Xtender XTM 4000-48 inverter;
- Studer Xtender series Battery Status Processor BSP 500;
- Studer Remote Control Center RCC-02;
- Studer Battery Temperature Sensor BTS-01;
- Honda EBK-2800 generator 2100VA;
- Visual alarm.

The electrical schema of the entire system can be found in the Appendix C (Figure 79). Basically, the solar panels are connected to the battery cells using maximum power point tracker (MPPT) regulators. Photovoltaic cells have a complex relationship between solar irradiation, temperature, and total resistance that produces a non-linear output efficiency known as the I-V curve (14 pp. 59-62). Based on the basic principle that power is the product of voltage and current, the MPPT technology adjusts the actual operating voltage or current of the PV cells so that the actual power approaches the optimum value as closely as possible, as shown in Figure 43 (23 p. 1). The battery cells are then connected to a battery status processor (BSP), to a battery temperature sensor (BTS), and eventually to an inverter. The BSP precisely calculates the state of charge (SoC) of the battery using an algorithm, while the inverter converts the direct current (DC) to alternative current (AC) at any required voltage and frequency. It produces a near-perfect sine wave output with practically no harmonic distortion making the current compatible with all AC electronic devices. As for the remote control center (RCC), it provides the display, the data logging, the system settings as well as the graphical display of the SoC history. A visual alarm is connected to the inverter and activates either when the battery is low and the SoC reaches 60% or when the power usage exceeds 80% of the inverter's power rating of 4000W. Once activated it automatically deactivates once the SoC reaches 70% or when the power usage remains under 3200W. Finally, a backup generator is available and can be turned on when the battery is too low, the visual alarm serves as a warning signal.

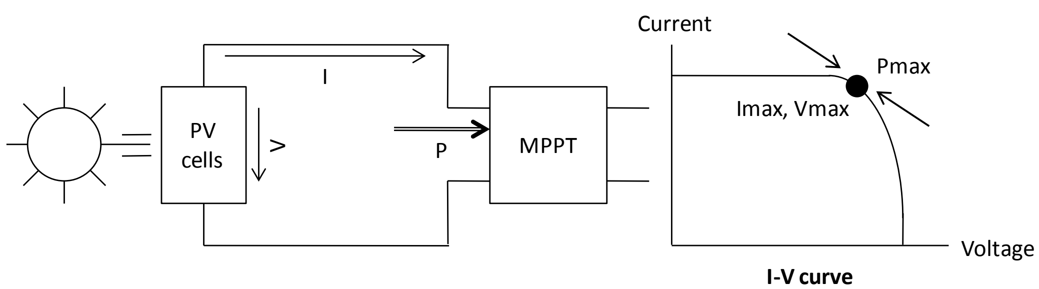


Figure 43: Maximum power point tracker principle (4).

The roof on which the solar panels were mounted is orientated at approximately 14° southwest and tilted at approximately 20° from horizontal, offering a near-optimal solar exposure considering the surrounding mountains and the location's latitude. In total, the school was equipped with 54 lamps (51 of 36W, 2 of 15W, and 1 of 26W) and 56 plugs (23 in the computer room, 2 in the office, 2 in the open hall, 2 in the teacher's quarter, and 1 in every other room).

On the 20th of October 2011, the Chaurikharka School Management Committee organized an inauguration ceremony with traditional dancing and singing for the Swiss association Lukla-Chaurikharka and for the completion of the "pilot" PV system (Figure 44) (Figure 45). The members of the association were offered "kata", which are considered as an auspicious symbol and meant to lend a positive note to the start of any venture or relationship. These long narrow scarves embody friendship, purity, goodwill, good fortune, harmony, and love. They are offered as a blessing, a thank you, or to wish someone good luck on a journey.

Figure 44: Traditional dancing and singing, 20th of October 2011 (4).

Figure 45: Distribution of "kata" as an offering of good fortune, 20th of October 2011 (4).

The following week was devoted to train the school personnel in order to guarantee the maintenance and the monitoring of the entire system over the long-term. A complete explanation on how the solar installation works was given to the teachers and a user manual was created to their attention. It is available in the Appendix C (Figure 80). In addition, all teachers and students were made aware of how fortunate they are to have such a reliable power source for themselves but were also sensitized on how to reduce their energy consumption by simply changing certain of their behaviors and by respecting a few guidelines. A poster and an etiquette resuming all the basic principles of energy conservation were created and are permanently displayed all around the school and above all the plugs. They can both be found in the Appendix C (Figure 81) (Figure 82).

Finally, the secondary school of Chaurikharka received several second-hand computers including 5 laptops from the United Kingdom charity Classrooms in the Clouds and another 6 desktops from a Korean sponsor. They were all installed in the computer room between the 22nd of November and the 2nd of December 2011 and are now fully operational (Figure 46) (Figure 47). This is a temporary solution while pending the purchase of brand new models by the Swiss association Lukla-Chaurikharka. The possibility of using thin clients and a terminal server is currently being explored with a volunteer information technology (IT) specialist, Nawang GELJEN. Basically, a thin client is a desktop computing device that has no hard drive and no application software running on it locally. Applications are executed from a terminal server while the thin client simply provides the screen display and a way to operate the keyboard and the mouse (24 p. 3). Compared to a system equipped with conventional computers, this technology could offer similar performances for a significantly lower price and power consumption, and less maintenance.

Figure 46: Computer room temporarily equipped with second-hand computers, 2nd of December 2011 (4).

Figure 47: Four of five laptops provided by the United Kingdom charity Classrooms in the Clouds, 2nd of December 2011 (4).

4.4. System evaluation

As stated previously, a remote control center was installed in the secondary school of Chaurikharka and connected to the stand-alone solar electric system. This electronic device enables the user to supervise the system and to adapt it totally to the needs by allowing the setting of the parameters available on the inverter. Thanks to its digital display, the RCC-02 provides clear and comprehensive indications on the state of the system. It also memorizes the events that occurred on the installation and therefore anticipates any future problems. A secure digital (SD) card reader is available, which allows the parameters recording and the data logging (25). Studer Innotec SA provides a data analysis tool programmed in Visual Basic. All the parameters available on the inverter were set by Bernard MAGNIN and myself on the 29th of October 2011. A complete explanation was given to the computer teacher, Kendra Mani RAI, a few weeks later. He was instructed to send the content of the SD card on a regular basis every six months in order to guarantee the monitoring of the system.

The first evaluation of the "pilot" PV system was done by analyzing the graphical display of the SoC history and battery current provided by the remote control center between the 1st of November and the 28th of December 2011. Figure 48 and Figure 49 clearly indicate the state of charge history; the high and low peeks correspond to the daily variations of the consumption versus the production (more energy consumption at the beginning and at the end of the day, more energy production in the middle of the day). Conditions of extreme fog occurred between the 2nd and the 6th of November 2011 and again between the 13th and 16th of November 2011 explaining the lower SoC during those time periods. The minimum and maximum values over the entire time period were 89.4% and 100%, respectively reached on the 15th and 7th of November 2011, while the average was 95%. The valve regulated lead–acid battery connected to the system is suitable for powering large loads over a long period of time. Its lifespan is guaranteed at 2,000 cycles for 50% depth of discharge or 1,200 cycles for 80% depth of discharge, meaning that maintaining the battery at a high SoC will prolong significantly its lifespan. Having installed the second-hand computers in the school was an excellent test for the "pilot" PV system as their energy consumption is greater than the models that are pending purchase (even more so if thin clients and a terminal server are considered) and that the weather conditions in November and in December 2011 were particularly bad. These values confirm that the system is in a healthy state and that the sizing was done appropriately.

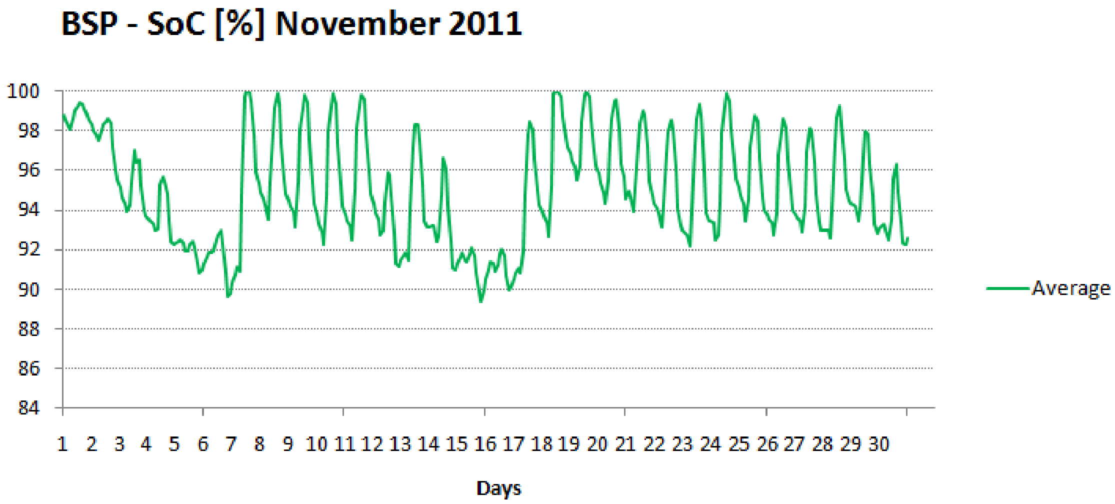


Figure 48: State of charge of the battery during the month of November 2011, expressed in percentage (4).

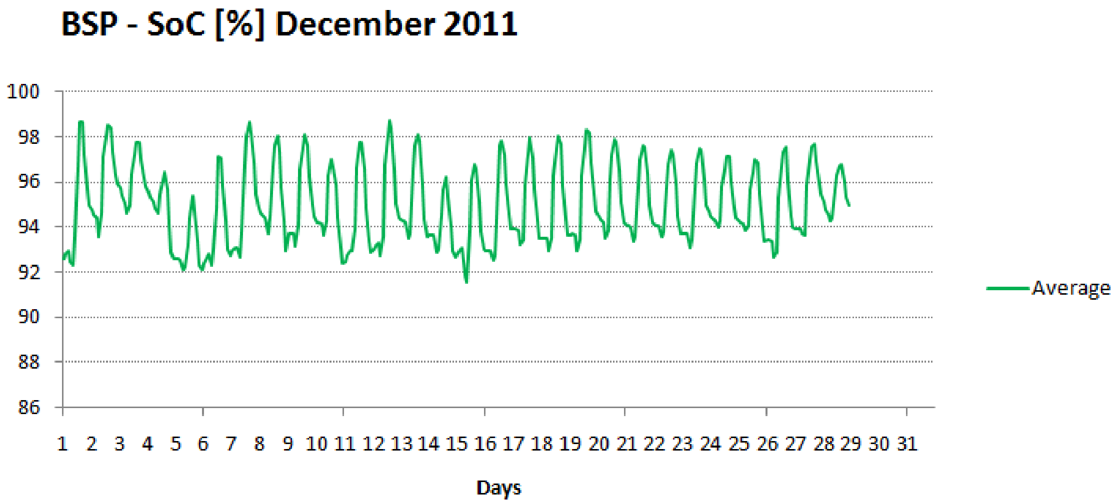


Figure 49: State of charge of the battery during the month of December 2011, expressed in percentage (4).

Figure 50 and Figure 51 indicate the battery current history; once again, the high and low peeks correspond to the daily variations of the consumption versus the production (negative current at the beginning and at the end of the day, positive current in the middle of the day). The effects of the extreme foggy conditions that occurred twice during an extended period of time in November 2011 can be easily seen when comparing the height of the positive peeks. The minimum and maximum values over the entire time period were -15.01A and 33.69A, respectively reached on the 23th and 18th of November 2011, while the average was -0.82A.

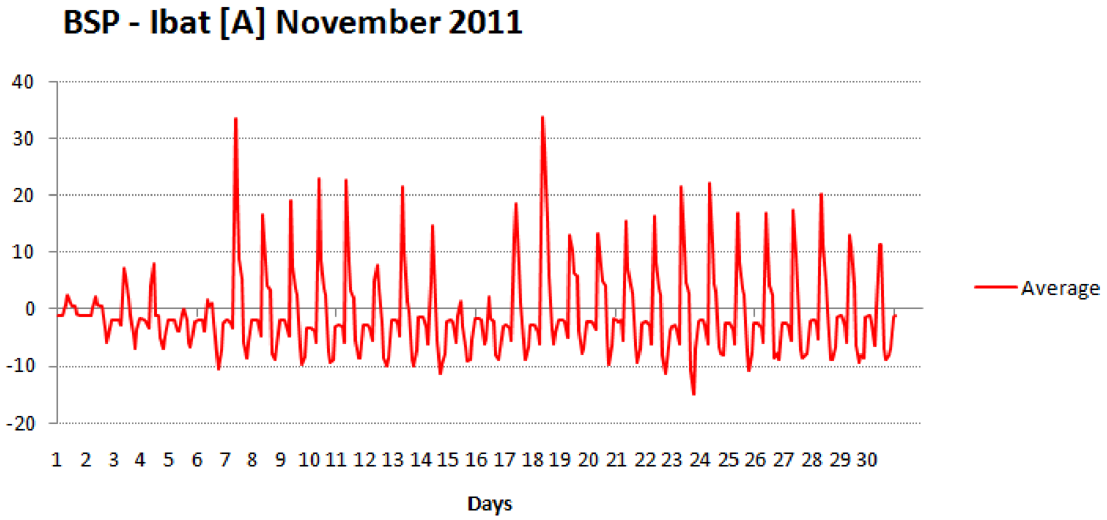


Figure 50: Battery current during the month of November 2011, expressed in amperes (4).

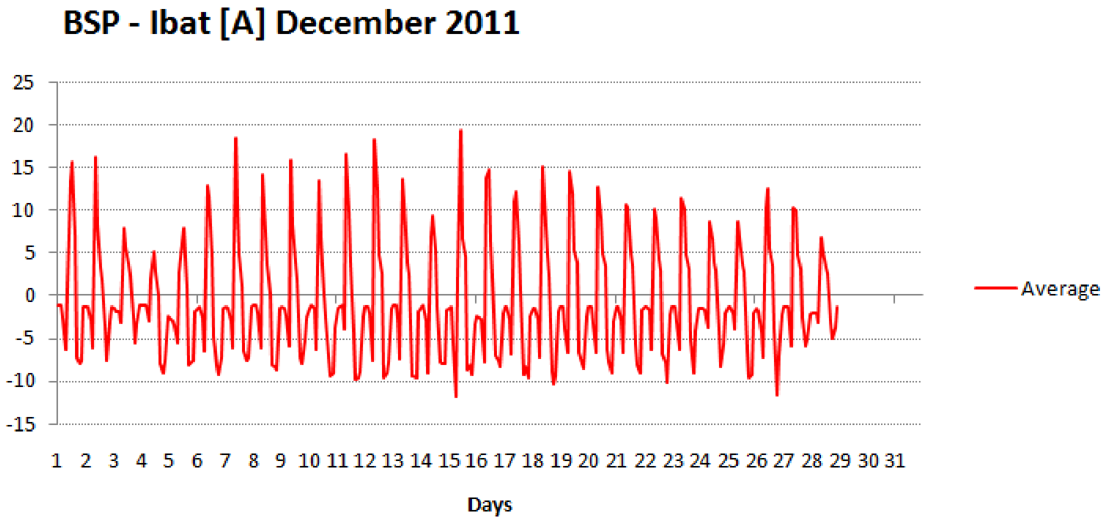


Figure 51: Battery current during the month of December 2011, expressed in amperes (4).

The PVsyst software was developed for the study, sizing and data analysis of complete photovoltaic systems. It deals with grid-connected, stand-alone, pumping, and DC-grid solar electric systems and includes extensive meteorological and component databases, as well as general solar energy tools (26 p. 1). In this case, it was used to conduct the second evaluation of the "pilot" PV system by estimating the electricity consumption of the secondary school of Chaurikharka and by running hourly production simulations. The basic parameters regarding the geographical site and the collector plane orientation were entered into the PVsyst software. These parameters include the latitude, longitude, altitude and time zone of the location as well as the tilt and azimuth of the installed solar panels. The consumption profile of the school was then computed by making an inventory of the daily consumptions (Table 7) and by defining the hourly distribution (Figure 52).

Annual values

Use 6 days a week	Number	Power	Use	Energy
Fluorescent lamps	54	36 W/lamp	5 h/day	9720 Wh/day
TV / Video-tape rec. / PC	11	100 W/app	5 h/day	5500 Wh/day
Total daily energy				15220 Wh/day

Table 7: Inventory of the daily consumptions in the secondary school of Chaurikharka (4).

The electric power for all the lamps and computers were intentionally overestimated with values of 36W per lamp and 100W per computer (local measurements done with a wattmeter suggest a maximum electric power of 75W per computer). The mean daily usage was also overestimated with values of 5 hours per day per lamp and 5 hours per day per computer. This represents a high consumption profile meant to test the "pilot" PV system's adequacy to practically any needs of the school. It is important to add that a six-day week was considered because there are no classes on Saturdays and that the holidays were counted as normal days.

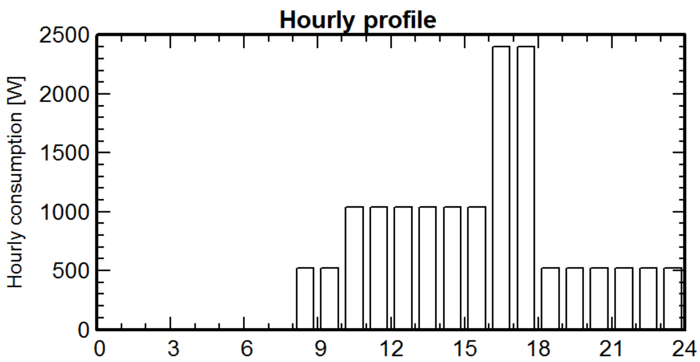


Figure 52: Hourly distribution of the consumption profile of the secondary school of Chaurikharka (4).

As for the hourly distribution, it was defined by four states: a maximum consumption of approximately 2,400W between 4pm and 6pm (mostly lighting), a high consumption of 1,000W between 10am and 4pm (mostly computers), a low consumption of 500W between 8am and 10am and between 6pm and 12pm (approximately 15 lamps for the kitchen, the dining hall, and the boys and girls hostel), and no consumption at all between 12pm and 8am.

The following adjustments were also made in the PVsyst software:

– The hourly values of air temperature and global solar irradiance collected between the 1st of October 2002 and the 31st of December 2009 in the station of Lukla-Chaurikharka were used to calculate pluriannual averages on an hourly basis over an entire year. These averages were then added to the existing meteorological database;

- The manufacturer specifications and model parameters of the Suntech STP180S-24/Ad 180W monocrystalline solar panels and the Amara Raja MF-VRLA 48V-1275Ah battery were added to the existing component database;
- The values of maximum input and output currents of the charging and discharging thresholds, as well as the values of power threshold and of nominal and maximal output powers of the TriStar MPPT-60A 12-48V regulator were modified. A multiplicative factor of two was applied to all of these values as two regulators were installed in the "pilot" PV system but the PVsyst software only admits one.

The results of the hourly production simulations are shown in Figure 53, expressed as normalized productions over the year. Basically, the solar panels produce approximately 5,740 kWh of electricity per year, of which 4,760 kWh are consumed and 870 kWh are in excess. The backup generator is used to produce 270 kWh during the raining season when the hours of sunlight are diminished. The solar fraction, meaning the amount of energy provided by the solar panels divided by the total energy required, is 94%. These values confirm that the sizing of the system was done appropriately. The complete evaluation report produced by the PVsyst software can be found in the Appendix D (Figure 83). If the monitoring of the "pilot" PV system reveals similar amounts of excess energy during the months between October and May, it would be of great interest to the local community to explore the possibilities of using it. The gompa monastery situated next to the school is already connected to a privately owned pico-hydro power plant, which is apparently frequently overloaded during the period of low water (that starts in November and ends around April or May). This point is currently being discussed among the committee members of the school and the Swiss association Lukla-Chaurikharka.

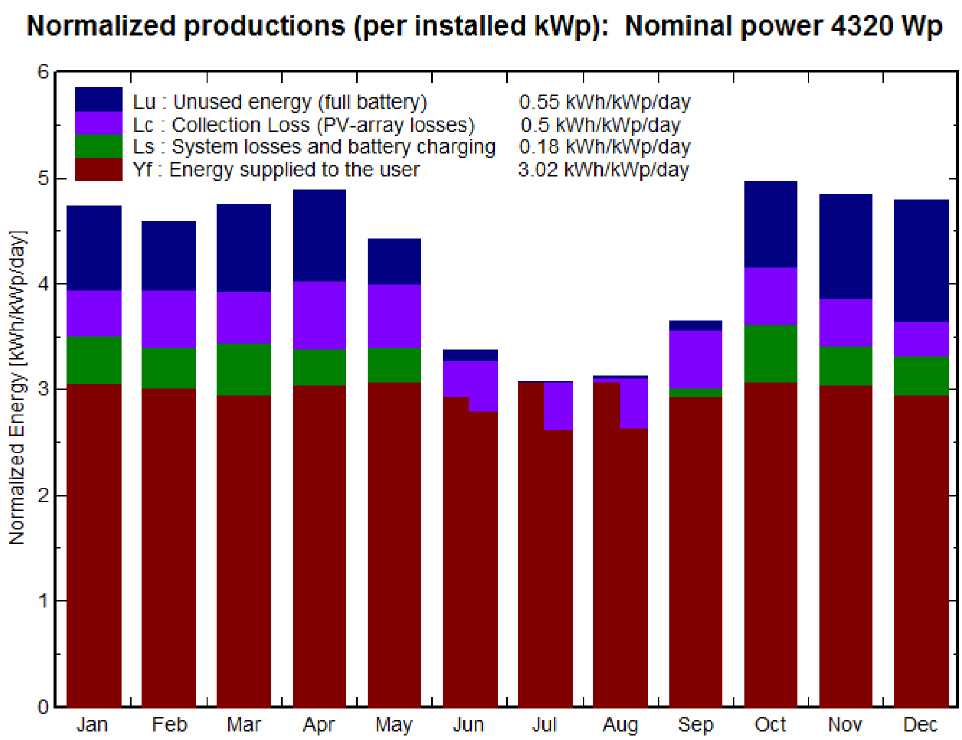


Figure 53: Normalized productions of "pilot" PV system over the year (4).

Chapter 5
Solar project design in Lukla

5.1. Context

The "pilot" PV system being completed in the secondary school of Chaurikharka, the question now remains whether the Lukla power grid can be considered as a reliable power source for the primary school of Lukla. Although this question has already been tacitly answered by the negative in Chapter 2, a feedback on the computer room that was built and equipped by the United Kingdom charity Classrooms in the Clouds in 2009 will confirm any doubts on the matter. Indeed, the computer room was provided with 12 brand new desktops that were directly connected to the school's electrical system without any electronic devices such as uninterruptible power supplies (UPS). This unfortunate lack of planning caused the permanent failure of 7 power units and probably several motherboards (Figure 54), leaving only 5 working desktops at present.

Figure 54: Seven power supplies that need to be replaced (4).

Hence, the electrical system in the primary school of Lukla, being faulty and subject to strong power shortages, represents an extremely harsh environment for the computers. Maintaining them in a working state is very challenging and presents an ongoing expense, a stand-alone solar electric system is therfore required.

In this chapter, the "pilot" PV system in the secondary school of Chaurikharka will be used as a reference to better size the future solar installation in the primary school of Lukla. An energy study and a solar installation design will be conducted by estimating its electricity consumption and by running hourly production simulations using the PVsyst software based on the collected meteorological data.

5.2. School information

Shree Lukla Lower Secondary School (referred to in this thesis as the primary school of Lukla for reading purposes) was founded in 1984 by Denis BERTHOLET and started off with a few classes being administered in private homes. The school was eventually recognized by the Government of Nepal and officially registered in 1986. It developed very rapidly ever since. Based on the statistical data that was collected on the school for over two decades and which is available in the Appendix B (Table 12) (Table 13), the following observations can be made:

- Between 1990 and today, the number of students has more than tripled, from 105 to 335 in total, and the number teachers doubled, from 6 to 12 in total. This suggests that the balance between the number of students and teachers has not been perfectly maintained throughout the years;
- As mentioned in Chapter 4, new classes for grades six and seven started to be administered in 2010 and 2011, increasing the population of the school by respectively 20 and 50 students. There is also a the possibility that a new class for grade eight will open starting from 2012;
- As a reminder, the gender ratio is defined by the proportion of boys to girls that attend the school; if it is equal to 1 there is a perfect balance in boy and girl attendance, if it is greater than 1 there is a gender imbalance in favor of boys, and if it is less than 1 the imbalance is in favor of girls. The evolution of the gender ratio between 1990 and today is given in Figure 55. The average over the entire time period is 0.96 and the linear regression indicates that the ratio of boys to girls is decreasing with the years;

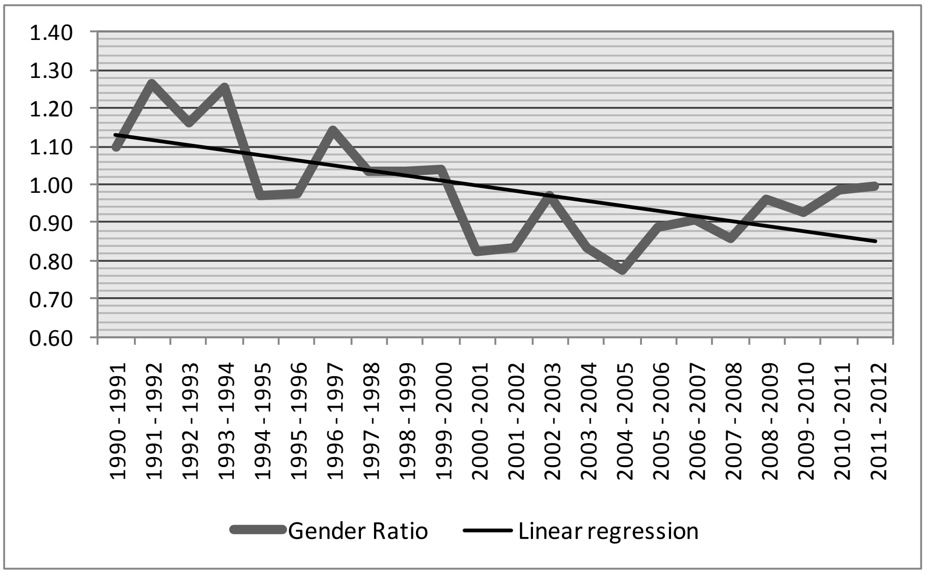


Figure 55: Evolution of the gender ratio in the primary school of Lukla between 1990 and today (4).

- The number of students per class from one grade and from one year to the next varies less than in the secondary school of Chaurikharka; the strongest positive and negative variations were respectively 38% and -79%, as opposed to 342% and -81%. The average variations from one grade to the next between 1990 and today is given in Table 8. It is important to add that the statistical data at hand included until today the number of students in grade one with the smaller children from the nursery, explaining the relatively strong negative value in **a)**.

G1-2	G2-3	G3-4	G4-5
-70%	-5%	-7%	-15%

a)

Table 8: Average variations in the number of students from one grade to the next in the primary school of Lukla between 1999 and today, expressed in percentage (4).

Although less noteworthy, the turnover of students in the primary school of Lukla is significant as well. It can be explained by the same external factors mentioned for the secondary school of Chaurikharka in the previous chapter such as education in Nepal being not compulsory, children having to help out their families, strong fluctuation of families moving in and out of the Khumbu valley, and students having to choose between the primary school of Lukla and the secondary school of Chaurikharka. Nonetheless, the school has known considerable development and a very rapid increase in the student population since the date of its foundation, as illustrated in Figure 56.

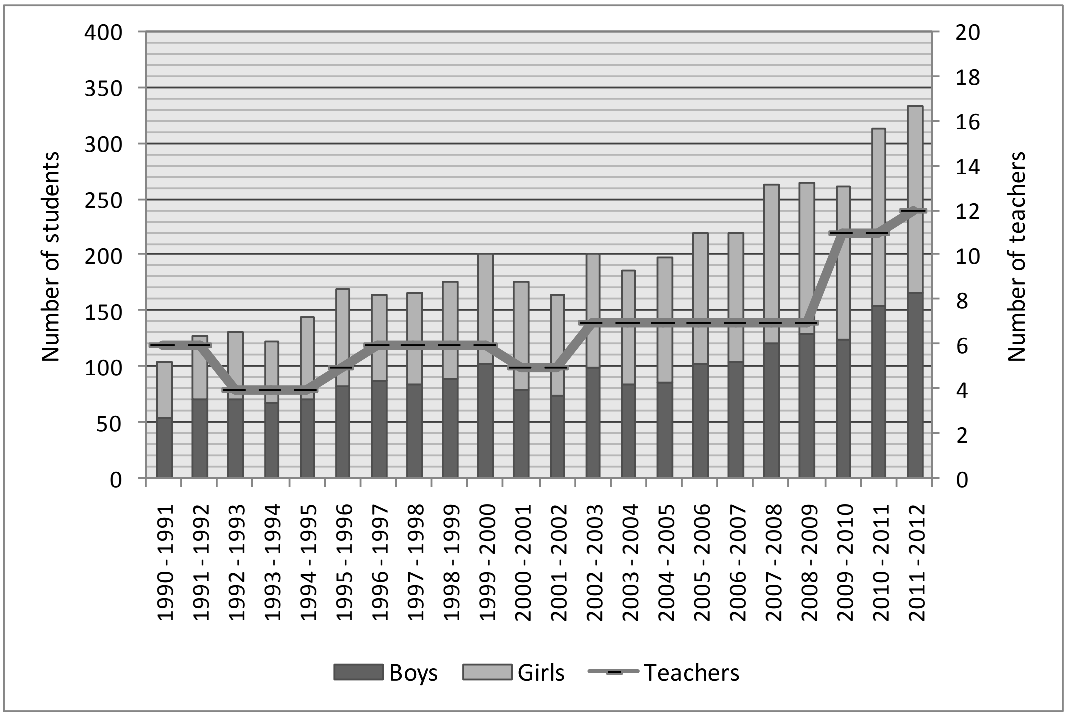


Figure 56: Number of students and teachers per year in the primary school of Lukla between 1990 and 2012 (4).

Such an impressive development was made possible with the involvement and support of diverse organizations such as associations, non-governmental organizations, foundations, and other financial institutions. For instance, the Swiss association Lukla-Chaurikharka and the United Kingdom charity Classrooms in the Clouds currently provide together four teacher salaries. The infrastructure (Figure 57) has also known considerable improvements throughout the years thanks to the following sponsors and partners:

– Frères de nos Frères, Switzerland, 1984 – Building A;
– Rotary Club of Lausanne[2], Switzerland, 1990 – Renovation of building A;
– Solidarité Enfants Népal, France, various dates – Buildings B & C;
– Classrooms in the Clouds, United Kingdom, 2009 – Computer room;
– Etat du Valais[3], Switzerland, 2010 – Reconstruction of building A;
– Classrooms in the Clouds, United Kingdom, 2011 – Library.

The other buildings were sponsored by private individuals or public entities from different countries at different times. Additional information on the primary school of Lukla, such as the names of the teachers and committee members for the year 2011-2012 as well as the student population projections, can be found in the Appendix B (Table 15) (Figure 78).

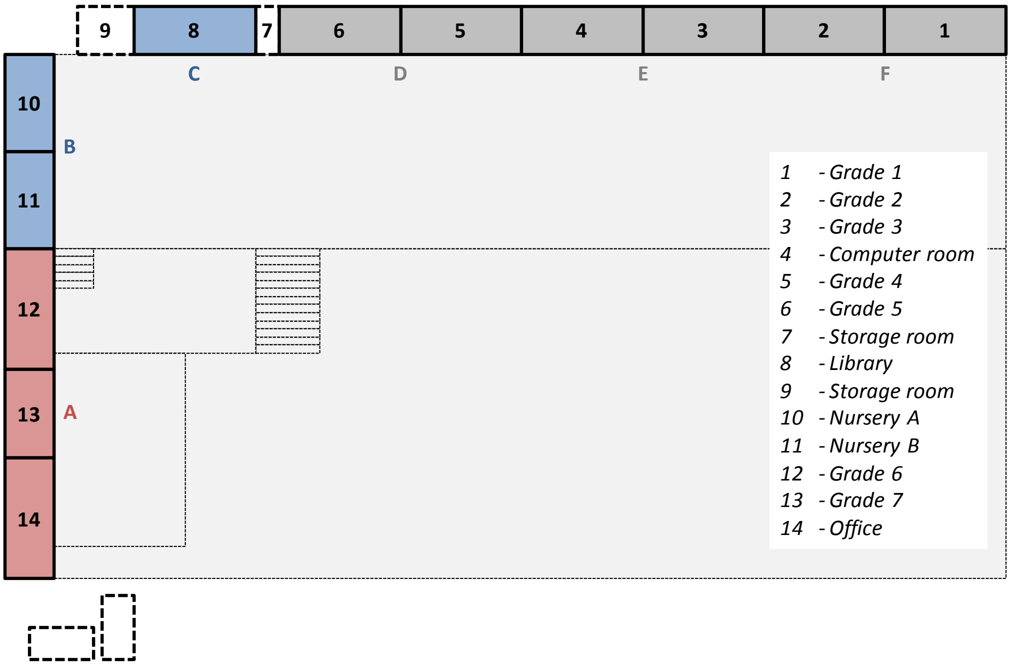


Figure 57: Plan of the primary school of Lukla (4).

5.3. Energy study & solar installation design

As stated in the previous chapter, the PVsyst software was developed for the study, sizing and data analysis of complete photovoltaic systems. It deals with grid-connected, stand-alone, pumping, and DC-grid solar electric systems and includes extensive meteorological and component databases, as well as general solar energy tools (26 p. 1). In this case, it was used to conduct an energy study and a solar installation design for a stand-alone solar electric system in the primary school of Lukla. The possibility of installing a grid-connected one in the strict sense of the term (i.e. without a battery) was not taken into consideration as the Lukla power grid is not a reliable power source. However, the possibility of replacing the backup generator by a connection point to the town network will.

[2] The sponsor was approached by Denis BERTHOLET on behalf of the school.
[3] The sponsor was approached by the Swiss association Lukla-Chaurikharka on behalf of the school.

The hourly values of air temperature and global solar irradiance collected between the 1st of October 2002 and the 31st of December 2009 in the station of Lukla-Chaurikharka were used to calculate pluriannual averages on an hourly basis over an entire year. These averages were then added to the existing meteorological database of the PVsyst software. The basic parameters regarding the geographical site and the collector plane orientation were also entered including the latitude, longitude, altitude and time zone of the location as well as the tilt and azimuth of the solar panels. The roof offering the optimal solar exposure in the school, considering the surrounding mountains and the location's latitude, is orientated at approximately 24° southwest and tilted at approximately 20° from horizontal. In total, the school would be equipped with 26 lamps (25 of 36W and 1 of 15W) and 36 plugs (23 in the computer room, 2 in the office, 2 in the library, and 1 in every other room). The consumption profile of the school was then computed by making an inventory of the daily consumptions (Table 9) and by defining the hourly distribution (Figure 58).

Annual values

Use 6 days a week	Number	Power	Use	Energy
Fluorescent lamps	26	36 W/lamp	4.5 h/day	4212 Wh/day
TV / Video-tape rec. / PC	12	100 W/app	5 h/day	6000 Wh/day
Total daily energy				10212 Wh/day

Table 9: Inventory of the daily consumptions in the primary school of Lukla (4).

The electric power for all the lamps and computers were intentionally overestimated with values of 36W per lamp and 100W per computer (local measurements done with a wattmeter suggest a maximum electric power of 75W per computer). The mean daily usage was also overestimated with values of 4.5 hours per day per lamp, which is less than in the secondary school of Chaurikharka as the primary school of Lukla does not include a kitchen, a dining hall or a boys and girls hostel, and 5 hours per day per computer. This represents a high consumption profile and thus acts as a sizing safety margin. Again, a six-day week was considered because there are no classes on Saturdays and that the holidays were counted as normal days.

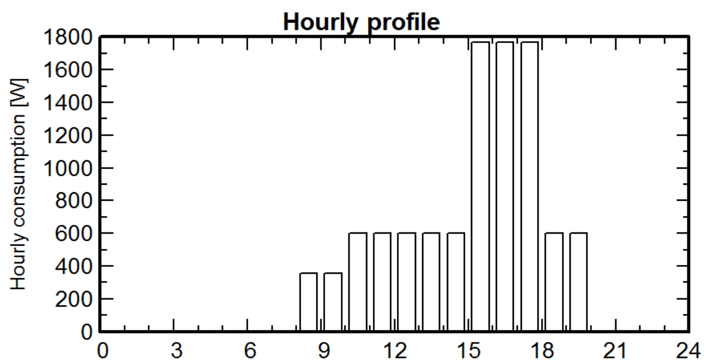


Figure 58: Hourly distribution of the consumption profile of the primary school of Lukla (4).

Due to the lack of a kitchen, a dining hall and a boys and girls hostel, the hourly distribution differs slightly from the one defined for the secondary school of Chaurikharka. The solar exposure is also less optimal and most of the lamps are generally turned on around 3pm instead of 4pm. Four states can be distinguished:

a maximum consumption of approximately 1,800W between 3pm and 6pm (lighting and computers), a high consumption of 600W between 10am and 3pm and between 6pm and 8pm (mostly computers), a low consumption of 350W between 8am and 10am (approximately 10 lamps for the office and a few rooms), and no consumption at all between 8pm and 8am.

At this stage of the design process, the PVsyst software offers a pre-sizing tool that determines approximately the size of the optimal photovoltaic array power and battery capacity required to match the school's needs. It is based on the values of the global solar irradiance, the collector plane orientation, the battery voltage, and two additional parameters: the desired system autonomy in days and the accepted loss-of-load (LOL), which is the probability that the school's needs cannot be supplied and that the battery is disconnected due to a low state of charge. The parameters were respectively set at 5 days for the former, due to the unpredictable weather conditions of the area, and at 5% for the latter, resulting to a suggested battery capacity of 1,200Ah and a suggested PV array nominal power of 3 kWp. The components used were the same than those installed in the secondary school of Chaurikharka, in view of the extremely successful outcomes of the first two months of the "pilot" PV system (no dysfunctional solar panels or battery cells, no damage during transport) as well as the very optimistic results of the evaluation conducted by the PVsyst software. The manufacturer specifications and model parameters of the Suntech STP180S-24/Ad 180W monocrystalline solar panels and the Amara Raja MF-VRLA 48V-1275Ah battery were added to the existing component database. A stand-alone solar electric system consisting of 16-panel photovoltaic array (2 modules in series and 8 in parallel) connected to a TriStar MPPT-60A 12-48V regulator and an Amara Raja MF-VRLA 48V-1275Ah battery was then selected.

The results of the hourly production simulations are shown in Figure 59, expressed as normalized productions over the year. Basically, the solar panels produce approximately 3,750 kWh of electricity per year, of which 3,200 kWh are consumed and 350 kWh are in excess. The backup generator is used to produce 160 kWh during the raining season when the hours of sunlight are diminished. The solar fraction, meaning the amount of energy provided by the solar panels divided by the total energy required, is 95%. These values confirm that the sizing of the system seems to be in adequacy with the school's needs. The complete report including the energy study and the solar installation design produced by the PVsyst software can be found in the Appendix D (Figure 84). As for the evaluation of the "pilot" PV system in the secondary school of Chaurikharka, amounts of excess energy can be noted during the months between October and May. It would be of great interest to the local community to explore the possibilities of replacing the backup generator by a connection point to the Lukla power grid. Not only would the load on the Bom Khola micro-hydro power plant diminish during the period of low water when the hydro resource is scarce (the school being completely autonomous), but the system would also contribute in supplying 350 kWh to the town network. Knowing that the school requires 160 kWh during the raining season when the hydro resource is abundant and the hours of sunlight diminished, the overall contribution would be approximately 190 kWh per year.

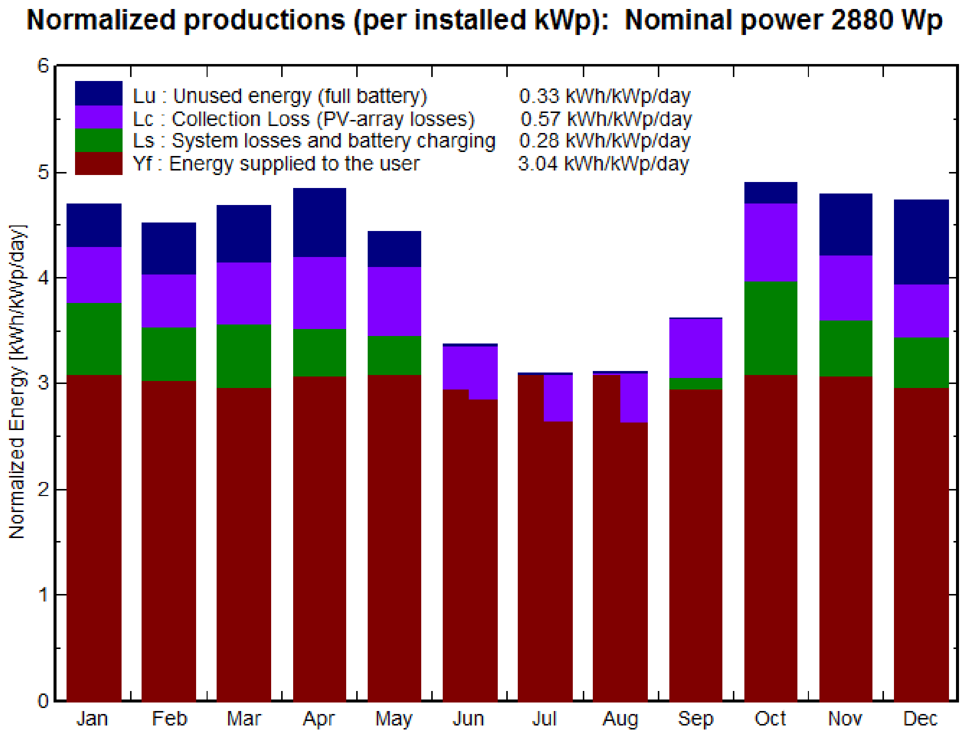


Figure 59: Normalized productions of the stand-alone solar electric system in the primary school of Lukla over the year (4).

Chapter 6
Method replication

6.1. Description

This chapter focuses on the guidelines to replicating the method of designing solar projects by estimating the electricity consumption of the user and by running hourly production simulations using the PVsyst software. It provides a simple modeling tool that extrapolates the collected meteorological data to any given geographical site beyond the four automatic weather stations installed in Lukla-Chaurikharka, Namche, Pheriche, and Lobuche (Figure 13). Given an altitude and a reference site (**the choice must be made depending exclusively on the local weather conditions**), it generates new hourly values of air temperature and global solar radiation that can be added directly to the existing meteorological database of the PVsyst software.

Basically, the modeling tool calculates the theoretical atmospheric pressure of the geographical site thanks to the following equation (27):

$$P = P_0 \cdot \left(\frac{T_0 - a \cdot H}{T_0}\right)^n$$

Where:

- $\mathbf{P_0}$ is the atmospheric pressure at sea level and is to 1013.25 hPa;
- $\mathbf{T_0}$ is the air temperature at sea level and is equal to 15°C or 288.15 K;
- **a** is the negative variation of air temperature with altitude and is equal to 0.0065°C/m;
- **n** is a dimensionless coefficient and is equal to 5.2561;
- **H** is the altitude of the geographical site that has been entered.

The theoretical atmospheric pressure is then used to calculate the theoretical global solar irradiance and the theoretical air temperature, both expressed in pluriannual daily mean values. In order to do so, two relationships were established: one between the atmospheric pressure and the global solar irradiance (Figure 60), the other between the atmospheric pressure and the air temperature (Figure 61). These relationships are based on the collected meteorological data and are defined by distinct linear regressions.

Finally, a correction factor and a temperature difference are obtained by comparing the theoretical global solar irradiance and the theoretical air temperature with the corresponding pluriannual daily mean values of the reference site. The correction factor and the temperature difference are then applied to the time series of hourly values of global solar irradiance and air temperature. It is important to note that these generated time series do not represent real ground measurements but only an extrapolation of existing ones. The modeling tool adjusts "vertically" one of the four curves displaying the global solar irradiance to the theoretical atmospheric pressure of the geographical site, which itself is calculated from the altitude that has been entered. Hence, in order for the generated time series to "take into consideration" the local weather conditions, the choice of the reference site must be made depending on the local weather conditions and not depending on the altitude or the geographical coordinates. As mentioned previously, the experience and observations provided by the local people can be used as reliable indicators.

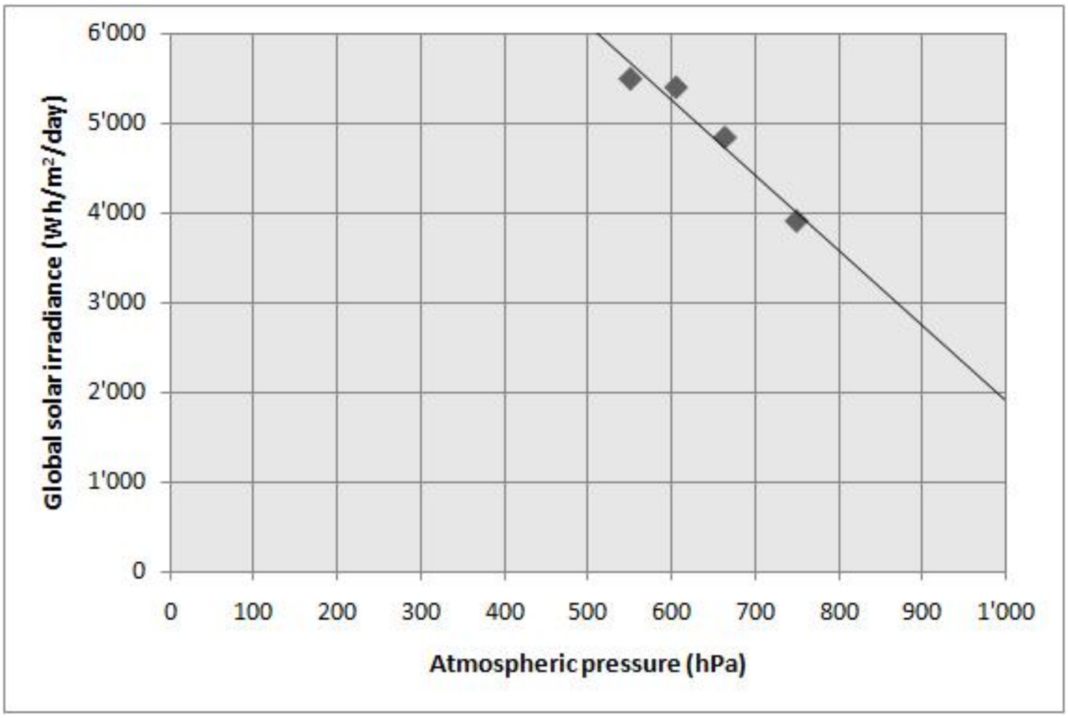


Figure 60: Relationship between the atmospheric pressure and the global solar irradiance defined by a linear regression (4).

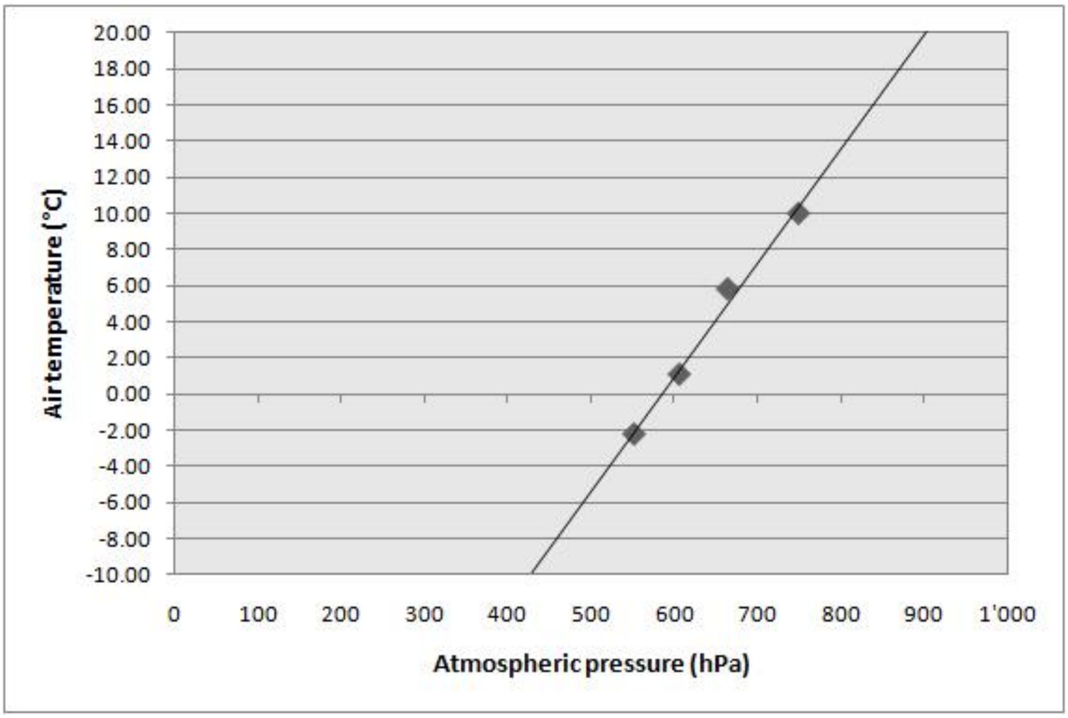


Figure 61: Relationship between the atmospheric pressure and the air temperature defined by a linear regression (4).

6.2. “How-to”

The modeling tool was developed with the Microsoft Office Excel 2007 software and can be used as described below.

<u>In the Microsoft Office Excel 2007 software</u>

1. Open the file ***Modeling_Tool.xltx***
2. Enter the geographical site, the altitude and the reference site (Figure 62)

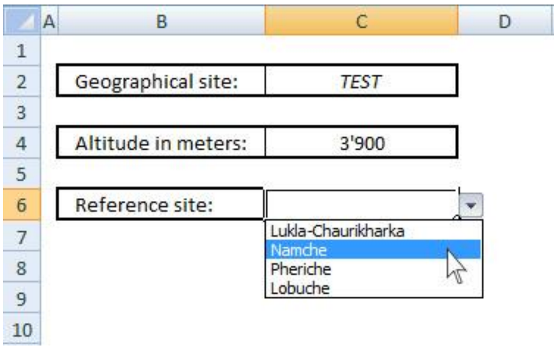


Figure 62: The choice of the reference site must be made depending on the local weather conditions (4).

3. Open the worksheet ***New Data***
4. Click on the ***Office Button***, on ***Save As***, and then on ***Other Formats***
5. Choose ***CSV (Comma delimited) (*.csv)*** (Figure 63)

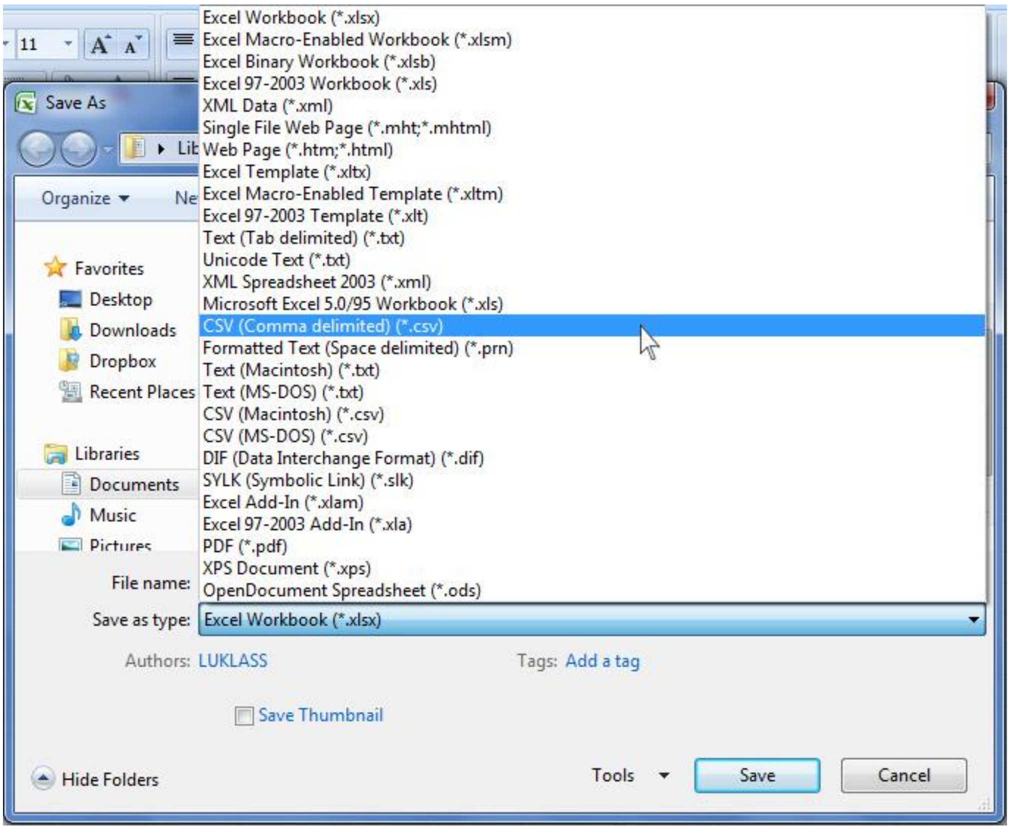


Figure 63: Save as CSV (Comma delimited) (.csv) format (4).*

In the PVsyst software

6. Click on ***Tools*** and then on ***Import ASCII meteo file***
7. To the right of **ASCII source file**, click on ***Choose*** and browse for the file created earlier with the Microsoft Office Excel 2007 software
8. Under **Files to be created**, enter the description of the meteo file as well as the country, and click on ***Open*** and on ***New Site***
9. Enter the site name, the country, the region, the latitude, the longitude, the altitude and the time zone and click on ***OK*** (Figure 64)

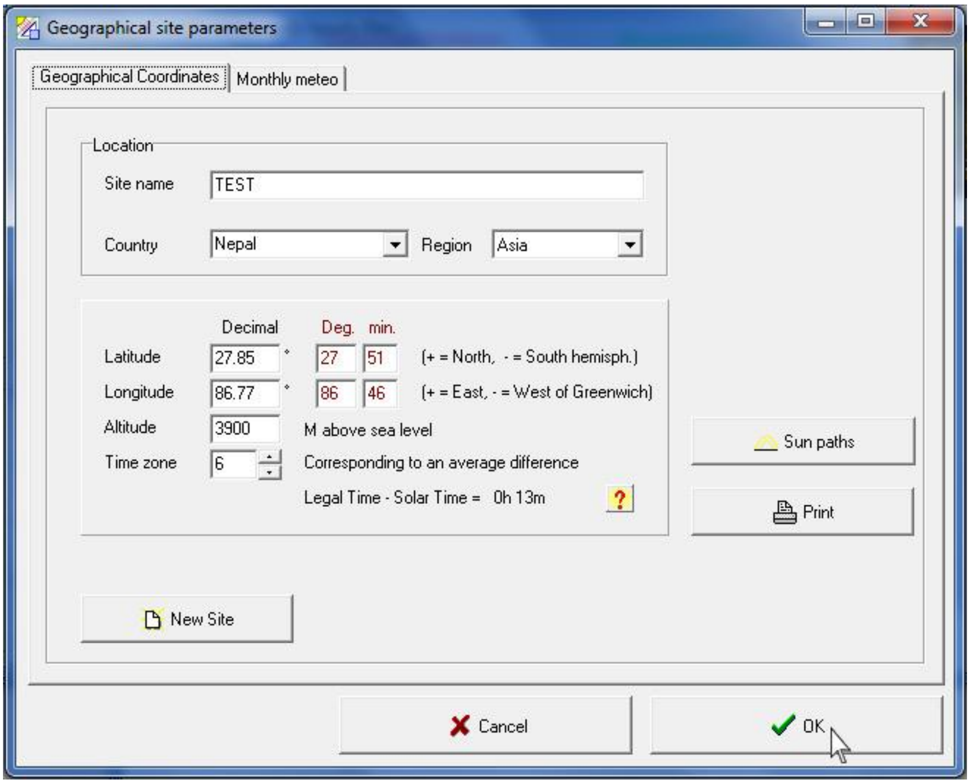


Figure 64: Basic parameters regarding the geographical site (4).

10. Under **Files to be created**, click on ***Choose***, enter a different file name than the one proposed and click on ***Save***
11. To the right of **Format protocol file**, click on the arrow that opens the list and choose ***Modeling_Tool.ME : Format for the Modeling Tool***
12. To the right of Starting year, enter any year
13. Click on ***Start Conversion*** and on ***OK***
14. When prompted: Do you want to open daily graphs now? Click on **Yes**
15. Click on ***Save Site*** and on ***Save***

A new geographical site has been created successfully!

Chapter 7
Conclusions

7.1. Synthesis

The Swiss association Lukla-Chaurikharka promotes and supports children's education as well as sustainable development in the Khumbu valley, in northeastern Nepal. It has recently adopted a new objective: equipping both the primary school of Lukla and the secondary school of Chaurikharka with proper lighting and computers in order to improve the quality of the education. Located at an altitude of approximately 2,700 meters and rather inaccessible, the schools had barely enough energy to electrify the classrooms, let alone an entire computer room. Although the construction of the 100kW Bom Khola micro-hydro power plant in Lukla and a few privately owned pico-hydro power plants in Chaurikharka, power shortages and overload problems occur frequently. Considering the issues at hand and certain matters of urgency, the following objectives were determined: install a "pilot" PV system in the secondary school of Chaurikharka; use it as a reference to better size the solar installation design for the primary school of Lukla; and ensure the subsequent replication of the method for the other schools and public infrastructures of the region.

The installation of the "pilot" PV system was completed successfully on the 19th of October 2011, providing the secondary school of Chaurikharka with 4.3 kWp of solar power and 60 kWh of battery supply. No damage was caused to the material during its transportation by plane, truck or helicopter and there were no dysfunctional solar panels or battery cells. The entire electrical system of the school was renovated and the computer room was equipped with 5 laptops and 6 desktops. A training was given to the school personnel in order to guarantee the maintenance and the monitoring of the system over the long-term. All these achievements are the result of the extensive efforts that were put forth by the volunteers in charge of the mission, by the members of the Swiss association Lukla-Chaurikharka, and by those of the local community. The outcomes of the first two months of the "pilot" PV system were extremely encouraging as the state of charge of the battery remained above 90% over the entire time period. The evaluation report produced by the PVsyst software confirmed that the sizing of the system was done appropriately. It estimated that the solar panels produce approximately 5,740 kWh of electricity per year, of which 4,760 kWh are consumed and 870 kWh are in excess. The backup generator is used to produce 270 kWh during the raining season, meaning the solar fraction equals 94%.

Although the primary school of Lukla is connected to the town network, its electrical system is faulty and subject to strong power shortages, making it an extremely harsh environment for the computers. Maintaining them in a working state is very challenging and presents an ongoing expense. As the Lukla power grid cannot be considered as a reliable power source, the possibility of installing a grid-connected solar electric system in the strict sense of the term, meaning without a battery, was rejected. The best alternative was to consider a stand-alone solar electric system and replace the backup generator by a connection point to the town network. The desired system autonomy and the accepted loss-of-load were respectively set in the PVsyst software at 5 days (due to the unpredictable weather conditions) and at 5%, resulting to a suggested battery capacity of 1,200Ah and a suggested PV array nominal power of 3 kWp. The components used were the same than those installed in the secondary school of Chaurikharka. A stand-alone solar electric system consisting of 16-panel photovoltaic array (2 modules in series and 8 in parallel) connected to a TriStar MPPT-60A 12-48V regulator and an Amara Raja MF-VRLA 48V-1275Ah battery was therefore selected. According to the report produced by the PVsyst software, the solar panels produce approximately 3,750 kWh of electricity per year, of which 3,200 kWh are consumed and 350 kWh are in excess. The backup generator is used to produce 160 kWh during the raining season, meaning the solar fraction is in this case worth 95%. These values confirm that the sizing of the system seems to be in adequacy with the school's needs. In both the primary school of Lukla and the secondary school of Chaurikharka, amounts of excess energy can be noted during the months between October and May (which correspond to the period of low water). It would be of great interest to the local community to provide electricity to the village of Chaurikharka or to the town of Lukla. The overall contribution would be approximately 600 kWh per year for the former and 190kWh for the latter, meaning the load on the hydro power plants would diminish.

In a more general manner, the solar potential in Nepal, and more precisely in the Khumbu valley, was demonstrated using area estimations derived from satellite-based models. Ground measurements were also obtained in Lukla-Chaurikharka, Namche, Pheriche, and Lobuche, from which the following observations were made:

- The inter-annual variability of the global solar irradiance remains relatively low, less than 5% of the reference annual average of the site;
- The inter-month variability rarely exceeds 25% and can be neglected or only partially accounted for depending on the consumption profile of the user and its distribution over the year (or in the case of a grid-connected solar electric system);
- The spatial variation is very high due to the differences in altitude, in solar exposure, and in local weather conditions of the considered sites. It is the combination of these factors that cause the absolute amount and seasonal evolution of global solar irradiance to vary so much.

Nonetheless, a simple modeling tool was developed. It extrapolates the collected meteorological data to any given geographical site beyond the four automatic weather stations mentioned previously. Given an altitude and a reference site, it generates new hourly values of air temperature and global solar radiation that can be added directly to the existing meteorological database of the PVsyst software. These generated time series can then be used for the sizing of any other school and public infrastructure of the region. It is important to note than certain precautions must be taken as they do not represent real ground measurements but only an extrapolation of existing ones.

To conclude, this project is a genuine milestone in the field of photovoltaics as well as a leading example of sustainable development for the local community in the Khumbu valley. It goes hand in hand with the growing awareness of the town officials, of the members of the direction of the hospital, and of the committee members of the schools, that the hydro resource is limited and that certain measures need to be applied rapidly. The absolute priority is the harmonization between the demand and the supply. This must first be accomplished on a daily basis by changing certain behaviors, by sensitizing the local people on energy conservation, and by introducing load shedding programmes. Then it can be done on a monthly and a seasonal basis by diversifying the energy supply sources with solar thermal and solar photovoltaic. But none of this would be possible without a proper education of the children, which has been the main objective of the members of the Swiss association Lukla-Chaurikharka since 1984.

Appendix A

Meteorological data

The following graphs illustrate the theoretical cumulated frequency of occurrence and bias in the station of Lukla-Chaurikharka for each month of the year, as well as that of the minimum and maximum months.

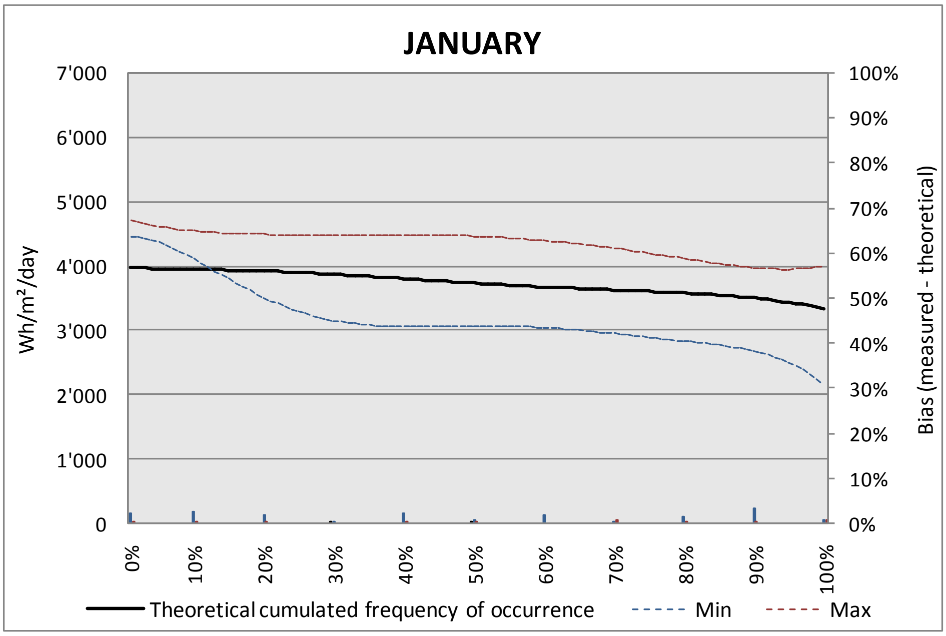


Figure 65: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of January, expressed in daily mean values and absolute percentage error (20).

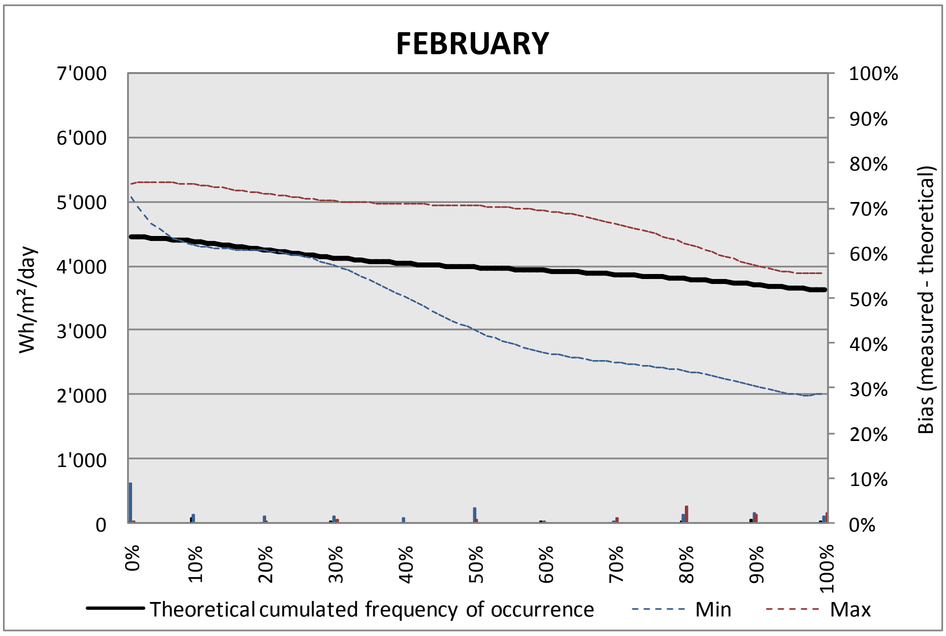


Figure 66: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of February, expressed in daily mean values and absolute percentage error (20).

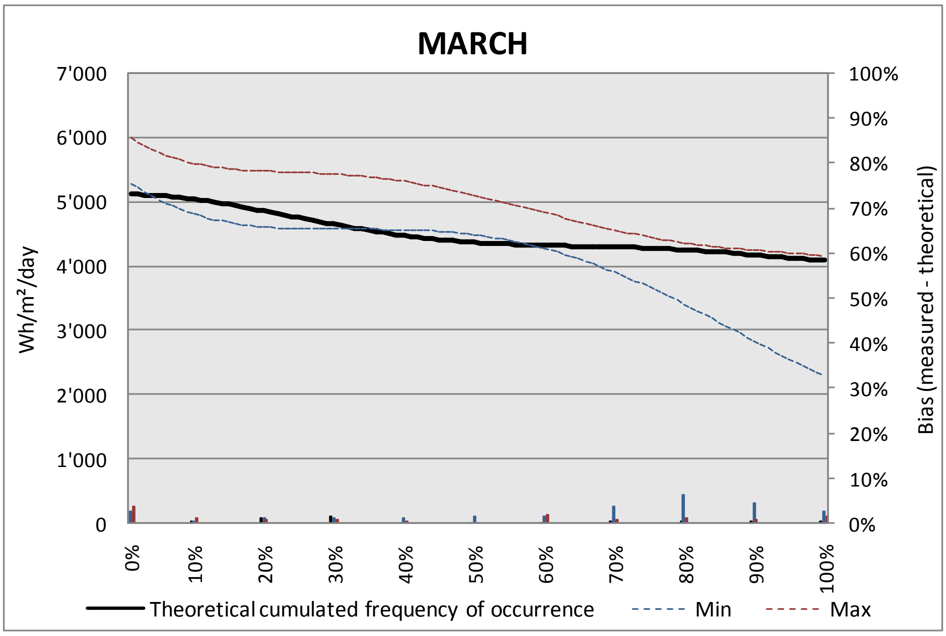


Figure 67: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of March, expressed in daily mean values and absolute percentage error (20).

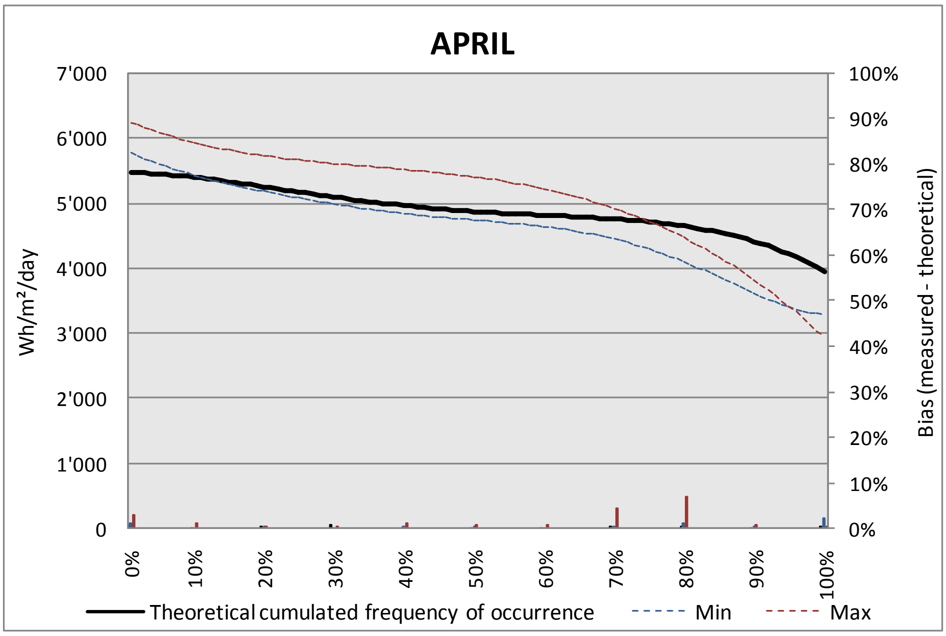


Figure 68: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of April, expressed in daily mean values and absolute percentage error (20).

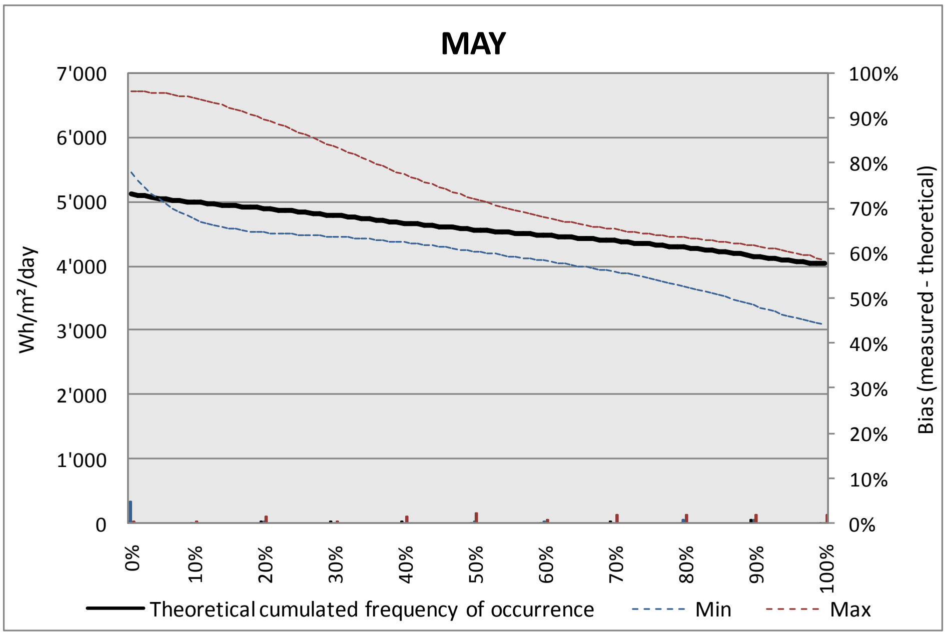


Figure 69: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of May, expressed in daily mean values and absolute percentage error (20).

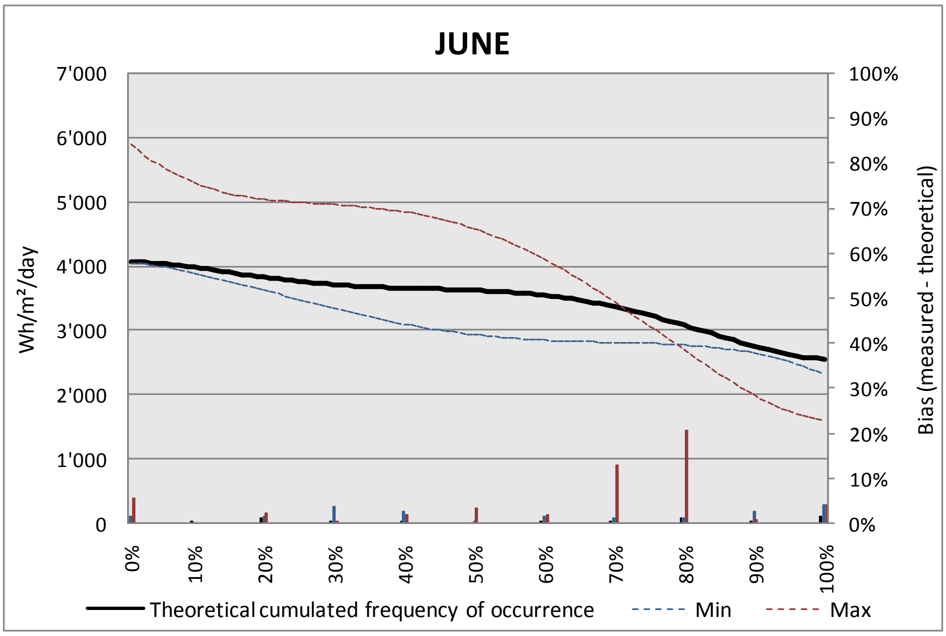


Figure 70: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of June, expressed in daily mean values and absolute percentage error (20).

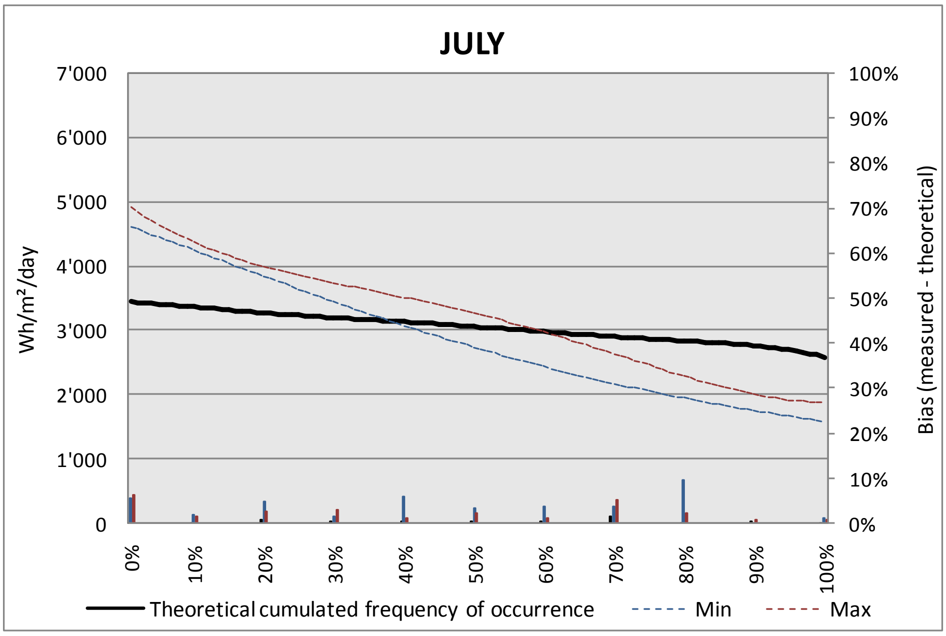


Figure 71: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the Lukla-Chaurikharka station for the month of July, expressed in daily mean values and absolute percentage error (20).

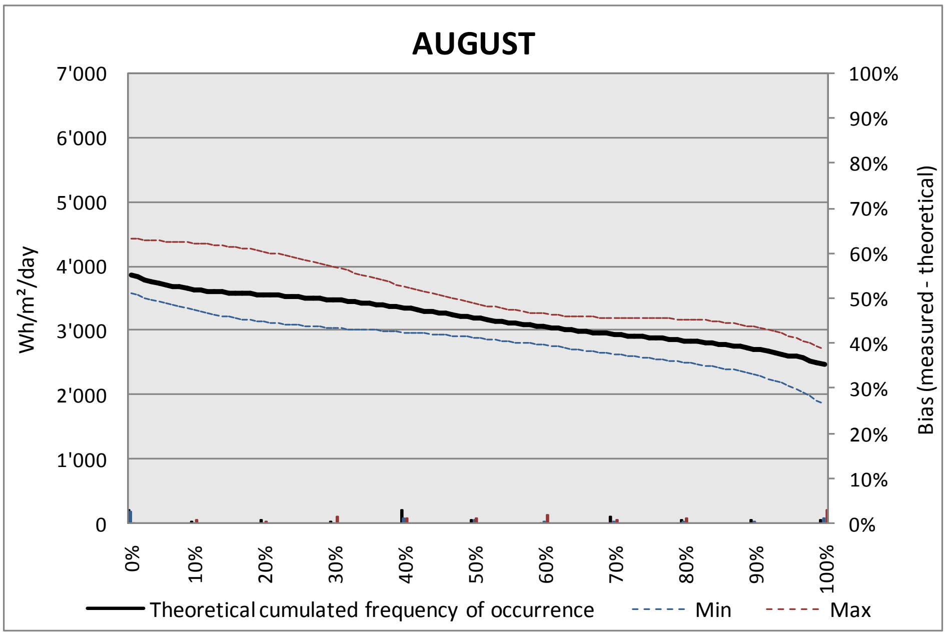


Figure 72: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the Lukla-Chaurikharka station for the month of August, expressed in daily mean values and absolute percentage error (20).

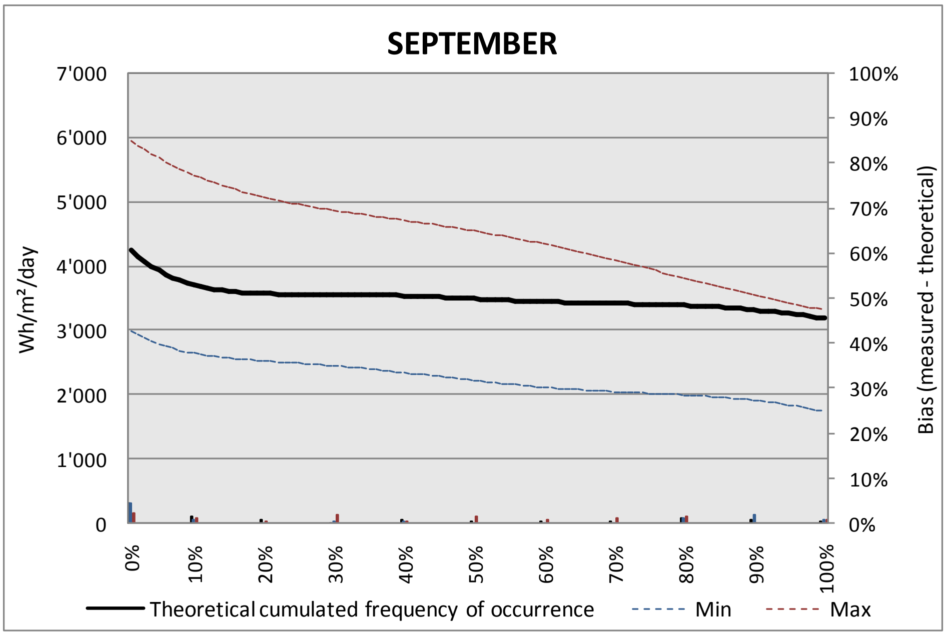


Figure 73: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of September, expressed in daily mean values and absolute percentage error (20).

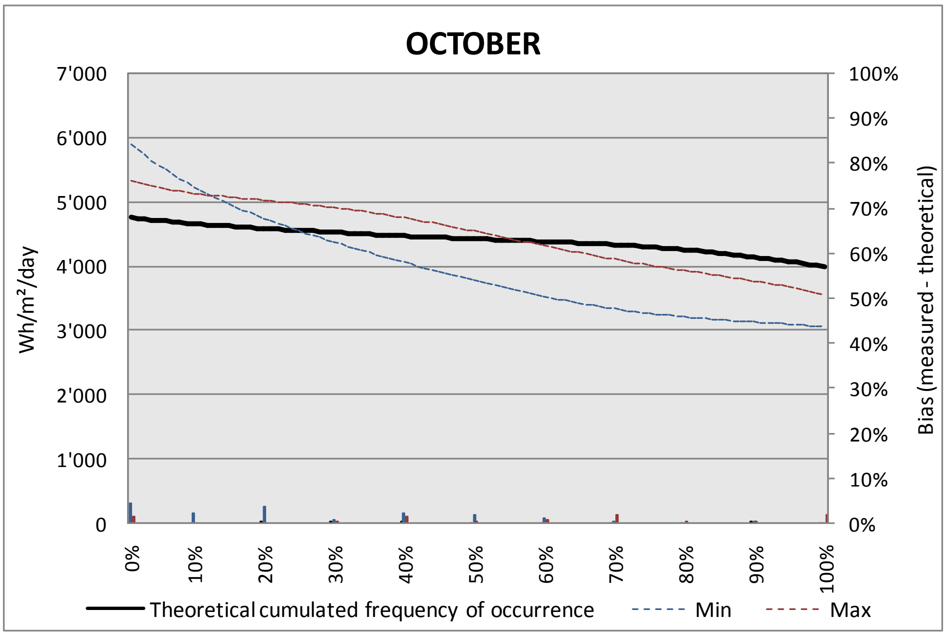


Figure 74: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of October, expressed in daily mean values and absolute percentage error (20).

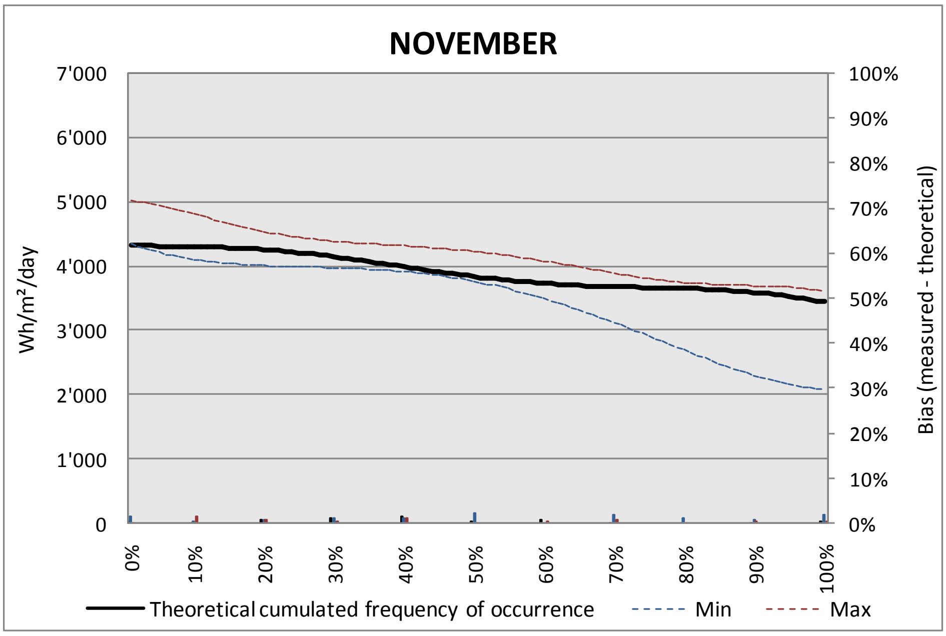


Figure 75: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of November, expressed in daily mean values and absolute percentage error (20).

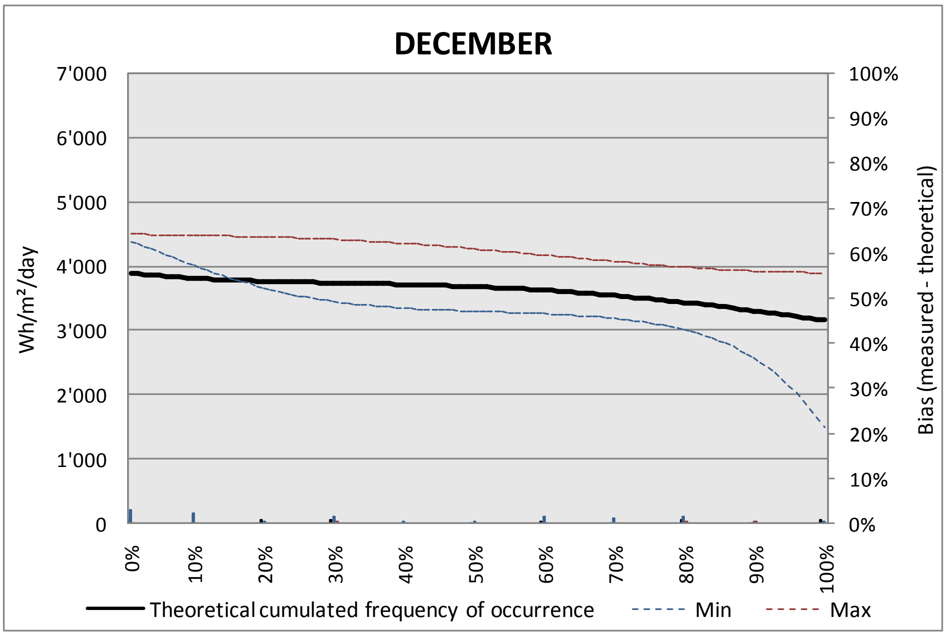


Figure 76: Theoretical cumulated frequency of occurrence of the global solar irradiance and bias for the station of Lukla-Chaurikharka for the month of December, expressed in daily mean values and absolute percentage error (20).

Appendix B
School data

The following tables present the statistical data, including the number of students and teachers per year, collected on the secondary school of Chaurikharka.

Year	Gender	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	Total
1999 - 2000	*Boys*	*22*	*7*	*6*	*8*	*17*	*28*	*9*	*12*	*13*	*8*			***108***
	Girls	*23*	*12*	*13*	*12*	*14*	*23*	*16*	*10*	*11*	*7*			***118***
	Total	**45**	**19**	**19**	**20**	**31**	**51**	**25**	**22**	**24**	**15**	**0**	**0**	**226**
2000 - 2001	*Boys*	*25*	*19*	*6*	*7*	*4*	*19*	*19*	*23*	*21*	*12*			***130***
	Girls	*18*	*14*	*10*	*6*	*7*	*14*	*19*	*24*	*25*	*14*			***133***
	Total	**43**	**33**	**16**	**13**	**11**	**33**	**38**	**47**	**46**	**26**	**0**	**0**	**263**
2001 - 2002	*Boys*	*25*	*11*	*9*	*6*	*9*	*27*	*21*	*12*	*12*	*6*			***113***
	Girls	*23*	*5*	*14*	*9*	*8*	*19*	*14*	*10*	*11*	*8*			***98***
	Total	**48**	**16**	**23**	**15**	**17**	**46**	**35**	**22**	**23**	**14**	**0**	**0**	**211**
2002 - 2003	*Boys*	*22*	*4*	*6*	*3*	*6*	*14*	*18*	*26*	*19*	*12*			***108***
	Girls	*24*	*5*	*7*	*7*	*10*	*21*	*15*	*20*	*13*	*13*			***111***
	Total	**46**	**9**	**13**	**10**	**16**	**35**	**33**	**46**	**32**	**25**	**0**	**0**	**219**
2003 - 2004	*Boys*	*20*	*6*	*4*	*7*	*8*	*19*	*14*	*18*	*26*	*9*			***111***
	Girls	*21*	*5*	*10*	*6*	*4*	*29*	*15*	*23*	*12*	*12*			***116***
	Total	**41**	**11**	**14**	**13**	**12**	**48**	**29**	**41**	**38**	**21**	**0**	**0**	**227**
2004 - 2005	*Boys*	*16*	*8*	*6*	*6*	*12*	*31*	*16*	*18*	*14*	*12*			***123***
	Girls	*24*	*8*	*8*	*4*	*6*	*22*	*15*	*18*	*20*	*15*			***116***
	Total	**40**	**16**	**14**	**10**	**18**	**53**	**31**	**36**	**34**	**27**	**0**	**0**	**239**
2005 - 2006	*Boys*	*20*	*12*	*7*	*5*	*8*	*23*	*30*	*24*	*17*	*11*			***137***
	Girls	*21*	*6*	*6*	*7*	*7*	*24*	*20*	*19*	*14*	*20*			***123***
	Total	**41**	**18**	**13**	**12**	**15**	**47**	**50**	**43**	**31**	**31**	**0**	**0**	**260**
2006 - 2007	*Boys*	*26*	*13*	*7*	*8*	*6*	*27*	*26*	*28*	*38*	*14*			***167***
	Girls	*20*	*10*	*9*	*4*	*14*	*26*	*24*	*26*	*19*	*12*			***144***
	Total	**46**	**23**	**16**	**12**	**20**	**53**	**50**	**54**	**57**	**26**	**0**	**0**	**311**
2007 - 2008	*Boys*	*20*	*9*	*9*	*7*	*7*	*33*	*30*	*24*	*29*	*17*			***165***
	Girls	*25*	*8*	*9*	*7*	*11*	*14*	*25*	*24*	*24*	*12*			***134***
	Total	**45**	**17**	**18**	**14**	**18**	**47**	**55**	**48**	**53**	**29**	**0**	**0**	**299**
2008 - 2009	*Boys*	*19*	*8*	*9*	*9*	*8*	*35*	*35*	*26*	*24*	*22*			***176***
	Girls	*20*	*12*	*7*	*11*	*12*	*21*	*14*	*26*	*31*	*20*			***154***
	Total	**39**	**20**	**16**	**20**	**20**	**56**	**49**	**52**	**55**	**42**	**0**	**0**	**330**
2009 - 2010	*Boys*	*5*	*11*	*6*	*12*	*10*	*34*	*29*	*27*	*28*	*17*	*11*		***185***
	Girls	*9*	*6*	*7*	*8*	*12*	*31*	*17*	*33*	*36*	*23*	*6*		***179***
	Total	**14**	**17**	**13**	**20**	**22**	**65**	**46**	**60**	**64**	**40**	**17**	**0**	**364**
2010 - 2011	*Boys*	*11*	*7*	*10*	*6*	*10*	*20*	*30*	*29*	*30*	*31*	*4*	*8*	***185***
	Girls	*9*	*5*	*7*	*9*	*6*	*20*	*26*	*21*	*24*	*24*	*7*	*6*	***155***
	Total	**20**	**12**	**17**	**15**	**16**	**40**	**56**	**50**	**54**	**55**	**11**	**14**	**340**
2011 - 2012	*Boys*	*21*	*8*	*7*	*11*	*5*	*24*	*24*	*30*	*27*	*18*	*5*	*5*	***164***
	Girls	*20*	*9*	*5*	*5*	*7*	*17*	*37*	*19*	*23*	*20*	*16*	*7*	***165***
	Total	**41**	**17**	**12**	**16**	**12**	**41**	**61**	**49**	**50**	**38**	**21**	**12**	**329**

Table 10: Number of students per gender and per year in the secondary school of Chaurikharka between 1999 and 2012 (4).

Year	Teachers	Year	Teachers	Year	Teachers
1995 - 1996	11	2001 - 2002	12	2007 - 2008	14
1996 - 1997	12	2002 - 2003	13	2008 - 2009	16
1997 - 1998	14	2003 - 2004	13	2009 - 2010	16
1998 - 1999	12	2004 - 2005	12	2010 - 2011	19
1999 - 2000	12	2005 - 2006	12	2011 - 2012	18
2000 - 2001	11	2006 - 2007	14		

Table 11: Number of teachers per year in the secondary school of Chaurikharka between 1995 and 2012 (4).

The following tables present the statistical data, including the number of students and teachers per year, collected on the primary school of Lukla.

Year	Gender	Nursery	Grade 1	G2	G3	G4	G5	G6	G7	Total
1990 - 1991	*Boys*	*32*		*7*	*8*	*8*	*0*	*0*	*0*	***55***
	Girls	*27*		*8*	*8*	*7*	*0*	*0*	*0*	***50***
	Total	**59**		**15**	**16**	**15**	**0**	**0**	**0**	**105**
1991 - 1992	*Boys*	*35*		*15*	*7*	*8*	*7*	*0*	*0*	***72***
	Girls	*26*		*10*	*8*	*7*	*6*	*0*	*0*	***57***
	Total	**61**		**25**	**15**	**15**	**13**	**0**	**0**	**129**
1992 - 1993	*Boys*	*36*		*6*	*12*	*9*	*8*	*0*	*0*	***71***
	Girls	*27*		*14*	*7*	*7*	*6*	*0*	*0*	***61***
	Total	**63**		**20**	**19**	**16**	**14**	**0**	**0**	**132**
1993 - 1994	*Boys*	*35*		*6*	*9*	*9*	*10*	*0*	*0*	***69***
	Girls	*24*		*7*	*12*	*6*	*6*	*0*	*0*	***55***
	Total	**59**		**13**	**21**	**15**	**16**	**0**	**0**	**124**
1994 - 1995	*Boys*	*34*		*13*	*8*	*10*	*7*	*0*	*0*	***72***
	Girls	*41*		*8*	*10*	*9*	*6*	*0*	*0*	***74***
	Total	**75**		**21**	**18**	**19**	**13**	**0**	**0**	**146**
1995 - 1996	*Boys*	*42*		*10*	*11*	*10*	*11*	*0*	*0*	***84***
	Girls	*43*		*9*	*10*	*11*	*13*	*0*	*0*	***86***
	Total	**85**		**19**	**21**	**21**	**24**	**0**	**0**	**170**
1996 - 1997	*Boys*	*46*		*11*	*12*	*10*	*9*	*0*	*0*	***88***
	Girls	*36*		*12*	*11*	*9*	*9*	*0*	*0*	***77***
	Total	**82**		**23**	**23**	**19**	**18**	**0**	**0**	**165**
1997 - 1998	*Boys*	*46*		*10*	*15*	*7*	*7*	*0*	*0*	***85***
	Girls	*42*		*17*	*8*	*11*	*4*	*0*	*0*	***82***
	Total	**88**		**27**	**23**	**18**	**11**	**0**	**0**	**167**
1998 - 1999	*Boys*	*51*		*14*	*10*	*11*	*4*	*0*	*0*	***90***
	Girls	*47*		*13*	*11*	*10*	*6*	*0*	*0*	***87***
	Total	**98**		**27**	**21**	**21**	**10**	**0**	**0**	**177**
1999 - 2000	*Boys*	*61*		*14*	*10*	*13*	*5*	*0*	*0*	***103***
	Girls	*58*		*11*	*11*	*10*	*9*	*0*	*0*	***99***
	Total	**119**		**25**	**21**	**23**	**14**	**0**	**0**	**202**
2000 - 2001	*Boys*	*42*		*15*	*11*	*5*	*7*	*0*	*0*	***80***
	Girls	*50*		*14*	*13*	*11*	*9*	*0*	*0*	***97***
	Total	**92**		**29**	**24**	**16**	**16**	**0**	**0**	**177**
2001 - 2002	*Boys*	*27*		*22*	*11*	*11*	*4*	*0*	*0*	***75***
	Girls	*47*		*10*	*14*	*10*	*9*	*0*	*0*	***90***
	Total	**74**		**32**	**25**	**21**	**13**	**0**	**0**	**165**

Year	Gender	Nursery	Grade 1	G2	G3	G4	G5	G6	G7	Total
2002 - 2003	*Boys*	*47*		*16*	*17*	*12*	*8*	*0*	*0*	***100***
	Girls	*56*		*16*	*8*	*13*	*10*	*0*	*0*	***103***
	Total	**103**		**32**	**25**	**25**	**18**	**0**	**0**	**203**
2003 - 2004	*Boys*	*33*		*10*	*17*	*14*	*11*	*0*	*0*	***85***
	Girls	*50*		*18*	*14*	*9*	*11*	*0*	*0*	***102***
	Total	**83**		**28**	**31**	**23**	**22**	**0**	**0**	**187**
2004 - 2005	*Boys*	*46*		*13*	*5*	*12*	*11*	*0*	*0*	***87***
	Girls	*49*		*21*	*21*	*15*	*6*	*0*	*0*	***112***
	Total	**95**		**34**	**26**	**27**	**17**	**0**	**0**	**199**
2005 - 2006	*Boys*	*58*		*12*	*14*	*6*	*14*	*0*	*0*	***104***
	Girls	*57*		*14*	*19*	*15*	*12*	*0*	*0*	***117***
	Total	**115**		**26**	**33**	**21**	**26**	**0**	**0**	**221**
2006 - 2007	*Boys*	*61*		*14*	*17*	*9*	*4*	*0*	*0*	***105***
	Girls	*57*		*14*	*13*	*21*	*11*	*0*	*0*	***116***
	Total	**118**		**28**	**30**	**30**	**15**	**0**	**0**	**221**
2007 - 2008	*Boys*	*65*		*15*	*15*	*18*	*9*	*0*	*0*	***122***
	Girls	*72*		*20*	*15*	*19*	*16*	*0*	*0*	***142***
	Total	**137**		**35**	**30**	**37**	**25**	**0**	**0**	**264**
2008 - 2009	*Boys*	*72*		*16*	*12*	*17*	*13*	*0*	*0*	***130***
	Girls	*69*		*25*	*15*	*13*	*13*	*0*	*0*	***135***
	Total	**141**		**41**	**27**	**30**	**26**	**0**	**0**	**265**
2009 - 2010	*Boys*	*61*		*22*	*16*	*11*	*16*	*0*	*0*	***126***
	Girls	*72*		*17*	*22*	*16*	*9*	*0*	*0*	***136***
	Total	**133**		**39**	**38**	**27**	**25**	**0**	**0**	**262**
2010 - 2011	*Boys*	*78*		*17*	*21*	*13*	*14*	*13*	*0*	***156***
	Girls	*75*		*22*	*19*	*18*	*17*	*7*	*0*	***158***
	Total	**153**		**39**	**40**	**31**	**31**	**20**	**0**	**314**
2011 - 2012	*Boys*	*47*	*19*	*27*	*17*	*17*	*13*	*14*	*13*	***167***
	Girls	*43*	*16*	*30*	*19*	*19*	*18*	*16*	*7*	***168***
	Total	**90**	**35**	**57**	**36**	**36**	**31**	**30**	**20**	**335**

Table 12: Number of students per gender and per year in the primary school of Lukla between 1990 and 2012 (4).

Year	Teachers
1987 - 1988	3
1988 - 1989	4
1989 - 1990	6
1990 - 1991	6
1991 - 1992	6
1992 - 1993	4
1993 - 1994	4

Year	Teachers
1994 - 1995	4
1995 - 1996	5
1996 - 1997	6
1997 - 1998	6
1998 - 1999	6
1999 - 2000	6
2000 - 2001	5

Year	Teachers
2001 - 2002	5
2002 - 2003	7
2003 - 2004	7
2004 - 2005	7
2005 - 2006	7
2006 - 2007	7
2007 - 2008	7

Year	Teachers
2008 - 2009	7
2009 - 2010	11
2010 - 2011	11
2011 - 2012	12

Table 13: Number of teachers per year in the primary school of Lukla between 1987 and 2012 (4).

The lists below contain the names of the teachers and committee members of the primary school of Lukla and secondary school of Chaurikharka for the year 2011-2012.

#	Name	Role
1.	Biruman Rai	Headmaster
2.	Chandi Prasad Ghimire	Teacher
3.	Purna Kumar Rai	"
4.	Bhubaneswar Chaudhari	"
5.	Harka Bahadur Dhanuk	"
6.	Kumar Mani Bastola	"
7.	Kumar Singh Rai	"
8.	Kendra Mani Rai	"
9.	Kampa Sher Rai	"
10.	Chhatra Bahadur Ghimire	"
11.	Bala Dhan Rai	"
12.	Bhabi Kumari Rai	"
13.	Rabika Rai	"
14.	Indra Kumari Rai	"
15.	Ganesh Kumar Khares	"
16.	Kesab Mainali	"
17.	Tej Bahadur Rai	"
18.	Ang Mingmar Sherpa	Lama

#	Name	Role
1.	Dawa Tshiring Sherpa	Chairman
2.	Phuri Gelzen Sherpa	Member
3.	Dawa Nuru Sherpa	"
4.	Pemba Diki Sherpa	"
5.	Ngawang Karsang Sherpa	"
6.	Phunuru Sherpa	"
7.	Sange Sherpa	"
8.	Biruman Rai	Secretary
9.	Kampa Sher Rai	Teacher representative

Table 14: Name lists of teachers and committee members of the secondary school of Chaurikharka for the year 2011-2012 (4).

#	Name	Role
1.	Bikram Kumar Rajbhandari	Headmaster
2.	Debendra Kumar Rai	Teacher
3.	Bhim Bahadur Karki	"
4.	Tilak Prasad Dhungana	"
5.	Ganesh Bahadur Tamang	"
6.	Nani Maya Acharya	"
7.	Mingma Chhamji Sherpa	"
8.	Ngima Yanjee Sherpa	"
9.	Kumar Tamang	"
10.	Sambhu Tamang	"
11.	Radha Dhungana	"
12.	Tika Debi Tamang	"

#	Name	Role
1.	Phunuru Sherpa	Chairman
2.	Ngima Tamang	Member
3.	Larke Sherpa	"
4.	Anjali Tamang	"
5.	Chhewang Sherpa	"
6.	Ngawang Namgel Sherpa	"
7.	Bhim Bahadur Karki	"
8.	Bikram Kumar Rajbhandari	Secretary

Table 15: Name lists of teachers and committee members of the primary school of Lukla for the year 2011-2012 (4).

The following graphs represent the student population projections for the primary school of Lukla and secondary school of Chaurikharka. Due to the lack of demographic data on the Lukla-Chaurikharka area and the constant turnover of students in both schools, simple logarithmic, linear, and exponential regressions were used. They are based on the statistical data at hand where both schools are considered individually. The logarithmic regression suggests that the attendance boundaries for both schools have reached their maximum point, as some students have to walk up to 3 hours per day to attend classes. As for the exponential regression, it suggests further development is still possible in both schools by improving their infrastructures, such as the boys and girls hostel that was built in the secondary school of Chaurikharka for the students living in remote villages. For these reasons, the logarithmic and exponential regressions are respectively considered as the minimum and maximum scenarios. It is safe to say the student population of both schools will most likely lie anywhere in between these two scenarios in a 5- to 10- year perspective.

To my opinion, the student population of the secondary school of Chaurikharka will remain in between the logarithmic and the linear regressions. The number of students actually decreased a little during the last two years because new classes for grades six and seven started to be administered in the primary school of Lukla, meaning the students do not necessarily have to change schools once they completed grade five. There is also a good probability a new class for grade eight will open as well. For these reasons, I believe the student population of the primary school of Lukla will remain in between the linear and the exponential regressions.

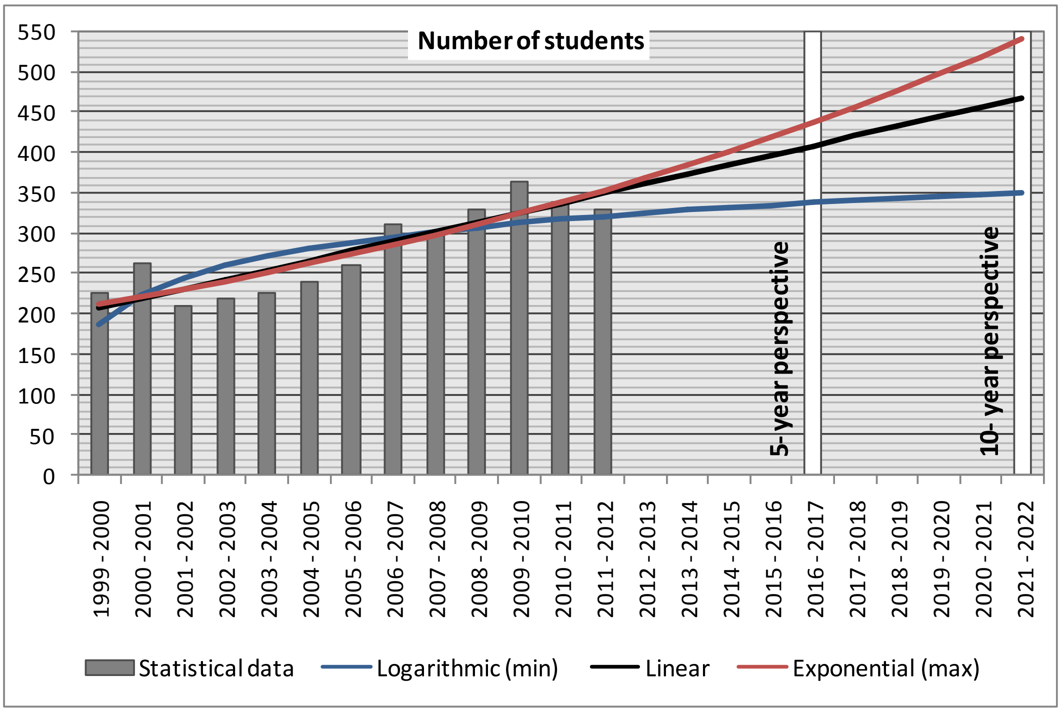


Figure 77: Student population projections for the secondary school of Chaurikharka using logarithmic, linear, and exponential regressions (4).

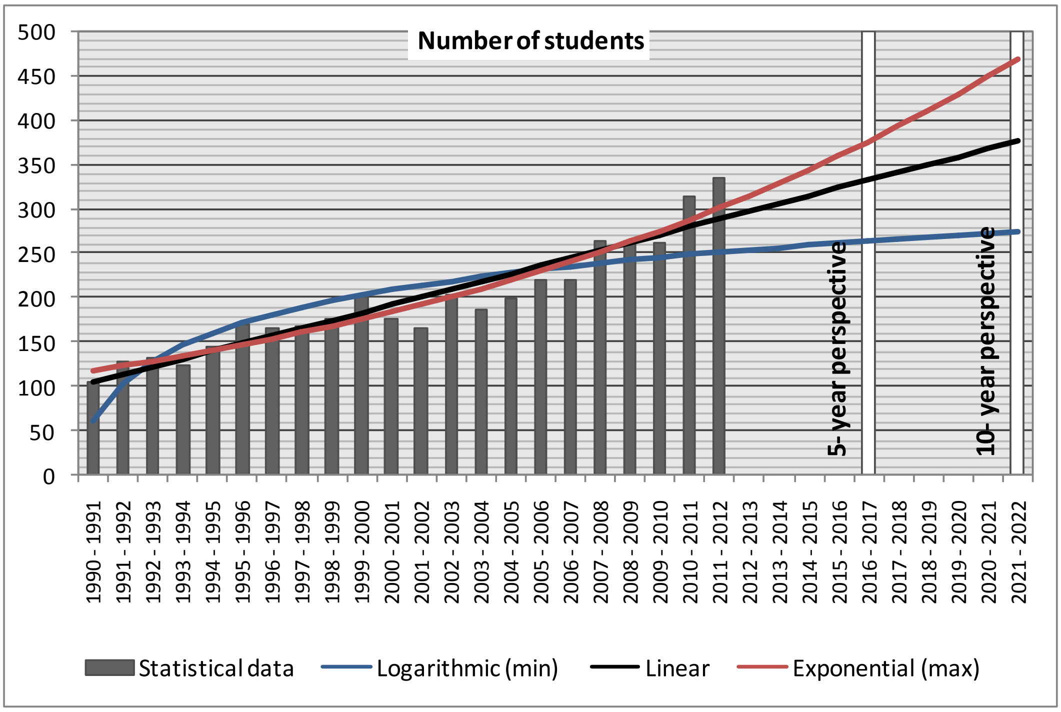


Figure 78: Student population projections for the primary school of Lukla using logarithmic, linear, and exponential regressions (4).

Appendix C

Solar installation in Chaurikharka

The following electrical schema illustrates the "pilot" PV system that was installed in the secondary school of Chaurikharka.

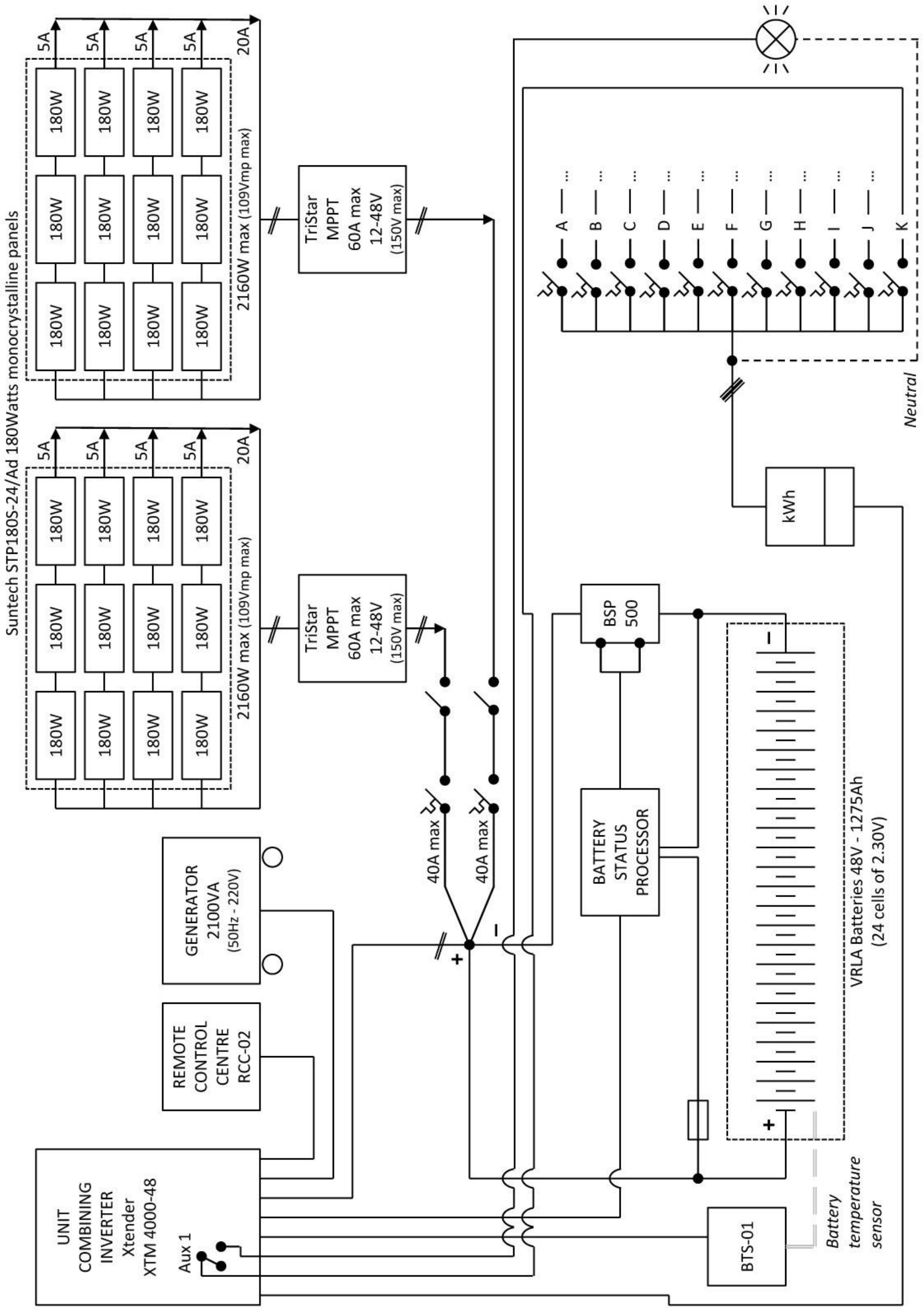


Figure 79: Electrical schema of the "pilot" PV system (4).

The budget report for the installation of the "pilot" PV system in the secondary school of Chaurikharka, including the material and the transport, is presented below.

Material / Transport	**Supplier**	**City**	**Country**	**Price**	
24 Suntech STP180S-24/Ad 180W monocrystalline solar panels, Amara Raja MF-VRLA 48V-1275Ah battery	Solar Solutions Pvt. Ltd.	Kathmandu	Nepal	NPR 2'678'775.00	CHF 31'518.86
2 TriStar MPPT-60A 12-48V regulators, Xtender XTM 4000-48 inverter, Xtender series Battery Status Processor BSP 500, Remote Control Center RCC-02, Battery Temperature Sensor BTS-01	Studer Innotec SA	Sion	Switzerland	-	CHF 4'469.00
Other material (cables, tubes, devices, etc.)	Coop	Bulle	Switzerland	-	CHF 327.40
	Jumbo	Bulle		-	CHF 665.80
	Hornbach	Villeneuve		-	CHF 723.50
	Solexis SA	Yverdon		-	CHF 1'500.00
	Electro Matériel SA	Renens		-	CHF 3'077.75
	Glasson	-		-	CHF 349.25
	Distrelec	-		-	CHF 255.85
Transport: *Switzerland to Nepal by plane* *Kathmandu to Jiri by truck* *Jiri to Chaurikharka by helicopter*	-	-	-	approximately	CHF 18'000.00
				TOTAL	**CHF 60'887.41**

NPR 1 = CHF 0.0117661478

Table 16: Budget of the "pilot" PV system in the secondary school of Chaurikharka (4).

The following user manual is a complement to the training that was given to the school personnel on the solar installation in the secondary school of Chaurikharka.

Mahendra Jyoti Higher Secondary School Chaurikharka

SOLAR INSTALLATION USER MANUAL

All the electricity in the school is provided by solar energy that is stored in 24 battery cells. In order for the installation to work efficiently and last it is crucial to respect these few guidelines:

- Turn off lights, computers, and all electronic devices when not in use.
- THE USE OF POWER STRIPS, RADIATORS, KETTLES AND HOT PLATES IS STRICTLY FORBIDDEN!
- Turn off the solar installation during the long vacations.

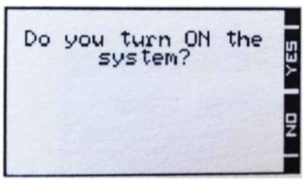
How to turn ON/OFF the solar installation?

There are two ways to turn ON/OFF the solar installation:

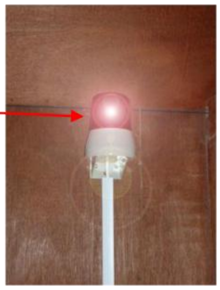
1. Pressing on the button  on the Xtender in the battery room.

2. Pressing on the **ESC** button on the Remote Control Centre in the office…

And confirming your choice by pressing on **YES**.



Page 1



What to do when the alarm is activated?

There are two reasons the alarm will activate:

1. Low battery
2. Circuit overload

1. Low battery

If the battery is too low, the Remote Control Centre in the office will display the following message:

Warning (000): Battery low

Electricity consumption needs to be reduced by turning OFF the maximum of lights, computers, and other electronic devices.

THE GENERATOR NEEDS TO BE TURNED ON. ONCE THE GENERATOR IS AT MAXIMUM POWER (which will take about 5 to 10 minutes) THE CABLE NEEDS TO BE PLUGGED IN.

The alarm will automatically stop once the batteries are sufficiently charged. THIS CAN TAKE A LONG TIME!

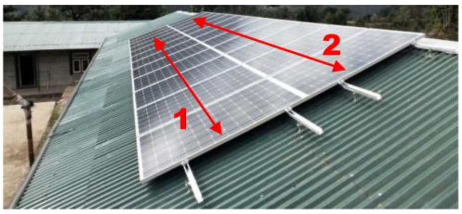
Minimum 2 hours after the alarm has stopped, the generator can be turned OFF and the cable unplugged.

2. Circuit overload

If there is a circuit overload **NO** warning message will appear on the Remote Control Centre in the office (only the alarm will be activated). ELECTRICITY CONSUMPTION NEEDS TO BE REDUCED BY TURNING OFF THE MAXIMUM OF LIGHTS, COMPUTERS, AND OTHER ELECTRONIC DEVICES!

The alarm will automatically stop once the circuit load is back to normal.

Switchboard arrangement



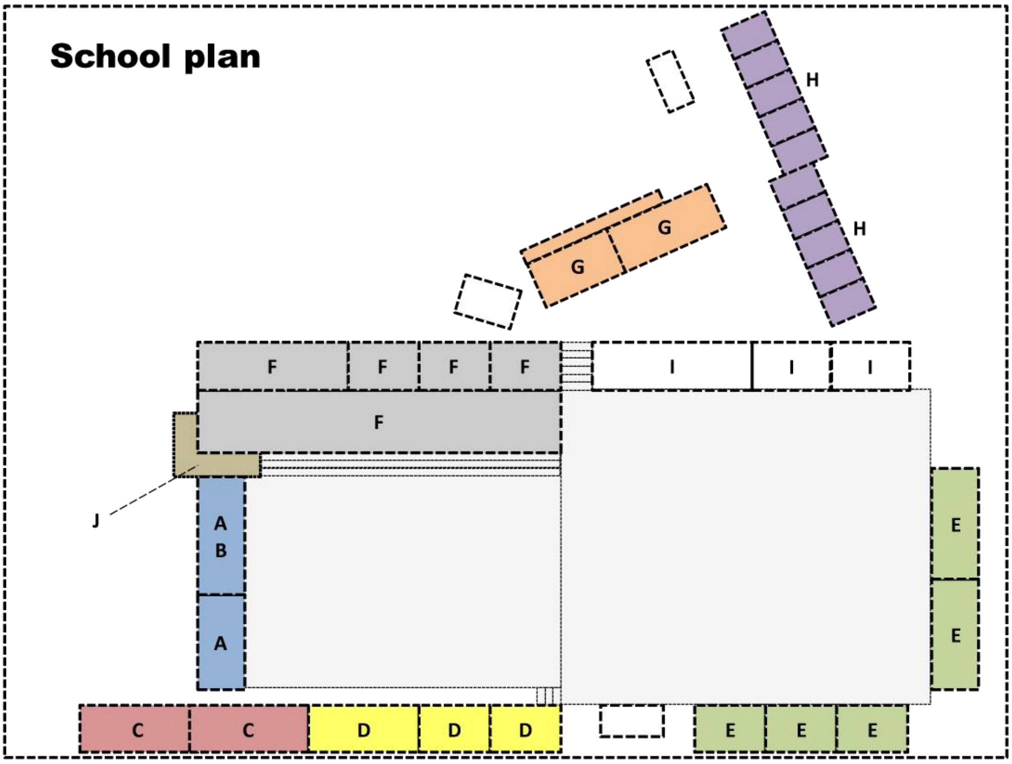
The switchboard is set as follows:

1. Lower solar panels
2. Upper solar panels

THESE SWITCHES MUST ALWAYS BE TURNED ON!

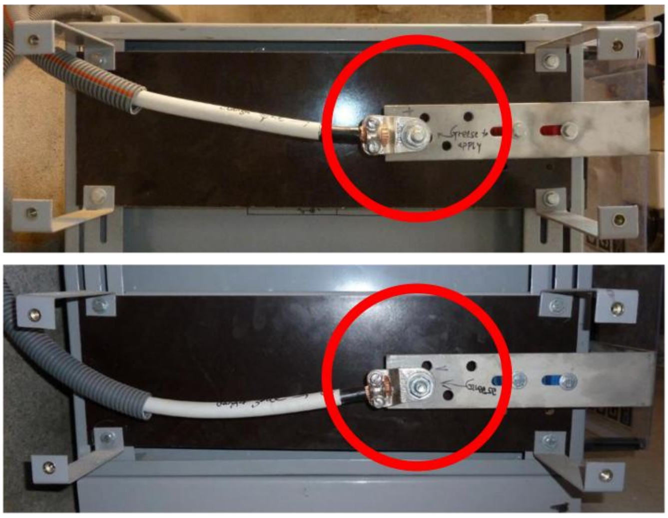
A. Computer room (*lights*) + Office
B. Computer room (*plugs*)
C. Sally room 2, Sally room 3
D. Sally room 1, Japanese building
E. German building
F. Open hall, Teacher's quarter, Grade 1, Grade 2, Grade 3
G. Kitchen, Dining hall
H. Boys hostel, Girls hostel
I. (*Reserve*)
J. Battery room
K. (*Regulation device*)

THESE SWITCHES MUST ALWAYS BE TURNED ON (except for I)!

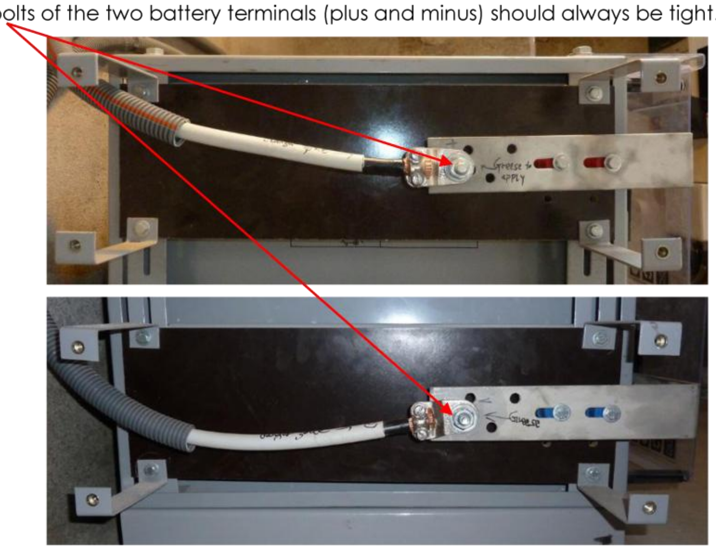


Maintenance guidelines

1. It is important to regularly remove the dust from the battery room and from the switchboard (do not clean the battery cells).
2. Grease should be regularly applied to the two battery terminals on the left (plus and minus).



3. The bolts of the two battery terminals (plus and minus) should always be tight.



Need HELP? Who to contact?

In case there is a problem that is not described in this user manual, make sure the installation is turned OFF and send an email to Bernard (b.mag@websud.ch) and Julien (julien.waehlti@gmail.com).

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Figure 80: Solar installation user manual (4).

The following poster and etiquette are a complement to the teacher and student sensitization that was carried out in the secondary school of Chaurikharka in order to reduce energy consumption.

Figure 81: Poster that is displayed all around the secondary school of Chaurikharka (4).

Figure 82: Etiquette that is displayed above all the plugs in the secondary school of Chaurikharka (4).

Appendix D

PVsyst reports

The document below is the evaluation report of the “pilot” PV system in the secondary school of Chaurikharka produced by the PVsyst software.

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Stand Alone System: Simulation parameters

Project :	**Lukla-Chaurikharka**			
Geographical Site	**Lukla-Chaurikharka**		**Country**	**Nepal**
Situation	Latitude	27.7°N	Longitude	86.7°E
Time defined as	Legal Time	Time zone UT+6	Altitude	2660 m
	Albedo	0.20		
Meteo data :	Lukla-Chaurikharka			

Simulation variant :	**Chaurikharka simulation variant 01**			
	Simulation date	19/01/12 09h16		

Simulation parameters

Collector Plane Orientation	Tilt	20°	Azimuth	14°

PV Array Characteristics

PV module Si-mono	Model	**STP180S-24/Ad**		
	Manufacturer	Suntech Power Co., Ltd.		
Number of PV modules	In series	3 modules	In parallel	8 strings
Total number of PV modules	Nb. modules	24	Unit Nom. Power	180 Wp
Array global power	Nominal (STC)	**4320 Wp**	At operating cond.	3811 Wp (50°C)
Array operating characteristics (50°C)	U mpp	98 V	I mpp	39 A
Total area	Module area	**30.6 m²**		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	42 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

System Parameter	System type	**Stand alone with back-up generator System**		
Battery	Model	**VRLA 48V-1275Ah IP2031**		
	Manufacturer	Amara Raja		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	1275 Ah
	Nb. of units	1		
	Temperature	Fixed (20°C)		
Regulator	Model	Tristar TS MPPT 120 - 48V		
	Manufacturer	Morningstar		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	99.0/97.4 %		
Battery Management Thresholds	Charging	54.0/52.3 V	Discharging	47.0/50.4 V
	Back-Up Genset Command	47.3/51.6 V		
Back-up generator (genset)	Model	1.5 kW		
	Manufacturer	Back-up generator		
	Power	2 kW		
User's needs :	Daily household consumers	Constant over the year		
	average	13.1 kWh/Day		

Stand Alone System: Detailed User's needs

Project : **Lukla-Chaurikharka**

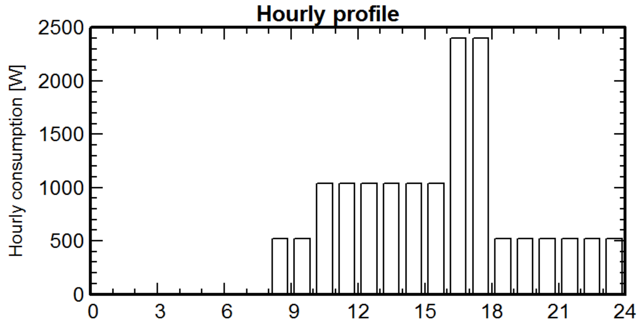
Simulation variant : **Chaurikharka simulation variant 01**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	20°	azimuth	14°
PV Array	Nb. of modules	24	Pnom total	**4320 Wp**
User's needs	Daily household consumers	Constant over the year	global	4764 kWh/year

Daily household consumers, Constant over the year, average = 13.1 kWh/day

Annual values

Use 6 days a week	Number	Power	Use	Energy
Fluorescent lamps	54	36 W/lamp	5 h/day	9720 Wh/day
TV / Video-tape rec. / PC	11	100 W/app	5 h/day	5500 Wh/day
Total daily energy				15220 Wh/day



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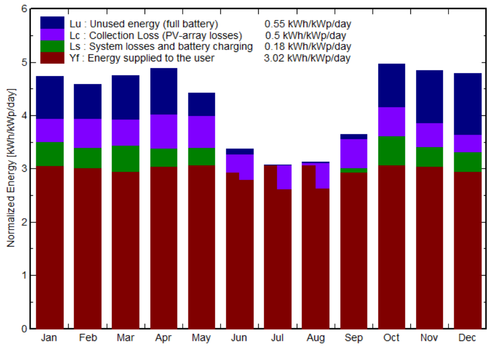
Stand Alone System: Main results

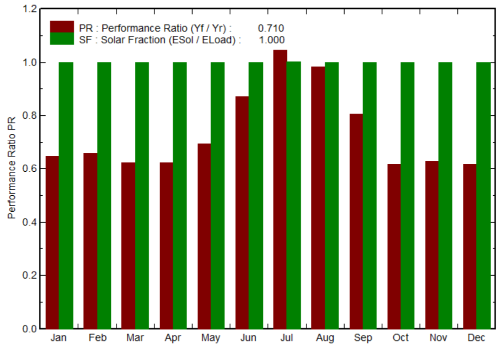
Project : **Lukla-Chaurikharka**

Simulation variant : **Chaurikharka simulation variant 01**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	20°	azimuth	14°
PV Array	Nb. of modules	24	Pnom total	**4320 Wp**
User's needs	Daily household consumers	Constant over the year	global	4764 kWh/year

Main simulation results				
System Production	**Available Energy**	**5736 kWh/year**	Specific prod.	1328 kWh/kWp/year
	Used Energy	4762 kWh/year	Excess (unused)	872 kWh/year
	Performance Ratio PR	67.0 %	Solar Fraction SF	94.3 %
Back-Up energy from generator	Back-Up energy	268 kWh/year	Fuel Consumption	161/year





Chaurikharka simulation variant 01

Balances and main results

	GlobHor kWh/m²	**GlobEff** kWh/m²	**E Avail** kWh	**EUnused** kWh	**E User** kWh	**E Load** kWh	**SolFrac**
January	115.0	142.9	564.0	104.6	410.7	410.9	0.999
February	112.0	125.4	477.7	77.9	365.0	365.3	0.999
March	139.1	143.3	555.7	108.9	395.4	395.7	0.999
April	146.4	142.3	536.8	112.4	395.4	395.7	0.999
May	141.2	131.8	492.3	55.9	410.8	410.9	1.000
June	104.4	97.4	353.5	11.4	380.6	380.5	0.842
July	93.6	87.4	312.6	1.2	411.1	410.9	0.779
August	98.6	93.3	335.9	1.6	411.1	410.9	0.747
September	107.5	105.7	384.1	9.4	380.6	380.5	0.968
October	136.7	150.3	578.3	108.2	410.7	410.9	1.000
November	117.3	141.9	558.4	126.7	395.3	395.7	0.999
December	112.0	144.7	587.2	153.6	395.3	395.7	0.999
Year	1424.0	1506.4	5736.3	871.9	4761.9	4763.9	0.943

Legends:

GlobHor	Horizontal global irradiation	E User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E Load	Energy need of the user (Load)
E Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (full battery) loss		

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Stand Alone System: Loss diagram

Project : **Lukla-Chaurikharka**

Simulation variant : **Chaurikharka simulation variant 01**

Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	20°	azimuth	14°
PV Array	Nb. of modules	24	Pnom total	**4320 Wp**
User's needs	Daily household consumers	Constant over the year	global	4764 kWh/year

Loss diagram over the whole year

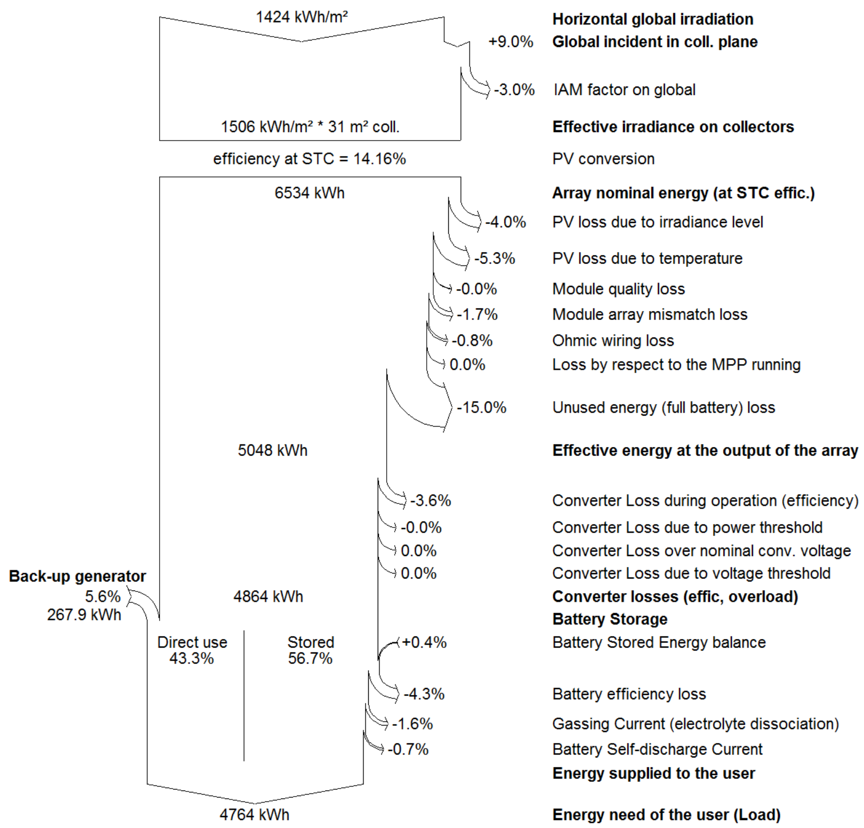


Figure 83: Evaluation report of the "pilot" PV system in the secondary school of Chaurikharka (4).

The document below is the report including the energy study and the solar installation design for the primary school of Lukla produced by the PVsyst software.

PVSYST V5.53		19/01/12	Page 1/4

Stand Alone System: Simulation parameters

Project :	**Lukla-Chaurikharka**			
Geographical Site		**Lukla-Chaurikharka**	**Country**	**Nepal**
Situation	Latitude	27.7°N	Longitude	86.7°E
Time defined as	Legal Time	Time zone UT+6	Altitude	2660 m
	Albedo	0.20		
Meteo data :	Lukla-Chaurikharka			

Simulation variant :	**Lukla Variant Stand-Alone 01**	
	Simulation date	19/01/12 13h39

Simulation parameters

Collector Plane Orientation	Tilt	20°	Azimuth	24°

PV Array Characteristics

PV module Si-mono	Model	**STP180S-24/Ad**		
	Manufacturer	Suntech Power Co., Ltd.		
Number of PV modules	In series	2 modules	In parallel	8 strings
Total number of PV modules	Nb. modules	16	Unit Nom. Power	180 Wp
Array global power	Nominal (STC)	**2880 Wp**	At operating cond.	2540 Wp (50°C)
Array operating characteristics (50°C)	U mpp	65 V	I mpp	39 A
Total area	Module area	**20.4 m²**		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind=1 m/s.)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	28 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

System Parameter	System type	**Stand alone with back-up generator System**		
Battery	Model	**VRLA 48V-1275Ah IP2031**		
	Manufacturer	Amara Raja		
Battery Pack Characteristics	Voltage	48 V	Nominal Capacity	1275 Ah
	Nb. of units	1		
	Temperature	Fixed (20°C)		
Regulator	Model	Tristar TS MPPT 60 - 48V		
	Manufacturer	Morningstar		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	99.0/97.4 %		
Battery Management Thresholds	Charging	56.6/50.4 V	Discharging	45.6/50.4 V
	Back-Up Genset Command	44.4/51.6 V		
Back-up generator (genset)	Model	1.5 kW		
	Manufacturer	Back-up generator		
	Power	2 kW		

User's needs :	Daily household consumers	Constant over the year
	average	8.8 kWh/Day

Stand Alone System: Detailed User's needs

Project : **Lukla-Chaurikharka**

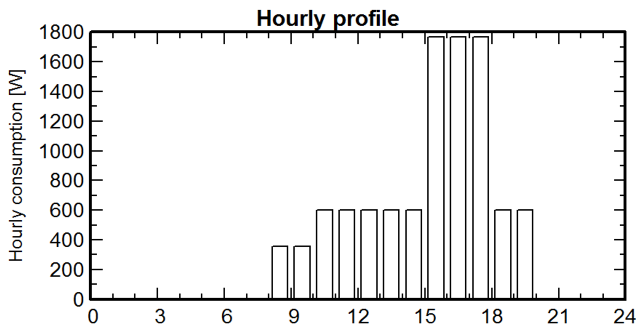
Simulation variant : **Lukla Variant Stand-Alone 01**

Main system parameters	System type	**Stand alone with back-up generator**			
PV Field Orientation	tilt	20°	azimuth	24°	
PV Array	Nb. of modules	16	Pnom total	**2880 Wp**	
User's needs	Daily household consumers	Constant over the year	global	3196 kWh/year	

Daily household consumers, Constant over the year, average = 8.8 kWh/day

Annual values

Use 6 days a week	Number	Power	Use	Energy
Fluorescent lamps	26	36 W/lamp	4.5 h/day	4212 Wh/day
TV / Video-tape rec. / PC	12	100 W/app	5 h/day	6000 Wh/day
Total daily energy				10212 Wh/day



Stand Alone System: Main results

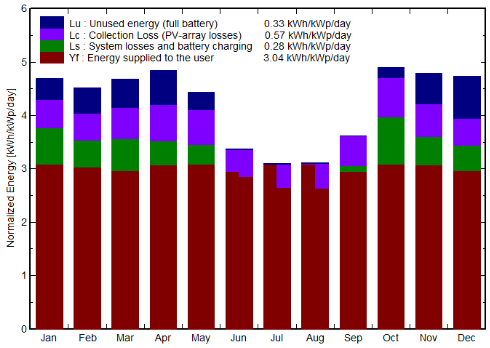
Project : **Lukla-Chaurikharka**

Simulation variant : **Lukla Variant Stand-Alone 01**

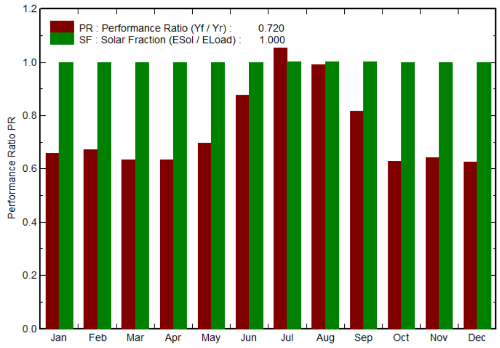
Main system parameters	System type	**Stand alone with back-up generator**		
PV Field Orientation	tilt	20°	azimuth	24°
PV Array	Nb. of modules	16	Pnom total	**2880 Wp**
User's needs	Daily household consumers	Constant over the year	global	3196 kWh/year

Main simulation results				
System Production	**Available Energy**	**3749 kWh/year**	Specific prod.	1302 kWh/kWp/year
	Used Energy	3195 kWh/year	Excess (unused)	347 kWh/year
	Performance Ratio PR	68.5 %	Solar Fraction SF	95.1 %
Back-Up energy from generator	Back-Up energy	156 kWh/year	Fuel Consumption	93/year

Normalized productions (per installed kWp): Nominal power 2880 Wp



Performance Ratio PR and Solar Fraction SF



Lukla Variant Stand-Alone 01

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E User kWh	E Load kWh	SolFrac
January	115.0	141.5	364.7	34.30	275.5	275.7	0.999
February	112.0	123.4	318.3	39.36	244.9	245.1	0.999
March	139.1	141.2	359.0	47.54	265.3	265.5	0.999
April	146.4	141.0	352.0	55.13	265.3	265.5	0.999
May	141.2	132.5	329.3	29.40	275.6	275.7	1.000
June	104.4	97.3	237.4	0.51	255.4	255.3	1.000
July	93.6	87.3	212.3	0.83	275.9	275.7	0.720
August	98.6	93.1	227.4	1.06	275.9	275.7	0.716
September	107.5	105.0	256.5	0.47	255.4	255.3	1.000
October	136.7	148.2	365.1	18.15	275.7	275.7	1.000
November	117.3	140.1	354.6	49.12	265.2	265.5	0.999
December	112.0	143.1	372.3	70.65	265.2	265.5	0.999
Year	1424.0	1493.8	3748.8	346.50	3195.2	3196.4	0.951

Legends:

GlobHor	Horizontal global irradiation	E User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E Load	Energy need of the user (Load)
E Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (full battery) loss		

Stand Alone System: Loss diagram

Project : **Lukla-Chaurikharka**

Simulation variant : **Lukla Variant Stand-Alone 01**

Main system parameters	System type	**Stand alone with back-up generator**			
PV Field Orientation	tilt	20°	azimuth	24°	
PV Array	Nb. of modules	16	Pnom total	**2880 Wp**	
User's needs	Daily household consumers	Constant over the year	global	3196 kWh/year	

Loss diagram over the whole year

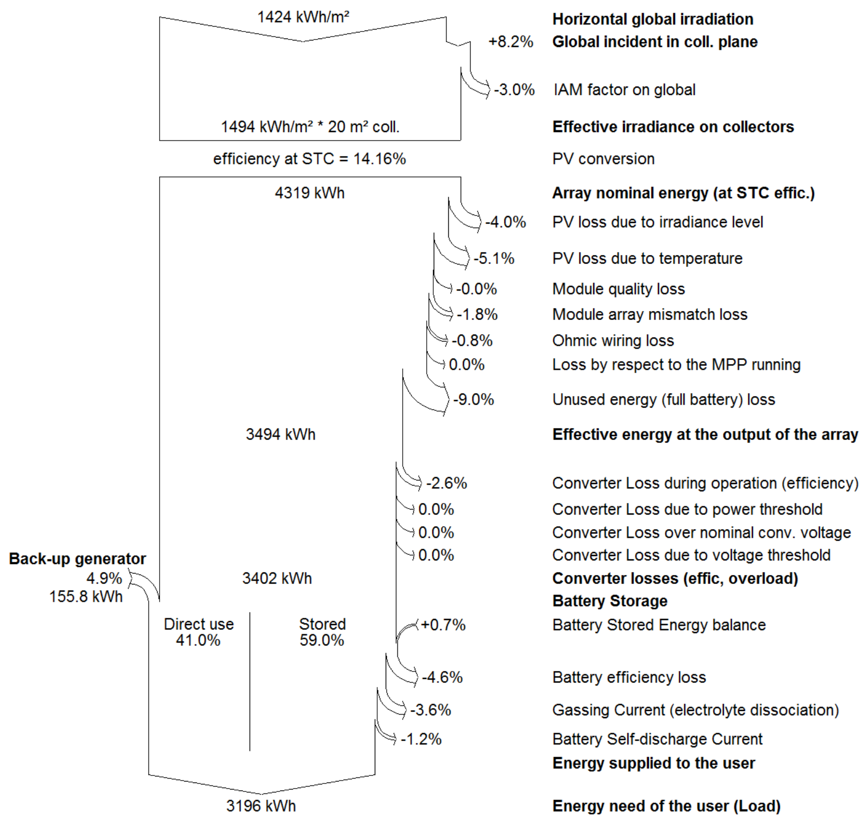


Figure 84: Report including the energy study and the solar installation design for the primary school of Lukla (4).

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