

Semester Thesis
Experimental

Analysis of the Energy Demand for Designing Off-Grid Energy Systems for Developing Countries Based on the Example of Nepal

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Abstract

For rural electrification in Nepal, the proven concept of off-grid hydroelectric power plants is the way to go. However, especially for properly designing small-scale stand-alone energy systems, load profiles are essential and required data. In today's research, load is only estimated and modelled by simulation-generated profiles but not measured.

As the current literature is lacking of such data, the present study's objective was to collect load data based on electrical measurements at households, lodges and schools in Manang District, a remote area in Himalayan Nepal. For this, the load at seven test subjects was logged for 24 hours with a 60 second resolution using simple and cost-efficient equipment.

When analysing the results, it can be stated that for a major period of time, electricity consumption was rather low, ranging between tens to a few hundreds of Watts. However, at several test subjects, mostly short-time peak loads of up to 1.9 kW were measured resulting in rather uneven load distributions.

Derived from the study's findings, a brief supply concept is presented. In addition, the results of the present study can be utilised to validate and complement the simulation-based data set.

Key Words: Developing Countries, Rural Electrification, Off-Grid Energy Systems, Energy Demand, Load Measurements

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Abbreviations

Abbrev.	Meaning
UNO	United Nations Organisation
MDG	Millenium Development Goals
GHG	Greenhouse Gas
GDP	Gross Domestic Product
HDI	Human Development Index
TPEC	Total Primary Energy Consumption
LPG	Liquified Petroleum Gas
NPC	National Planning Commission
NEA	Nepal Electricity Authority
IPP	Independent Power Producer
HPI	Human Poverty Index
MHP	Manang Hydropower Plant
SHP	Sabje Hydropower Plant
CHP	Chame Hydropower Plant
AC	Alternating Current
DC	Direct Current
NPR	Nepali Rupees
CFL	Compact Fluorescent Light
LBS	Lophelling Boarding School

Notation

Symbol	Unit	Explanation
<i>I</i>	[A]	Current
<i>I_m</i>	[A]	Transduced current (current clamp)
<i>w</i>	[-]	Coil number
<i>P</i>	[W]	Power
<i>V</i>	[V]	Voltage

1 Introduction

1.1 Motivation

Basic Motivation

1.2 billion people have no access to electricity, especially in rural and remote areas of sub-Saharan Africa and developing Asia (IEA 2015). “A functioning energy supply is important for the stability of a country [...]; it has a significant influence on the quality of the local and global environment” (BMZ 2007, 3). This certainly includes supply with electricity, representing the most flexible and modern energy form.

Hence, providing access to electricity is a big challenge and was consequently designated as one of the Millennium Development Goals (MDG), stated by the United Nations Organisation (UNO) (GNESD 2007), (UNO 2005). The MDG represent a schedule developed by the UNO to settle the foundations for fighting global poverty and famine.

The issue of rural electrification is relevant more than ever in times of rising refugee movements. Besides rather short-term causes of migration, such as wars and conflicts, there are also long-term ones, for instance poverty, food insecurity and finally energy scarcity. The German Federal Ministry for Economic Cooperation and Development plans to fight the causes for flight and migration by improving especially rural energy and electricity supply infrastructure. Energy supply security provides a solid foundation for economic development and, therefore, is an important part of the solution to this humanitarian issue (BMZ 2017).

In addition, climate change is a pressing global challenge. For too long, economic development was given preference over ecological concerns. In this way, the development of today’s industrialised nations contributed massively to exceeding greenhouse gas (GHG) emissions responsible for today’s rapidly changing climate, resulting in more and more extreme weather conditions. But especially for developing countries, adaptation to rough weather conditions is difficult due to a weak infrastructure and non-existent funds (Zeriffi and Wilson 2010). Hence, nations that have caused the smallest share of climate change, will have to cope with the biggest problems linked to its consequences (BMZ 2007), (Zeriffi and Wilson 2010). Therefore, it is important for developing countries not to choose the same path of unsustainable development as today’s industrialised nations did. Their task is to find ways that coherently fight their own poverty and gain both, maximum economic and ecological benefits, without interfering with development on a social and economic level. The task of industrialised nations’ research is to help them finding this way.

Fortunately, there is a great way of fighting both, the problems of rural poverty caused by the lack of access to electricity as mentioned above (Yadoo and Cruichshank 2012), and climate change (Weisser 2007) by utilising renewable energies. Thus, it is possible to provide people of rural and remote areas in developing countries with electricity, and to promote sustainable development.

Specific Motivation

Overall, the electrification rate in Nepal is estimated to be around 75% (NPC 2015), (World Bank 2012). Particularly remote areas often have no access to electricity because connecting them to the national grid is not cost-efficient due to hilly terrain and dispersed population (Barnes 2005), (Zeriffi 2007). Hence, off-grid and stand-alone energy systems are needed to push electrification rates forward. These solutions have been developed and applied in Nepal since the 1960s, using off-grid hydroelectric power plants (AEPC 2011). However, the nation is still far away from being 100% electrified. Therefore, as the country has a great potential for hydropower (Horlacher 2003), generating electricity “from a very small to large-scale power stations” (BMZ 2007, 22) is the way to go.

To properly design those off-grid systems, detailed knowledge of the electricity consumption patterns of the individual consumers, such as load profiles, is needed. Today’s designing process is based on load profiles generated by using simulations and modelling. No validated data derived from actual consumption measurements is available in literature. Therefore, the aim of the present study is to overcome this lack of measured electricity demand data. This should be done afield by collecting electricity consumption data of different individuals and buildings in remote areas based on electric measurements. The knowledge of detailed electricity demand data of remote areas in Nepal would allow to validate and complement the simulation-based load profiles available today. Thus, more properly designed and consumer-oriented off-grid systems could meet the people’s demands in an improved manner to overcome the problems of rural energy poverty in remote areas.

1.2 Task

To address the lack of objectively measured data of the electricity demand in developing countries, the present study’s main task is to gain such data of people living in remote areas, as those people are most relevant for off-grid solutions. Data on electricity demand will be complemented by demand data of other energy sources. Thus, a holistic understanding of the test subjects’ energy demand on the one hand and the opportunity to properly interpret their electricity demand on the other hand is obtained.

Electricity demand data will be collected afield through time-resolved measurements of the power consumption at the test subjects’ main boxes. Afterwards, load profiles will be calculated based on measured data. Complementing the measurements, additional insights about the individual’s energy consumption in general will be gained through on-site observation, survey and expert interviews.

A secondary task of the present study is to assess the practicability and data quality of the rather basic measurement equipment used.

After processing the collected data, the results will be presented and interpreted. Thereby, an emphasis is put on the measured electricity consumption data, while other collected data will be outlined only supplementarily.

Finally, conclusions and suggestions for practice will be derived. Furthermore, ways to utilize the collected data when designing off-grid energy systems will be developed.

Information gained through the review of literature and through the present study's results will be used to make projections about possible future trends regarding electricity consumption patterns of remote areas in Nepal.

1.3 Outline of the Thesis

At the outset, chapter 2 provides the theoretic foundations needed for a proper comprehension of the present study. An overview of the energy situation, with emphasis on electricity, is given first for Nepal in general, secondly for the study area of Manang District in particular. Afterwards, basic information about electrical metrology and a brief outline of some previous research is presented.

Methods applied within this study are load measurements, survey and observation, and expert interviews. In chapter 3, the applied methods are described in detail. Thereby, insights into the development of the final test design are given. The experimental equipment and how it was used for the electrical measurements is presented as well as the questionnaire used for the surveys.

The results of the collected data are presented in chapter 4. 24-hour load profiles and load duration graphs, both calculated from measured data, represent the test subjects' electricity demand data. In addition, only the most relevant data gained from the surveys and observation are shown. After presenting the results for each test subject individually, data of measurements, surveys and observation are interpreted individually, too.

General conclusions and implications for practice are contents of chapter 5. In addition, future projections on the test subjects' energy demand are derived from the results of the present study. Furthermore, a brief concept of a very small off-grid hydroelectric energy system for the supply of just a few households is presented, based on the study's findings.

After a critical reflection of the methodology and the performance of the study in chapter 7, a summary and an outlook are given in chapter 8.

2 Theoretical Background

2.1 Energy Situation in Nepal and Particularly in Manang District

Though the present study's goal is to collect data about the energy demand of remote areas in Nepal, this section addresses a basic understanding of the energy supply situation, both on national level in Nepal and in the study area of Manang District. In this paragraph, also basic facts about the important relevance of off-grid systems for providing electricity in remote areas in Nepal are elaborated.

The necessity to also cover the supply side in this thesis derives from the consideration that when energy is scarce, as it is in Nepal with electricity, supply may have an influence on demand. When devices can not be run because of power outages, they may be used instead when electricity is back and, therefore, at a different time. Moreover, when the supply reliability of a certain source of energy is utterly low, people might switch to another energy source. In both ways, the bad quality of supply would have an influence on demand.

At first a general overview of the country Nepal and its energy situation is given. Afterwards, an emphasis is put on electricity supply through the national grid and off-grid systems all over Nepal and in Manang District, where fieldwork was performed.

2.1.1 Overview of Nepal

Among other countries like Zimbabwe, Haiti and Bangladesh, Nepal is not only considered a developing country but even listed as least developed country according to UNO (UNO 2015), (UNO 2016). The country is particularly weak in terms of gross national income per capita, adult literacy rate, remoteness and the share of agriculture, forestry and fishing in its gross domestic product (GDP). According to the Human Development Index (HDI), the Himalayan nation ranks at 145 out of 188, with 14.99% of the population living in pressing poverty (BMZ 2016).

Nepal: General Information

With a national territory of 147 181 m², Nepal is a landlocked country, situated between India in the South and China in the North (see figure 2-1). Terrain varies from flat river plains of the river Ganges in the South (the so-called Tarai) to a central hill region with the rugged mountains of the Himalayas in the North, making Nepal the country with the highest mean elevation of 2 565 m (CIA 2016). The enormous amount of water draining southwards out of the Himalayas provides an excellent potential for hydropower use (Horlacher 2003). When considering the geographical situation, most of Nepal is trapped between the Himalayas and India, resulting in the nation's strong economic dependence on India (Asian Times 2016).

Population has linearly risen since 1960 (see figure 2-2), resulting in a total number of 28 513 700 inhabitants in 2015 (World Bank 2015). Most of the population (81.4%) is living in the countryside in the Tarai region, while the population density in northern, hilly regions is quite low (CIA 2016), (CBS 2001). The two most important urban regions are the capital city Kathmandu's metropolitan area (1 003 285 inhabitants) and Pokhara (264 991) (CBS 2014).



Figure 2-1: Map of Nepal with its 14 administrative zones [Own Illustration; Data based on Open Street Map (2017)]

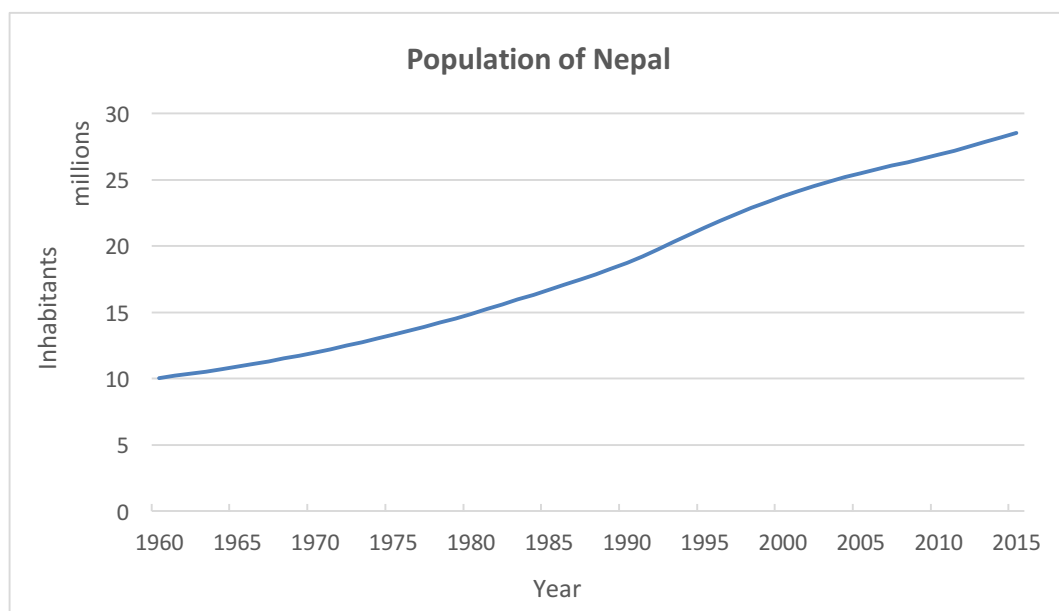


Figure 2-2: Population of Nepal from 1960 to 2015 [Own Illustration; Data based on World Bank (2015)]

In the fiscal year of 2015 the GDP was around 20.88 billion USD, achieving a significant growth since 1960 (see figure 2-3). However, with a GDP per capita of only 723.30 USD, Nepal still rates among the poorest nations of the world (World Bank 2015).

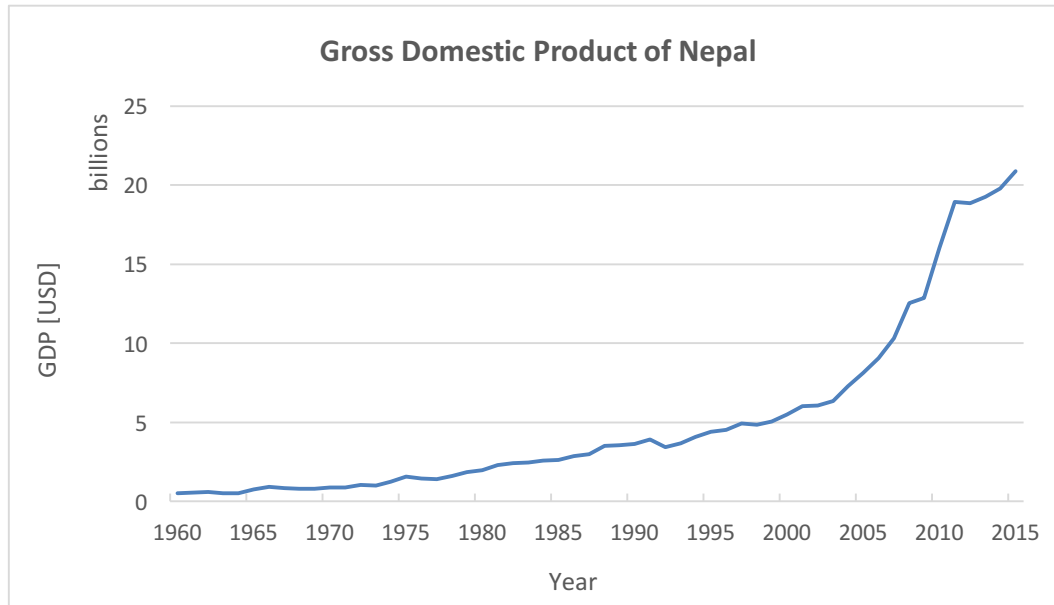


Figure 2-3: Gross domestic product of Nepal from 1960 until 2015 [Own Illustration; Data based on World Bank (2015)]

Energy Situation

The energy market in Nepal has experienced constant growth for many years (see figure 2-4), leading to a total primary energy consumption (TPEC) of 11 534 ktoe in 2014 (IEA 2014). Consumption was composed of 81.41% biofuels and waste, mostly traditional biomass like fuelwood, used to generate heat for cooking and space heating. This pattern is widely common in developing countries (REN21 2016).

The share of biofuels and waste use in Nepal can be classified as very high, when compared to the world average value of 8.9% (REN21 2016). Fuelwood dominating the energy consumption is the cause for several growing problems in Nepal, especially in the Himalayan regions. Unsustainable deforestation in combination with high fuelwood demand is resulting in forest degradation and rural environmental problems, such as landslides (Pokharel 2003), (Rijal 1995). In addition, the black-carbon aerosols resulting from biomass combustion cause a decrease in surface albedo of the Himalayan glaciers and, therefore, accelerate their melting. This process jeopardises the sustainable freshwater supplies of billions of people (Li, et al. 2016). These pressing environmental issues call for a reduction of the biomass consumption through an increased utilization of alternative energy sources.

In 2014, oil products like gasoline and diesel, accounted for only 11.49% of the TPEC. However, as Nepal has hardly any national resources of fossil fuels, it is and will continue to be highly dependent on energy imports. In this way, a lot of money is draining out of the already weak economy (dena 2009). Oil product imports, all of them from India, account for a share of 20% of total imports (MOF 2016). This high dependency on imports from India climaxed in the so-called Nepal Blockade in 2015 (Süddeutsche Zeitung 2015-1). After Nepal's severe earthquakes in April and May of 2015, most of the trucks bringing

liquefied petroleum gas (LPG) for cooking, fuel for transportation, medicine and other vital goods from India were restrained (Süddeutsche Zeitung 2015-2) (BBC 2015). This blockade condensed in a drop of petroleum products supply of 41.8% during the first eight months of 2015 compared to the same period in the year before (MOF 2016). Since these events and the resulting fuel crisis, the government has more than ever been willing to promote renewable energy sources in order to alleviate Nepal's dependency on India.

Appendix A provides more detailed information about the share of Nepal's TPEC compared to the TPEC in Germany both for the year 2014, showing that the quality and quantity of energy consumption differs a lot between those two nations (IEA 2014).

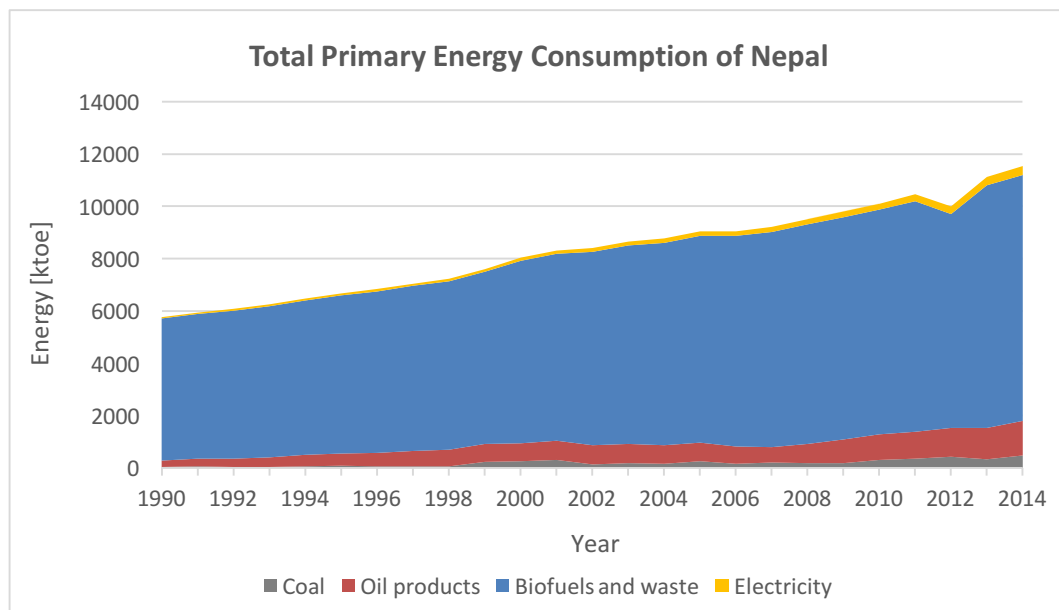


Figure 2-4: Total primary energy consumption of Nepal from 1990 until 2014 [(Own Illustration; Data based on IEA (2014))]

As mentioned above, Nepal's economy is mainly based on agriculture and forestry. This is also reflected in the table of sectoral shares of TPEC, where residential consumption is dominating with a proportion of 83.65% and industrial consumption is comparatively low (see figure 2-5). The share of biofuels and waste use in residential TPEC even accounts for 96.53% and is mainly composed of fuelwood for cooking and heating. Residential petroleum product use, primarily LPG for cooking in cities, sums up to only 1.8% (IEA 2014), (BBC 2015). These facts underline the massive contribution of residential individuals to the TPEC. When considering these facts and the mentioned high share of rural population, the potential of promoting renewable energy technologies in rural and remote areas in Nepal can be estimated as considerably high.

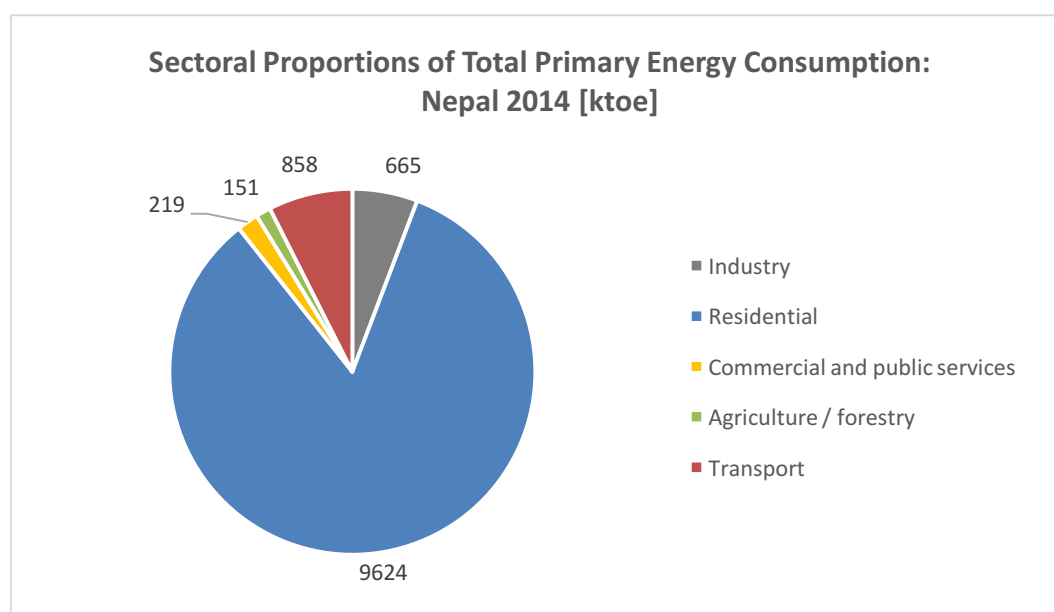


Figure 2-5: Sectoral proportions of the total primary energy consumption in Nepal for 2014 [Own Illustration; Data based on IEA (2014)]

2.1.2 Electricity Demand and Supply in Nepal

Electricity Demand

Electricity demand has risen constantly since 1960 (see figure 2-6), with a total demand of 3 893 GWh in 2014 (IEA 2014). Electricity consumption however, shows different proportions from the TPEC (compare figure 2-5 and figure 2-6). Residential consumption contributes only 47.01% while industry has a share of 34.01% (IEA 2014). This may be a result of the mostly rural population using fuelwood as their main energy source while the industry, plausibly settled in urban areas, rather needs electricity.

When put into an international perspective, Nepal shows extremely low electricity consumption per capita as shown in figure 2-7, although the demand constantly rose during the last 40 years (see figure 2-8). In fact, Nepal's power consumption per capita is the seventh lowest worldwide when compared to the available data of 179 countries (IEA 2014).

The share of electricity use is relatively low while the consumption of other energy sources like fuelwood and LPG is relatively high, with the above mentioned environmental issues and dependency on fuel imports. This led the National Planning Commission (NPC), a governmental organisation in charge of development and reaching UNO's MDG, to promote the use of electricity instead of fuelwood as the main source of energy in their Three Year Interim Plan of 2007 (NPC 2007) and Sustainable Development Goals 2016 – 2030 report of 2015 (NPC 2015). The future projected electric power consumption of both reports (see table 2-1) is shown in figure 2-8 along with the actual electric power consumption. On which assumptions the NPC's future projections are based on could not be investigated.

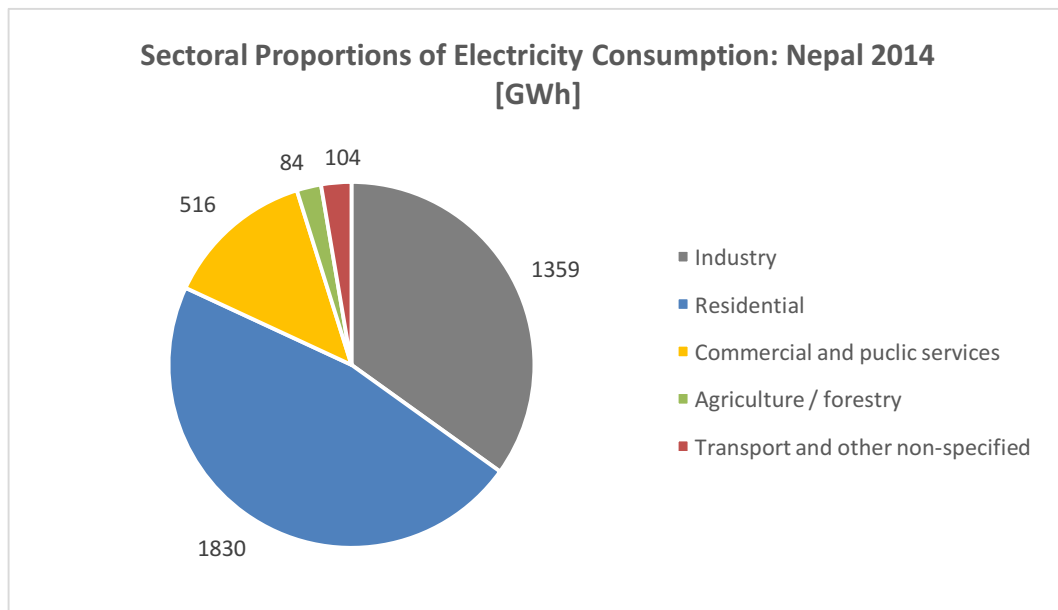


Figure 2-6: Sectoral proportions of the electricity consumption in Nepal for 2014
[Own Illustration; Data based on IEA (2014)]

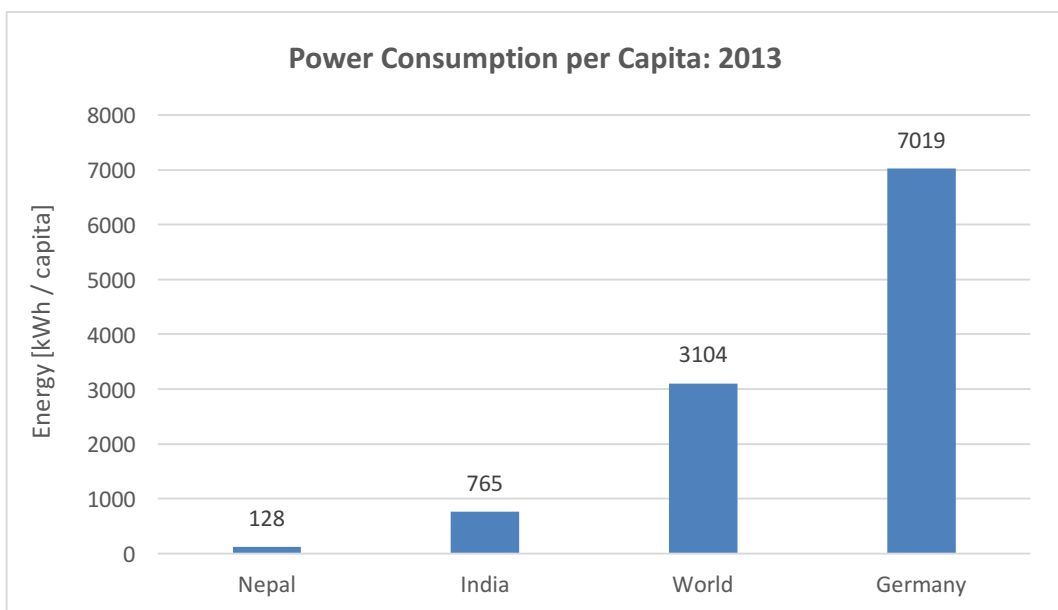
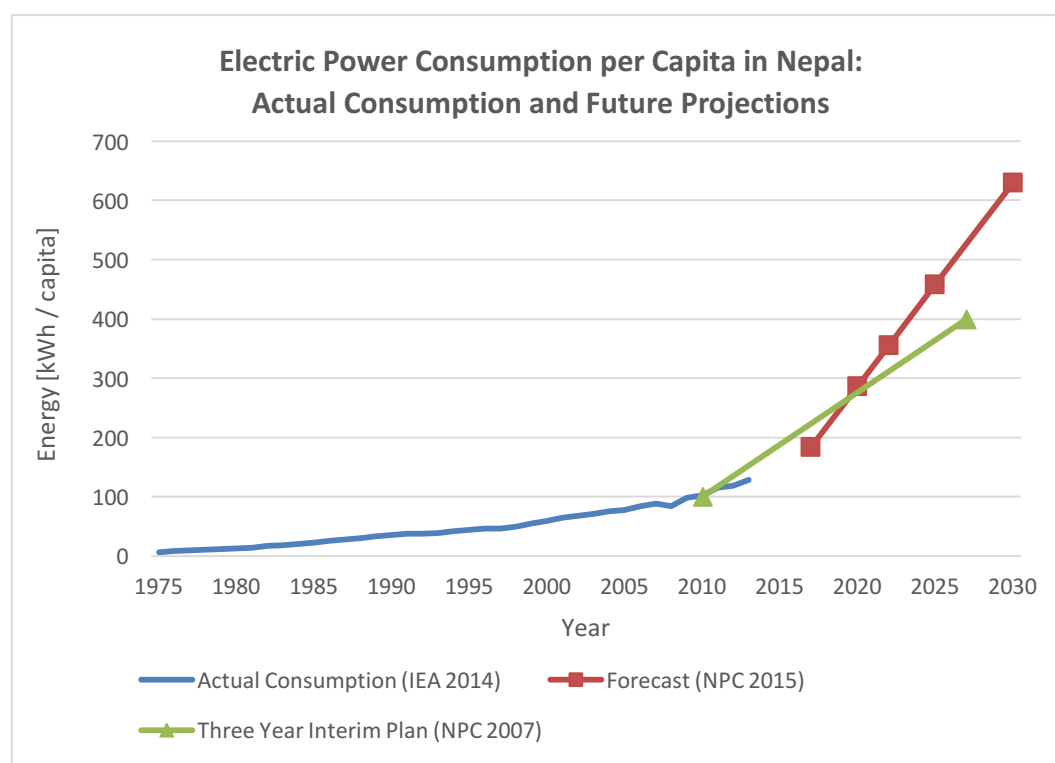


Figure 2-7: Power consumption per capita of Nepal, India, Germany and the world average in 2013
[Own Illustration; Data based on IEA (2014)]

Table 2-1: Projected annual electric power consumption per capita in kWh [Data based on NPC (2007, 2015)]

	NPC 2007 [kWh]	NPC 2015 [kWh]
2010	100	-
2017	-	183.1
2020	-	286.3
2022	-	355
2025	-	458.1
2027	400	-
2030	-	630

**Figure 2-8: Actual (blue) and projected (red and green) annual electric power consumption per capita in kWh [Data based on IEA (2014) and NPC (2007, 2015)]**

In 2014, 2 558 726 domestic customers (NEA 2015) consumed 1 830 GWh of electricity (IEA 2014), resulting in about 715 kWh/a per customer on average (1.96 kWh/d). In general, the consumption in rural areas is expected to be significantly lower than in urban areas, as the Human Development Index is significantly higher in urban areas (0.579) than in rural areas (0.464) (NPC 2014).

Electricity Supply

If not indicated otherwise, the following information is based on Nepal Electricity Authority's Year Review Report of 2014/2015 (NEA 2015).

As already mentioned, Nepal has a great potential in hydropower (Horlacher 2003). Therefore, 93.20% of the installed electricity supply capacity is provided by hydroelectric power plants. The Nepal Electricity Authority (NEA), the nation's parent producer and distributor of electric power under governmental supervision generates its power mainly with its own plants. Since the Power Purchase Agreement of 1992, the NEA, however, also buys electricity from so-called Independent Power Producers (IPP). This market opening agreement was the first step to a NEA- and grid-independent generation of electrical power. IPP capacity has a share of 32% (256 MW) of the total installed power plant capacity of 787 MW. The residual 531 MW are provided by NEA-owned power plants, with 478 MW supplied by hydropower plants. See Appendix B for a map of Nepal with the ten biggest NEA-owned hydropower plants and the five biggest IPP-plants.

In 2015 the peak demand was 1 291.80 MW. Insufficient installed capacity to cover the demand during peak times lead to power imports granted by India. Those power purchases summed up to 1 370 GWh in 2015, accounting for 27% of Nepal's total available energy of 5 006 GWh. The gap between those 5 006 GWh of total available energy and the above mentioned annual electricity demand (3 893 GWh) exists mainly due to transmission losses of around 22% (IEA 2014). In comparison, German transmission losses usually account for around 6% (STATISDE 2016).

Despite the power purchases from India, the NEA system is a supply deficit one, resulting in load shedding of above 30 hours a week in 2008 (WECS 2010) and up to 16 hours a day in 2016 (Maskey 2016). Hence, the NEA is trying hard to increase the installed capacity with 1 044 MW of hydropower plants under construction. Appendix C shows a map of Nepal with the 5 biggest hydroelectric power plants under construction. Upper Tamakoshi Hydroelectric Project, to be commissioned in the near future, will provide 456 MW, 58% of today's total installed power plant capacity of 787 MW.

As mentioned before, the electrification rate in Nepal is said to be around 75% (NPC 2015), (World Bank 2015), but only part of the service comes from a connection to the national grid. Especially in remote and sparsely populated areas, establishing a grid connection is not cost-efficient. In these regions, stand-alone and off-grid energy systems are used for decentral electricity generation (Pokharel 2003), (de Gouvello and Maigne 2002), (Kirshnaswamy 2010). Such off-grid power plants are either operated by the NEA, or community-owned by the local population. However, in any case they are rather small hydropower systems ranging from a few kW up to around 500 kW.

Electrification rates of grid-connected urban areas (96%) are significantly higher, than of rural areas (60%) (CBS 2011). Furthermore, people living in the more densely populated southern Tarai region (see Appendix D) are more likely to have access to electricity, mostly through grid connection, than people residing in northern Himalayan regions (CBS 2011), which are often supplied by off-grid systems. Appendix E shows the current expansion of Nepal's national grid, indicating clearly that transmission lines mostly run through the flat Tarai region. This is because of the easier terrain and, consequently, simpler implementation and better cost-effectiveness due to higher population density (de Gouvello and Maigne 2002).

However, even with access to electricity, service quality is not even close to being comparable to industrialised nations' standards. 42% of the respondents valued service quality as bad during Central Bureau of Statistics' survey in 2011 compared to 18% in the 2003/2004 survey (CBS 2011). Especially in grid-connected urban areas, service quality was reported as bad. In general, respondents in off-grid rural areas valued electricity service better than in grid-connected urban areas. This could be a result of the urban population having higher expectations or an actually worse service. Mr. Maharjan, manager of a small off-grid hydropower plant in the Himalayas reported that in terms of load shedding the situation in Kathmandu was much worse than in the remote area he lived in (Maharjan 2016). In any case, when reliable electricity is crucially needed e.g. for running a business, off-grid should be taken into consideration even in regions with grid connection. When switching from grid to off-grid, service quality may improve and the overloaded grid could be relieved.

Besides load shedding, voltage quality is not as good as for example in Germany, either. See Appendix F for a 24-hour measurement of the voltage in Kathmandu, compared to Munich, Germany. The voltage graph of Kathmandu shows load shedding and significant volatility.

The data of the previous paragraph also call for a precise definition of the term *electrified*. In India, any household, that has an electric line going in from the main transmission line is defined as electrified (Kirshnaswamy 2010). Even with a proportion of only 10% of the households provided with electricity, a village is deemed electrified (The Hindu 2016). Assumably, the definition of electrification is comparable in Nepal in terms of having no adequate requirements on the quality or quantity of the electricity service. It is, therefore, suggested to take a close look when dealing with electrification rate data.

Until 2030, the NPC is planning to have 99% of the nation with access to electricity. To achieve this ambitious rate, a mixed strategy of grid connection for flat regions and increased application of off-grid solutions for remote areas is suggested. Only for sparsely populated rural areas, which are close to the edges of the existing national grid network, electricity supply by extending the grid is economically reasonable (de Gouvello and Maigne 2002), (Kirshnaswamy 2010). However, by pursuing the mixed strategy mentioned, not only cost-effectiveness is addressed. Connecting remote areas to the grid is often related to high costs and low returns on investment due to low projected levels of consumption. As it is the case in India (Kirshnaswamy 2010), maintenance and service may be poor or even non-existent (Yadoo and Cruichshank 2012). Therefore, in many cases off-grid systems seem to be the better choice in terms of service.

Since 2006, the NEA, however, has managed to supply electricity to a rising additional number of people. NEA customer growth has gone far beyond national population growth, allowing the assumption that it is linked to rising electrification rates. Figure 2-9 indicates the relation between electricity consumption and NEA customer growth.

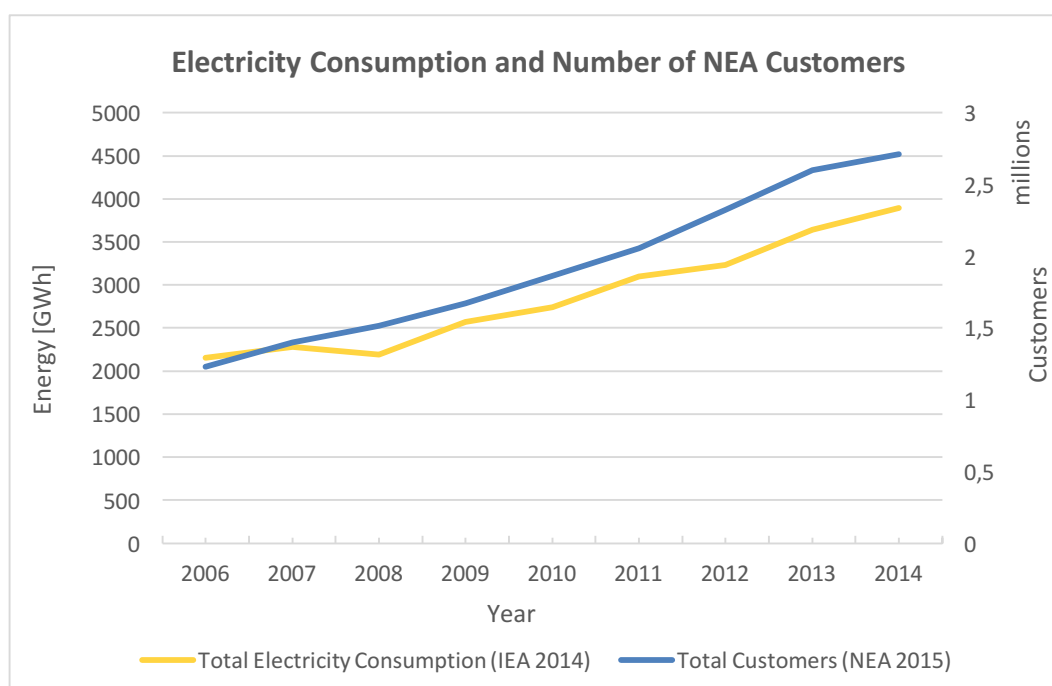


Figure 2-9: Total electricity consumption compared to total NEA customers [Own Illustration; Data based on IEA (2014) and NEA (2015)]

2.1.3 Electricity Supply in Manang District

As Manang District served as study area for fieldwork and collecting data, some basic information about Manang District in general and its energy supply situation are provided in the following paragraph.

Manang District: General Information

As depicted in figure 2-10, Manang District is located in the North-West of Gandaki Zone, bordering Tibet Autonomous Region of China in the North and Dhawalagiri Zone in the West. The district covers an area of 2 246 m² and had a population of 6 538 inhabitants in 2011 (CBS 2014). With 1 480 households in total, the average household size in Manang District is 4.42 (5.44 in Nepal on average) (CBS 2014). Settlements mainly exist along Marsyangdi river in the so-called Manang Valley with Manang Village and district headquarters Chame accounting for the two most important towns. As the famous trekking route *Annapurna Circuit* along Marsyangdi River up to the Thorong La pass crosses Manang District, many Manangis run their own hotel business. Tourism, therefore, has a considerable influence on people's lives, making Manang District relatively wealthy compared to residual Nepal (see Appendix G for a map of the Human Poverty Index (HPI) distribution for Nepal's 75 districts).

There is no paved road in Manang District (as from 2016), so transportation is only possible by foot, pack animals and all-terrain vehicles. A ride from Chame to Besisahar, the nearest town with access to paved roads, takes a minimum of nine hours by jeep, making

Manang District a remote area. Going from Besisahar to Kathmandu takes a minimum of four hours.

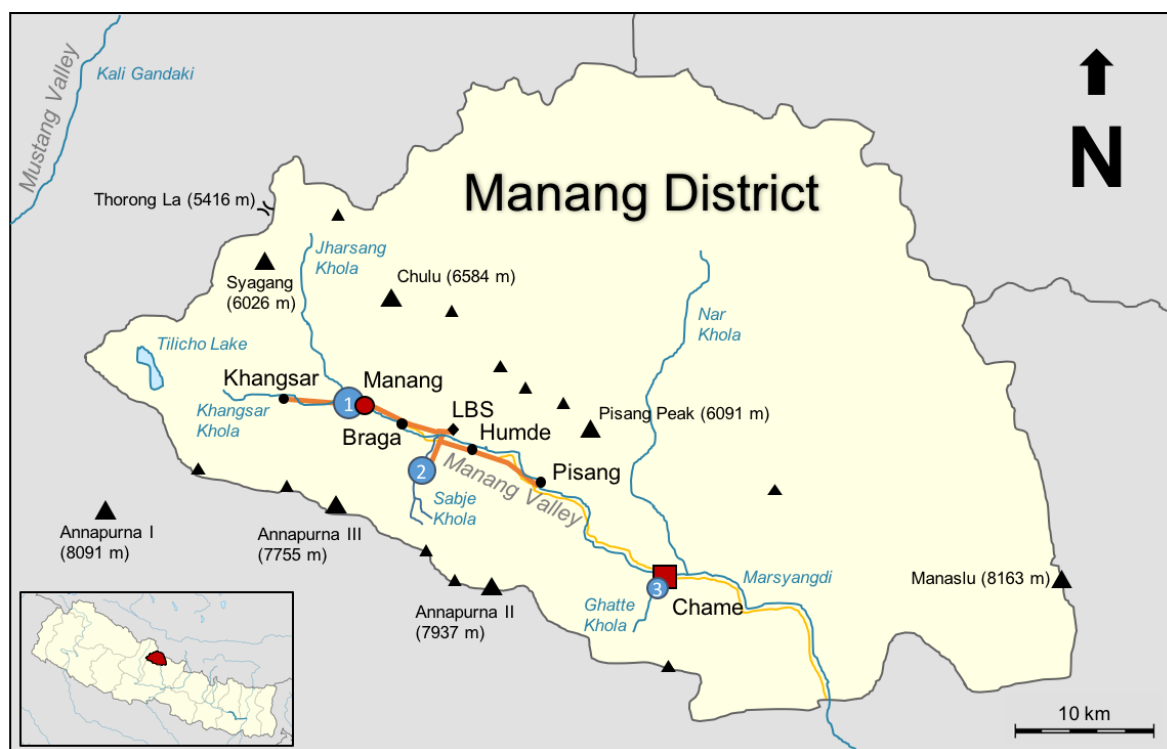


Figure 2-10: Manang District. The blue circles represent the three hydropower stations relevant for the present study with an area according to the installed capacity. The orange line depicts the distribution line of the stand-alone grid of Sabje Hydropower Plant, the yellow line represents the off-road track along Marsyangdi River coming from Besisahar and ending at the beginning of Manang Village. [Own Illustration; Data based on Open Street Map (2017)]

Energy Situation

Energy sources like diesel, gasoline, LPG and kerosene must be transported to Manang District via jeep or tractor from Besisahar, resulting in comparably high prices. Fuelwood prices are also considerably high due to deforestation being strictly regulated by local authorities to avoid excessive clearing.

Like in the rest of Nepal, the main energy source for Manangi people is firewood, used for generating heat for cooking and heating (CBS 2012). Above mentioned environmental issues of high fuelwood consumption call for switching to electricity driven appliances, especially when considering that power generation in Manang District is 100% renewable. LPG does not represent a viable alternative to biofuel use because of the high local prices and its GHG emissions. To protect the local and global environment, AEPC promotes switching to off-grid hydropower electricity as energy source wherever possible (AEPC 2016).

When conducting the fieldwork for the present study, the energy prices given in table 2-2 were investigated. However, it is essential to note that these prices just represent rough numbers and can differ locally and from time to time.

Table 2-2: Energy prices in Manang District

Resource	Price [USD] per customary unit	Price [USD] per kWh
Fuelwood	6.3 ct/kg	3.4 ct/kWh
LPG	27 USD per 15 kg Cylinder	13.2 ct/kWh
Kerosene	1.56 USD/l	16.3 ct/kWh
Electricity	3.7 – 11.6 ct/kWh	3.7 – 11.6 ct/kWh

Electricity Supply

As in most remote areas, as mentioned before, power supply in Manang District is not provided via national grid but from stand-alone hydropower plants. In total, Manang District is supplied by eleven rather small hydroelectric power stations ranging from 8 to 100 kW (AEPC 2016). Figure 2-10 depicts the three hydropower plants relevant for this study, namely Manang Hydropower Plant (MHP) (100 kW), Sabje Hydropower Plant (SHP) (80 kW) and Chame Hydropower Plant (CHP) (45 kW). MHP, completed only in 2012, was entirely financed by five influential and wealthy Manangi business men and, therefore, exclusively supplies Manang Village. SHP provides electricity to several towns from Manang to Pisang (represented by the orange transmission line in figure 2-10). CHP supplies the town of Chame only.

In general, electricity supply by off-grid hydropower systems in Manang District is predominantly reliable in terms of load shedding. However, the installed power plant capacity is by far not enough. That is why AEPC refers to Manang District's electricity supply situation as "energy crisis" (AEPC 2016). For example, the 45 kW CHP faces peak demands of 75 kW (Gale 2016), resulting in significant voltage fluctuations (see figure 2-12). Power plant overload is reflected in voltage quality. When demand is too high for the generator, frequency and, consequently, voltage goes down below 150 V during peak times in the evening. Comparable circumstances could be found when measuring voltage at buildings connected to SHP (see figure 2-14). For MHP no voltage measurements could be performed due to maintenance during field work. However, voltage is said to be very stable and reliable due to sufficient overcapacities of MHP (Gale 2016). Peak demand at MHP is around 50 kW, while installed capacity amounts to 100 kW (Gale 2016).

From AEPC's *District Climate and Energy Plan for Manang District* (2016), the following numbers and conclusions can be derived: CHP supplies 161 power connections with a capacity of 45 kW. Hence, 280 W of power is available per connection on average. Individuals supplied by SHP are provided with 158 W of power per connection on average (80 kW for 506 power connections). Considering that those numbers are average values for all types of buildings with a power connection, it seems imaginable that the average capacity available for households may be less. With only 280 W or even 158 W of power available on average, merely low power applications, such as lighting, entertainment (television or radio) and communication devices (internet or mobile phones) can be run. To generate heat from electricity for cooking or space heating and, thus, reduce the problematic fuelwood use, installed capacities are by far not enough. In contrast to CHP and SHP, the 96 power connections of Manang Village supplied by the 100 kW MHP have 1 042 W per power connection. Regarding the whole district, it can be assumed that only in Manang

Village, where the wealthy business men of the region reside, electricity supply is decent due to sufficient overcapacities.

The following three pages contain the primary technical data, some pictures and voltage profiles calculated from the electrical measurements data of CHP (table 2-3, figure 2-11 and figure 2-12), SHP (table 2-4, figure 2-13 and figure 2-14) and MHP (table 2-5 and figure 2-15). For information, how the data for calculating the voltage profiles shown in figure 2-12 and 2-14 was collected, see chapter 3. Technical data of the power plants was collected through several expert interviews (Gale 2016), (Gurrang 2016), (Gurung 2016) and AEPC's *District Climate and Energy Plan: Manang District* (2016).

Table 2-3: Main technical data of Chame Hydropower Plant

Capacity	45 kW
Generator	3 Phase AC Synchronous Generator BHEL Electrical Machines Ltd., India
Turbine	Crossflow Turbine Thapa Engineering Industries (P) Ltd., Nepal
Nett Head	59.3 m
Discharge Rate	180 l/s



Figure 2-11: Powerhouse (a) and penstock (b) of Chame Hydropower Plant [Own Illustrations]

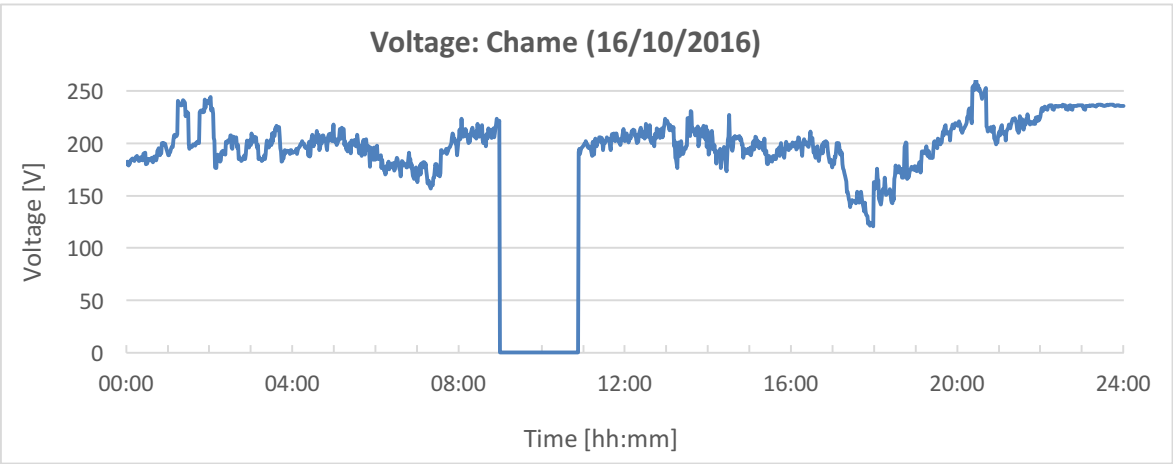


Figure 2-12: Voltage graph of a lodge in Chame supplied by Chame Hydropower Plant measured on 16/10/2016 [Own Illustration]

Table 2-4: Main technical data of Sabje Hydropower Plant

Capacity	80 kW
Generator	3 Phase AC Synchronous Generator Kerala Electrical and Allied Engineering Co.Ltd., India
Turbine	2 x Crossflow Turbine Thapa Engineering Industries (P) Ltd., Nepal
Nett Head	~ 35 m
Discharge Rate	380 l/s

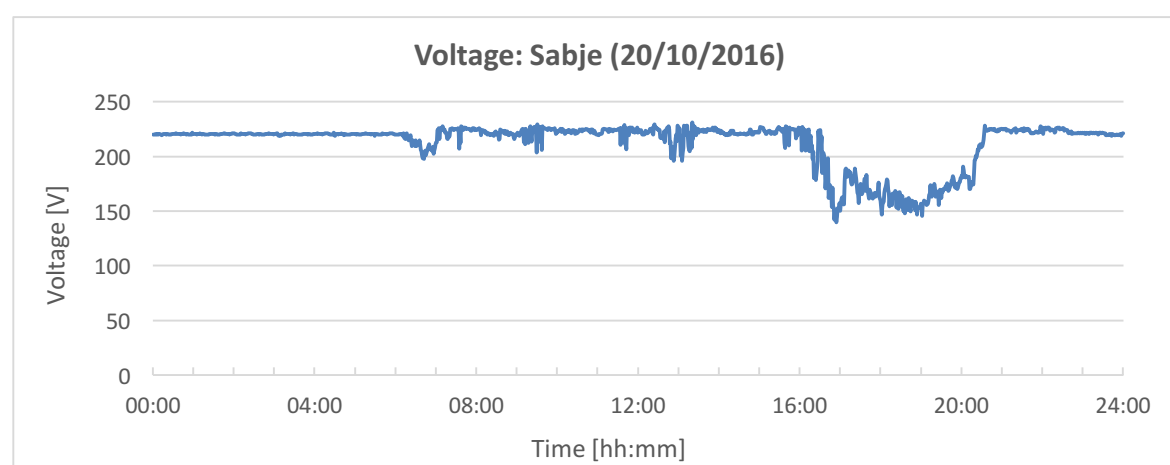
**Figure 2-13: Sabje Hydropower Plant with its penstock [Own Illustration]****Figure 2-14: Voltage at Lophelling Boarding School supplied by Sabje Hydropower Plant measured on 20/10/2016 [Own Illustration]**

Table 2-5: Main technical data of Manang Hydropower Plant

Capacity	100 kW
Generator	3 Phase AC Synchronous Generator Beijing Zanwei Hydropower Technology Co.Ltd., China
Turbine	Vertical Francis Turbine Beijing Zanwei Hydropower Technology Co.Ltd., China
Nett Head	11 m
Discharge Rate	1 300 l/s



Figure 2-15: MHP power house with penstock (a & c) and vertical Francis turbine with generator (b) [Own Illustrations]

2.2 Measurement Technology

This section serves as a theoretical introduction to chapter 3, Methodology. Basic physics and technical details behind methods and equipment used for the electrical measurements in the present study are presented as follows.

2.2.1 Introduction

During the electrical measurements for collecting electricity consumption data, voltage and current measurements were performed to calculate the load. As these techniques are very common and represent the most basic methods in today's electrical methodology, only essential information are given in this section. Furthermore, all measurements were performed with alternating current (AC) power grids used as voltage source. Therefore, foundations are primarily assessed for AC measurements in this paragraph. There are additional ways of measuring voltage, current and load, still only methods relevant to the study's use case are presented.

For further, more detailed information, see Mühl (2014).

2.2.2 Foundations of Current, Voltage and Load Measurement

2.2.2.1 Voltage Measurement

To measure the electrical potential difference between two points in an electrical circuit, the voltage V , a so-called voltmeter is used. Connected in parallel, digital voltmeters can display the dropping voltage of a resistor R using an analog to digital converter. Thereby, the input voltage is converted into a digital value and then displayed in numeric form.

As the voltmeter is connected in parallel, measuring the voltage V is both, simple as well as safe. The electrical circuit does not have to be opened.

2.2.2.2 Current Measurement

Applicable instruments for measuring electric currents I are called ampere meters. Thereby, the current to be measured must pass through the measuring unit. Current I , going through the resistor R , can be measured by opening the circuit and connecting the device in series to the resistor R . In today's practice, usually digital ampere meters are used. Those devices use a low ohmic shunt resistor, a digital voltmeter and Ohm's Law. The dropping voltage at the shunt resistor with known current sensor resistance is measured by the digital voltmeter. Using Ohm's Law, the flowing current being proportional to the dropping voltage is calculated and displayed.

Today's most common current measurement device, the digital multimeter, combines a digital voltmeter and a digital ampere meter with several additional functionalities depending on the complexity of the device. Many multimeters also have interfaces for connecting computers and logging data. Figure 2-16 depicts a hand-held digital multimeter,

suitable for measuring both, alternating current (AC) and direct current (DC) voltage, current, frequency and resistance. With an infrared interface and the provided free software, data logging on an external computer is possible.



Figure 2-16: Mobile Multimeter for measuring AC and DC voltage, current, frequency and resistance with a digital display and an infrared interface for data logging [(Conrad 2017)]

As safety issues arise when dealing with higher currents, alternatives to circuit opening methods are helpful. In addition, if the electrical circuit can remain closed while measuring, handling and practicability are improved. A convenient way to do so is by using a current clamp, a special form of transducers utilising the transformer effect. While using digital multimeters, currents can only be measured up to 10 or 20 A. In contrast, current clamps allow currents to be measured up to 400 A. For simple AC measurements, a current clamp consists of a coil with the coil number w and an opening toroidal core (see figure 2-17). When introducing the conductor with the flowing current to be measured I into the toroidal core, a transducer with the coil number ratio of 1: w results and I_m is calculated as follows:

$$I_m = I \cdot w^{-1} \quad (2.1)$$

Utilising this principle, only AC currents are measurable, as a change of the magnetic field is needed. Static DC magnetic fields cannot be quantified with this method.

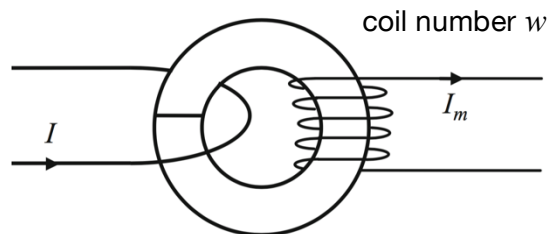


Figure 2-17: Schematic illustration of a conductor with the current I to be measured on the left, the opening toroidal core in the middle and the coil with the secondary conductor and the current I_m on the right [(Mühl 2014)]

More elaborate devices additionally have a resistor at the secondary coil for current/voltage conversion or integrated measurement systems and digital displays for indicating the current to be measured. To measure direct currents (DC), combined AC/DC current clamps with Hall sensors are needed. When using Hall sensors, both, AC and DC currents can be measured but only weak signals are produced. Hence, amplifying electronics must be installed needing external power supply such as batteries (Fischer 2016). Figure 2-18 shows a current/voltage converting current clamp adapter (a) and a current clamp with integrated measurement system, digital display and Hall sensors for combined AC/DC measurements (b).

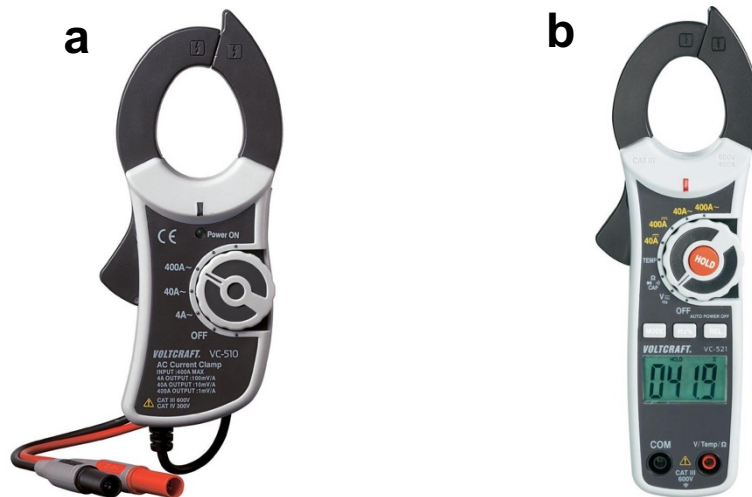


Figure 2-18: Current/voltage converting current clamp adapter (a) and a current clamp with integrated measurement system, digital display and Hall sensors for combined AC/DC measurements [(Conrad 2017)]

Figure 2-19a depicts a grid voltage measurement and data logging with a laptop using the digital multimeter shown in figure 2-16. A convenient and cost-efficient way to perform current measurements is using the current clamp adapter presented in figure 2-18a plugged into the same digital multimeter for data logging (see figure 2-19b).

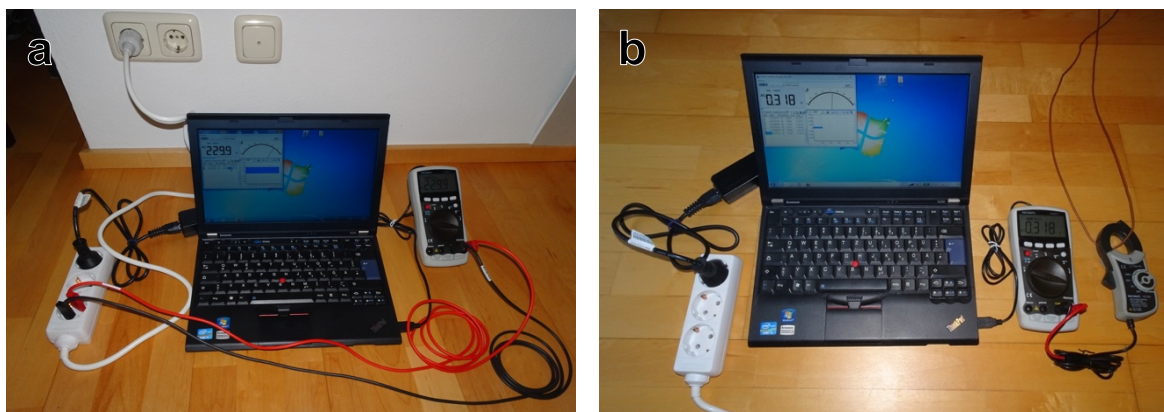


Figure 2-19: Grid voltage measurement (a) and current measurement of a single conductor (b), both with data logging [Own Illustration]

2.2.3 Load Measurement

To appropriately dimension small-scale and off-grid renewable energy systems, data must be collected beforehand. However, not only potential data covering the supply side but also data concerning demand side is needed. Thereby, the distribution of the electrical power of a consumer over a certain period, the so-called load profile, represents the most important piece of data. In this way, essential dimensioning data, such as peak load, mean load and load distribution and fluctuation can be gained.

Electrical power P is measured in Watts [W] and for purely resistive load it is given by:

$$P = V \cdot I \quad (2.2)$$

Metering and logging the electrical power directly is feasible with power meters. When measuring the electrical power of consumers with constant voltage power grids as voltage source, measuring current and multiplying with the constant voltage is also imaginable. In this way, for example 24-hour load profiles can be gained through simply logging the current for the equivalent period. Appendix H shows a load profile of an electrical geyser for kitchen sinks derived by simply multiplying the current graph with the constant grid voltage value of 230 V in Germany. Grid voltage, measured in Munich, Germany for 24 hours and presented in Appendix F can be considered sufficiently stable to assume a constant voltage of 230 V with negligible inaccuracies for a wide range of practically oriented use cases.

In countries with less reliable grids, as it is the case in Nepal as mentioned before, often grid voltage is less constant, resulting in non-negligible fluctuations (see Appendix F). This calls also for the grid voltage to be logged, when metering the current for calculating load profiles.

2.3 Previous Research

In this section, a brief overview of previous related research is provided. Furthermore, the present study's position and its potential among the previous research is outlined.

Literature is available about general energy use patterns with statistics also for remote areas, with most of it being reports by Nepali governmental organisations (CBS 2011). However, detailed and valid electricity demand data, such as load profiles based on measurements, is non-existent, neither for remote areas of Nepal, nor for remote areas of other developing countries. In the review paper by Mandelli et al. (2016) on off-grid energy systems in developing countries for rural electrification no indications on available measured load profiles can be found. Even in Nepal's national research on energy demand of remote areas, no actual measurements of electricity demand and consumption have been performed yet. Studies about "Household Energy Use in Nepal" (Dahal und Kunwar 2009), (Bhochhibhoya 2012) only gained electricity demand data through questionnaires, observations and reading main boxes. In these studies, load profiles are just estimated based on test subjects' reports.

For Germany, representative standard load profiles are available, allowing simplified power consumption predictions for different kinds of consumers (Schwab 2015). However,

as mentioned above, no measured or standardised load profiles are available for remote areas of developing countries at this stage. Today's dimensioning process of off-grid energy systems for remote regions is based on load profiles generated with simulation and modelling methods without validation.

One way of generating and adapting load profiles for certain use cases is by using the Monte Carlo Simulation Method. See Nahrstedt (2015) for details about this method. Thereby, application tailored load profiles can be generated, premised on particular consumption patterns. One of the most important advantages is to adapt load profiles to changing circumstances. Load profile changes due to additional devices, or seasonal consumption fluctuations can be addressed more easily by flexibly adapting the input data of load Monte Carlo Simulations. In this way, sufficiently load profiles for a whole year can be generated with only a tiny fraction of the resources needed as if repeatedly measured for a long period. Furthermore, simulations allow the setup of scenarios by modifying the input parameters. However, without validation by objective electrical measurements afield, this data set is nothing more than a simulation based on subjective reports about the user's own pattern. Therefore, validation is needed, to check, if the simulation based load profiles match with reality and, if not, to adapt and complement them with measurement data. As measurements afield are a highly time consuming procedure and they only represent a pattern snapshot if not repeated, simulations are an irreplaceable element in the design process. In conclusion, simulation and measurement-based data should be regarded as complementary. Through validation with measurement data, simulations are an optimised and even more powerful tool for designing off-grid energy systems.

For designing off-grid hydroelectric power plants such as the ones in Manang Valley, the AEPC simply provides a certain amount of power per household. This amount increased from initial 100 W to currently 125 W. At this stage, an upgrade to 200 W for future plants is under consideration. Anyway, even with only 200 W of power provided per household, no heat generating devices can be powered. Therefore, the problematically high fuel-wood consumption cannot be reduced as only low-power appliances, such as lighting, entertainment and communication can be run. Thus, Prof. Dr.-Ing. Ramesh Kumar Maskey of Kathmandu University, one of the nation's most important hydropower researchers, suggests supplying each household with at least 700 W to be able to run devices such as rice cookers, and low-power water boiling jugs. (Maskey 2016)

To sum up, today's available literature is lacking of detailed data about electricity demand in developing countries' remote areas based on actual electrical measurements. By collecting these data, the present study marks an important step towards a more consumer oriented and valid way of dimensioning off-grid energy systems. In addition, the designing approaches of the AEPC and Prof. Dr. Maskey's upgrade suggestion can be assessed with the present study's results.

3 Methodology

The main task of this study is to collect objective data regarding electricity demand in remote areas of Nepal. For this, load profiles of different consumers like households, commercial buildings such as hotels and public buildings such as schools were gained. Data acquisition was based on electrical measurements of electricity consumption, due to a lack of such data in the literature. Measurements were conducted afield in Manang District, a remote area in the Himalayan mountains of Nepal.

A secondary aim was to assess whether it is possible to satisfactorily perform load measurements with the rather basic and cost-efficient method, presented in this chapter.

In addition, survey and observation of test subjects was performed to triangulate the gained results with load measurement data and to gain a better understanding of the test subjects' electricity and energy use in general. Furthermore, several semi-structured and unstructured expert interviews were conducted the days before, during and after fieldwork. This was done to collect complementary and basic information about the energy situation in Nepal.

In this section, performed methods, namely load measurements, structured surveys and observations of test subjects, and unstructured expert interviews are described in detail.

3.1 Performance of the Study

Study Area

Fieldwork was conducted in Manang Valley, located in Manang District (see figure 2-10) from 14/10/2016 to 26/10/2016. Due to the Annapurna Circuit trekking route crossing the region, Manang District is rather wealthy compared to other remote areas in Nepal (see Appendix G for a Map of the Human Poverty Index of Nepal's 75 districts). Thus, touristic influence resulting in comparably high living standards cannot be neglected. Therefore, results may not be transferable to other, poorer regions of Nepal. On the other hand, the touristic infrastructure can be helpful when conducting such a study. Better transportation and improved knowledge of basic English among the local population result in better practicability. Moreover, when designing an energy system, possible future demand growth should be considered. By analysing the consumption pattern of a rather high standard remote region, future developments for low standard areas may be derivable. While designing the study, different regions were considered as test areas. Due to the above-mentioned advantages, namely transportation infrastructure and communication, Manang Valley was selected as study area.

3.1.1 Load Measurements

In this section, the test design of the method load measurements will be presented according to the chronological order of its development.

General Test Design

The time available to perform the electrical measurements afield was limited to 14 to 21 days. This limitation was taken into consideration when choosing an applicable test design. To achieve a balanced compromise between data quality and quantity, it was decided that a 24-hour period per measurement and test subject may be appropriate. In this way, the number of test subjects would not get too low. At the same time data for a reasonable period of time per test subject could be collected. Conducting 72-hour or repeated measurements would have been more attractive, but were not feasible due to time constraints. In order to get a total overview of an individual's consumption pattern, it would be necessary to measure the electricity consumption on weekdays and weekends as well as in every season of the year. Like this, both the weekly and seasonal demand fluctuations can be met. This was not possible either due to time constraints. However, with 24-hour measurements it must be considered that the data just represents a snapshot of the consumers' pattern, underlying a certain principle of chance. 24-hour measurements, therefore, can be named a relatively "quick and dirty" method. Nevertheless, it is expected that valuable conclusions can be drawn from the present study's results.

The measurements were conducted from midnight to midnight to gain data of one entire day. Data was logged every 60 seconds, as this was assumed appropriate for the study's use case.

Test Subjects

As the study was conducted in Manang Valley, all participants were Manangi residents. Test subjects were chosen in accordance with the aim of the study, i.e. assessing the electricity and energy demand of remote areas in Nepal. As in Nepal, and especially in remote areas of Nepal, energy consumption is predominantly domestic, giving priority to households seems plausible. Besides domestic households, also small commercial consumers, such as small hotels (so-called lodges), were selected as test subjects. It can be assumed that lodges tend to use more electric devices than households and may have a more modern stock of appliances in general. Therefore, they may be suitable to make predictions where energy consumption of households might lead to. Also, small businesses might have enough money to invest in off-grid solutions and are, thus, relevant to collecting consumption data. Furthermore, schools and healthcare stations were examined, as they may function as a centre of an energy supply system where for example households can be connected to.

Test subjects for load measurements were two households (H1 & H2; both in Braga), three lodges (L1, L2 & L3, all in Chame) and two schools (S1 in Braga, S2 between Braga and Humde). See figure 2-10 for a map of Manang District showing the exact locations of the test subjects.

Main Hardware

As the measurements were conducted in a developing country's remote area with bad transportation, the equipment had to be selected carefully in advance. Once afield, getting

access to additional equipment often was often impossible. During the method and equipment selection procedure, several criteria for the measurement system were phrased. They are listed below in no particular order:

Expediency: The equipment must serve the purpose, namely measuring the load of a consumer.

Data quality: To gain sufficiently valid and reliable data, the equipment must meet some certain minimum standard of measurement quality.

Digitality / possibility of data logging: It is paramount, to digitally record and process the data. Logging the value once every minute must be possible.

Suitability for long-term measurements: As the measurements will take a minimum of 24 hours each, the equipment must be suitable to perform such long-term measurements in a steady quality.

Energy autarky: Measurements must proceed during possible power outages. Therefore, the equipment must have its own power supply through batteries. Additionally, battery life should be as long as possible.

Weight: As the equipment is used in a remote area with limited possibilities of transportation, the equipment should be as light as possible. Thus, it can be carried in one backpack by foot.

Robustness: Transportation to Manang District is only possible by off-road vehicle on bumpy roads. Equipment, carried in a backpack, therefore must be robust to a certain extent.

Flexibility: Because of weight constraints when going on foot, more flexible and multifunctional equipment should be chosen in order to reduce the number of devices. Furthermore, in remote areas, flexible and multifunctional devices may be useful, when having to cope with unexpected events and no access to other equipment.

Safety: While handling electricity, work safety is mandatory. Therefore, the measurement method should be as safe as possible.

Financial expenditure and simplicity: Due to budget constraints, the equipment should be relatively low-cost and cost-efficient.

In addition, a secondary aim of the present study was to assess whether in-field load measurements could be performed with rather basic and low-cost equipment in a satisfactory manner in terms of feasibility and measurement data quality. Therefore, the above listed criterion of financial expenditure and simplicity was slightly privileged.

After evaluating the possible ways of performing load measurements presented in section 2.2, the final method and equipment was selected in accordance to the above listed criteria. In general, the method of choice was measuring and logging voltage and current values separately once per minute for a period of 24 hours. Afterwards, load profiles can be calculated using the measured voltage and current. In this way, very basic equipment could be used.

For metering the voltage, a basic digital hand-held consumer multimeter, namely Voltcraft VC820-1 (see figure 2-16), was used. In figure 2-19a the final setup of the voltage measurements conducted in the present study is shown. For logging, a USB cable was

connected to a laptop using the infrared interface of the multimeter. In total two multimeters, two USB/infrared cables and two laptops, a MacBook Pro early 2015 and a Lenovo ThinkPad X220, were used. Voltage was measured at a randomly chosen power socket in test subjects' buildings.

Current measurements were performed at the test subjects' commonly single phased main boxes using a current clamp. The main line was simply introduced into the toroidal core by enclosing it with the current clamp adapter. In this way, the current could be metered easily and safely without interrupting the individuals' power supply by opening the electrical circuit. This so to speak contactless method is highly convenient both, for the investigator and for the test subject. Thus, it may increase the chances of convincing a possible test subject to participate in the study. AC only current clamp adapters, namely Voltcraft VC-510 (see figure 2-18a) were used due to lower power consumption compared to combined AC/DC current clamps, whose battery life often is less than 24 hours. Therefore, the criteria of energy autarky would not be met in a satisfactory manner. For logging the current, the current/voltage converting current clamp adapter was connected to the voltage inputs of the multimeter. Multimeters were connected to the laptops in the same way as when measuring voltage (see figure 3-1b). With this simple method, only resistive currents but no reactive currents, such as refrigerators or blenders, can be measured. However, as the clear majority of the consumers' load was resistive, this simplification can be estimated as acceptable. For correctly measuring reactive currents, a more elaborate and cost-intensive equipment would be necessary.

For choosing the right wire going out of the main box, an additional current clamp with a digital display, namely Voltcraft VC-531 (see figure 2-18b) was used. For validation, main box meter readings were compared to the measured data. In total, two AC-only current clamp adapters and one digital display current clamp were used. In Appendix I a full list of main equipment with the corresponding costs can be found. One measurement setup, excluding the laptop, consisting of the digital hand-held multimeter with the infrared/USB cable and the AC current clamp adapter sums up to a retail price of around 130 USD (Conrad 2017).



Figure 3-1: a: Main box with current clamp adapter enclosing the main wire of the single phased main box. b: Complete current measurement setup. [Own Illustration]

Auxiliary Hardware

In addition to the main hardware, auxiliary hardware was used. It consisted of equipment like extension cords, plugs, adaptors and a soldering iron to be able to flexibly adapt the equipment's wiring to the individual circumstances in the field. A full list of the auxiliary equipment can be found in Appendix I.

All the main hardware was estimated to be robust enough to withstand the physical stress, when carried in a backpack or when riding an off-road vehicle on bumpy roads, except the laptops. To provide extra transportation safety, a wooden hard case was built for each of the laptops (see figure 3-2).

For extending the laptops' battery life in case of long-time power outages, two power banks with 15 600 mAh of capacity (12 V) each were used.

Though theoretically, plug types C and F, common in Germany and most of Europe, fit into Nepali power sockets (see figure 3-3a), adapters with type D Nepali plugs (see figure 3-3b) are recommended for a more firm and secure fit. For field work, a Nepali type D plug was attached to a German type C/F socket strip, to power the equipment brought from Germany. With this adapter, the most firm and secure fit was achieved.



Figure 3-2: Self-made wooden hard case and inner soft sleeve for protecting the laptops from mechanical stress [Own Illustration]

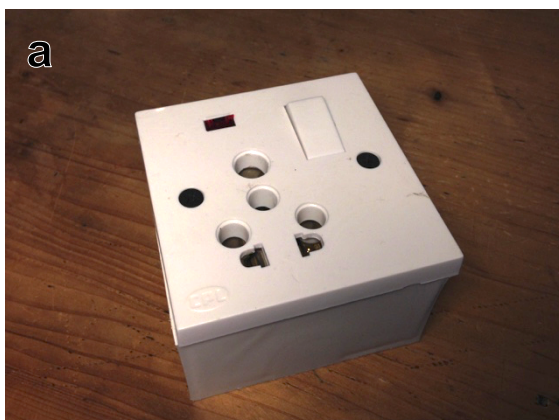


Figure 3-3: Nepali power socket (a) and Nepali type C (left) and type D (right) plugs (b) [Own Illustration]

Software

For logging the data measured by the multimeters, the software VC820 V2.00, coming free of charge with the multimeter, was used. The software allows to choose logging intervals of down to one second and to export the data as an excel sheet. Appendix J depicts the user interface of the software and an excel sheet showing some measured voltage data.

The software is available only for Windows operating systems. For running it on the MacBook, the software Parallels 12 desktop was used.

Summary of the Final Test Design

Voltage was measured using a multimeter, connected to a laptop. Current was measured with an AC voltage/current converting current clamp adapter connected to the voltage input of the multimeter. Voltage and current values were logged once every 60 seconds for a period of 24 hours for each test subject. Logging every minute for a 24-hour period resulted in 1 440 measurement points. With a total of two multimeters available, voltage and current were measured simultaneously with the two multimeters. Afterwards, load profiles were calculated using the measured voltage and current. For validation, the consumption balance calculated from measured data was compared to the meter readings of the main box.

Preliminary Tests

To assess the final procedure of the load measurements method, preliminary tests were performed. Voltage fluctuation was measured to see if a voltage measurement in addition to the current measurement is necessary or if voltage can be assumed constant. Appendix K shows voltage fluctuations of the two power plants supplying the respective test subjects. Due to significant fluctuations, it was decided that an additional measurement of the voltage is essential for data reliability.

Before choosing AC-only current clamps with sufficient battery life, using a modified AC/DC current clamp with an external power supply unit was taken into consideration. The idea was rejected, as AC-only current clamp adapters supplied by ordinary batteries were considered more suitable in terms of energy autarky.

When performing the current measurements at test subjects' main boxes, different wiring lengths of the current clamp and the multimeter were used, ranging from 10 cm (see figure 3-1b) to approximately 10 m (figure 3-1a). In a preliminary test, no significant effect on measured data was found.

As the laptops' battery life was below 24 hours, they needed external power supply. For this, the power connection being measured was used. Laptops were connected permanently to ensure an approximately steady load. In this way, a constant wattage value, determined in a preliminary test, could be subtracted off the measured load to eliminate influences on consumption data by the measuring equipment.

3.1.2 Survey and Observation

Power consumption was objectively assessed through electrical measurements. To determine the consumption of other energy sources and to gain general information about the test subjects' energy demand, a combined survey and observation was conducted. For this, a questionnaire was developed (see Appendix L). It consisted of a demographic, a power demand and a general energy demand section. Observation was done during load measurements, to gain the information necessary for interpreting the calculated load profiles.

Survey and observation was performed with all the load measurements' test subjects and additionally with one household (H3 in Humde) and a healthcare station (HC1 in Manang). Table 3-1 provides an overview of all test subjects where load measurements, survey and observation (M & SO) or only survey and observation (SO) was performed. The main survey results are presented in chapter 4 for each test subject individually. A protocol of the answered questionnaires is given on the data CD (see Appendix T). Observation findings complementing the discussion of results are presented in chapter 4.

Table 3-1: Overview of test subjects and performed methods

#	Test Subject	Location	Methods applied
H1	Family Dorjee	Braga	M & SO
H2	Family Rangold	Braga	M & SO
H3	Family Dolma	Humde	SO
L1	Hotel Shangri-La	Chame	M & SO
L2	Hotel Mona Lisa	Chame	M & SO
L3	Moonlight Guesthouse	Chame	M & SO
S1	Lophelling Boarding School	Braga / Humde	M & SO
S2	Braga Primary School	Braga	M & SO
HC1	Himalayan Healthcare Station	Manang	SO

3.1.3 Expert Interviews

Before, during and after fieldwork from 14/10/2016 to 26/10/2016 in Manang District, several unstructured expert interviews were performed. Table 3-2 provides an overview of the experts interviewed and the main topic of the interview. The results of the expert interviews are shown, where appropriate, in the present study. Full protocols are provided in Appendix M.

Table 3-2: Overview of expert interviews

#	Expert	Main Topic
E1	Prof. Dr.-Ing. Ramesh Kumar Maskey	General Energy Situation of Nepal
E2	Dhama Raj Maharjan	Chame Hydro and Efficient Devices
E3	Chirring Lopsang Gurrang	Manang and Sabje Hydro
E4	Bir Bahadur Gale	Manang, Sabje and Chame Hydro
E5	Chatur Gurung	Sabje Hydro

3.2 Statistical Data Evaluation and Processing

Load measurement data is processed and presented descriptively in chapter 4. Load profiles, load duration curves and simple indicators, such as mean load, are calculated from measured voltage and current. A selection of the most relevant data gained through the questionnaire-based survey is presented in section 4, whereas the full records are given on the data CD (see Appendix T). The results of the expert interviews are, implemented where reasonable, from section 2 to section 5.

4 Results and Discussion

In order to assess the electricity demand of people living in remote areas in Nepal, several methods explained in chapter 3 were performed. These included electrical load measurements of the 24-hour electricity demand, surveys, observations and expert interviews. Two domestic households, three lodges, two schools and one healthcare station served as test subjects. The results of the study conducted in Manang District are presented for each test subject individually. As main results the measured load profiles with a time resolution of 1 minute are given. Load distribution is an important factor when designing off-grid energy systems, especially for constant output power systems, such as a hydroelectric plant. Therefore, load duration graphs were calculated by sorting the 1 440 measurement points according to their value. The tables given below the load profiles and load duration curves show the most important measurement data, as well as a comparison of the total measured consumption and the main box meter readings. On the subsequent page, the main results of the questionnaire-based interviews are presented. Following, the results of the load measurements, surveys and observations are interpreted combinedly. This sequence is repeated for each test subject individually. After presenting the results and discussion for all test subjects of one type (such as *household* or *lodge*), a combined discussion of the total energy demand, the heat and cooling demand and general conclusions for each type of test subject are given. In this way, emphasizing the study's features and maximum transparency of the results and conclusions could be achieved.

In chapter 5, conclusions for practice, derived from results and discussion are drawn. The desired electric and heating / cooling devices are listed according to the test subjects' preferences. The input power of the electric devices was read off their labels or measured, if no labels could be found (indicated with [measured]). Appendix N shows pictures of a selection of devices mentioned in this section, such as an improved cooking stove and a smokeless metal stove.

4.1 Households

During voltage measurements in household 1 (H1), one of the two multimeters showed evidence of faultiness (see Appendix O). As it was not possible to log voltage and current simultaneously with solely one working multimeter left, only current was measured for household and school test subjects. The test subjects were all supplied by Sabje Hydro-power Station. Therefore, voltage was recorded only once on 20/10/2016. With this voltage data, the load profiles of all household and school test subjects were calculated.

The income of the families is given in Nepali Rupees (NPR). The exchange rates on 13/01/2017 were 107.146 NPR/USD and 113.824 NPR/€ (oanda 2017).

4.1.1 Household 1: Family Dorjee

4.1.1.1 Results

Measurements at family Dorjee's were performed on the 21/10/2016. The family consists of the two parents and their adult son residing in a traditional house in Braga at an altitude of 3 470 m (see figure 4-1 and 4-2). In total, they have five types of electrical devices: A rice cooker, a television with satellite receiver, mobile phones and light bulbs. Load profile is shown in figure 4-3, load duration curve in figure 4-4. See section *Survey* for detailed information about the household's characteristics gained through the questionnaire.

The mean load during measurements was 26.4 W, resulting in a total power consumption of 633.5 Wh/d. When compared to the main box meter readings of 0.63 kWh/d, an accordance of 99% was calculated. Peak load was 65.8 W.



Figure 4-1: Household 1 – living room [Own Illustration]



Figure 4-2: Household 1 – patio [Own Illustration]

Load Measurements

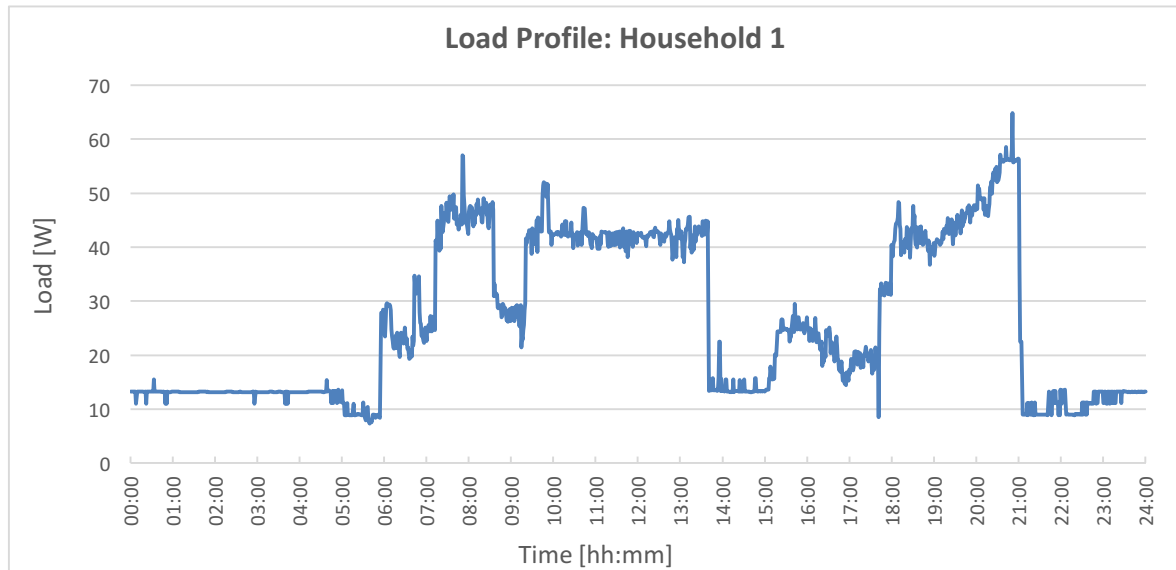


Figure 4-3: Household 1 – load profile [Own Illustration]

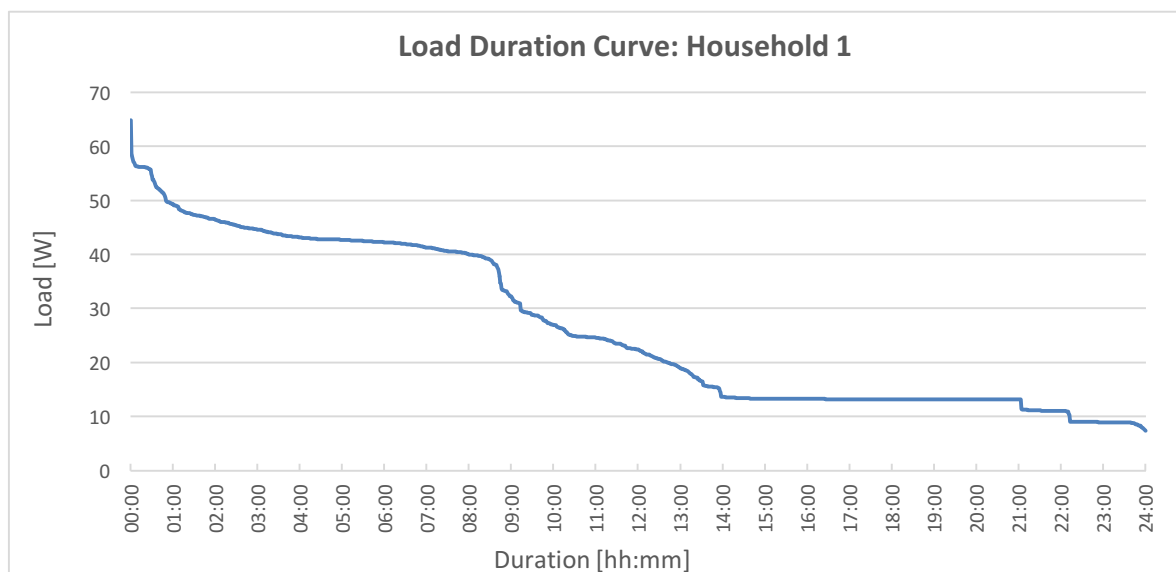


Figure 4-4: Household 1 – load duration curve [Own Illustration]

Table 4-1: Household 1 –primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	634 Wh/d	Energy consumed (MB)	0.63 kWh/d
Mean load	26.4 W	Accordance	99%
Peak load	65.8 W		

Survey

<i>Family members:</i>	3 adults (father, mother & son)
<i>Income of the family:</i>	28 000 NPR / month on average
<i>Electric devices:</i>	- rice cooker (500 W); once a week - television (50 W) with receiver (10 W); daily for 3 – 6 hours - 2 mobile phones; charged daily - 3 light bulbs (6 – 22 W); daily in the evening and morning
<i>Desired electric devices:</i>	1. Electric heater 2. Small fridge
<i>Space heating:</i>	improved cooking stove (combined cooking and heating) 30 / 30 m ² living space is heated
<i>Cooking:</i>	- improved cooking stove; mainly - 2-burner LPG stove; when no heat needed - rice cooker
<i>Energy consumption:</i>	firewood: ~ 4 285 kg / year LPG: ~ 15 kg / year electricity: ~ 20 kWh / month (~ 0.67 kWh/d)
<i>Desired heating / cooling devices:</i>	1. Electric heater 2. Small fridge

4.1.1.2 Discussion

In general, H1's power consumption pattern can be estimated as rather low leveled. Peak load (65.8 W) as well as consumed electrical energy (634 Wh/d) were considerably low. Only the television (low-power LED computer screen) with its receiver, compact fluorescent light (CFL) bulbs, and mobile phones were in use. No highly consumptive heat generating appliances like heating or cooking devices were run. This is the reason why the peak remained below 100 W.

The load profile's three major peaks (7:15 – 8:30, 9:15 – 13:45 & 17:45 – 21:00) resulted from television use (see figure 4-3). Patio night lighting yielded in a continuous load of around 13 W during night times.

The load value distribution can be classified considerably balanced, when analysing the load duration curve (see figure 4-4).

Measured electrical energy consumption is 634 Wh/d while the reported average consumption accounts for 0.67 kWh/d. Furthermore, the measured electric device use corresponds to the pattern reported during the survey (see section 4.1.1.1.2). Thus, it can be assumed that the measured load profile matches the average consumption pattern of the test subject quite well.

When considering the desired electric devices, the consumption may rise in future. H1 reported that a few years back, they did not have a television due to cultural reasons. However now, as using a television has become quite common, they recently purchased one. In a few years, it might be the same case with devices like a small fridge or electric heaters, H1 said.

4.1.2 Household 2: Family Rangold

4.1.2.1 Results

The measurements at Family Rangold's household were conducted on 22/10/2016. Family members included the two parents and their adult son, living in a traditional house in Braga (altitude: 3 470 m) comparable to H1 (see figure 4-5 and 4-6). In total, they owned five different types of electric devices: A rice cooker, a blender, a water boiling jug, a radio, light bulbs and mobile phones. Load profile of H2 is given in figure 4-7, load duration curve in figure 4-8. See section *Survey* for detailed information about the household's characteristics evaluated through the questionnaire-based survey.

Mean load during measurements was 42.0 W, resulting in a total power consumption of 1 010 Wh/d. When compared to the main box meter readings of 1.13 kWh/d, an accordance of 89% was calculated. Peak load was 1 740 W. In order to highlight the pattern in the range of lower load values, the scale in figures 4-7 and 4-8 was adjusted, resulting in three peaks being cut off. Their values are 372 W, 1 694 W and 1 165 W. The load profile and load duration curve of H2 in full scale can be found in Appendix P.



Figure 4-5: Household 2 – patio with mother and son [Own Illustration]



Figure 4-6: Traditional houses in the neighborhood of H1 and H2 in Braga [Own Illustration]

Load Measurements

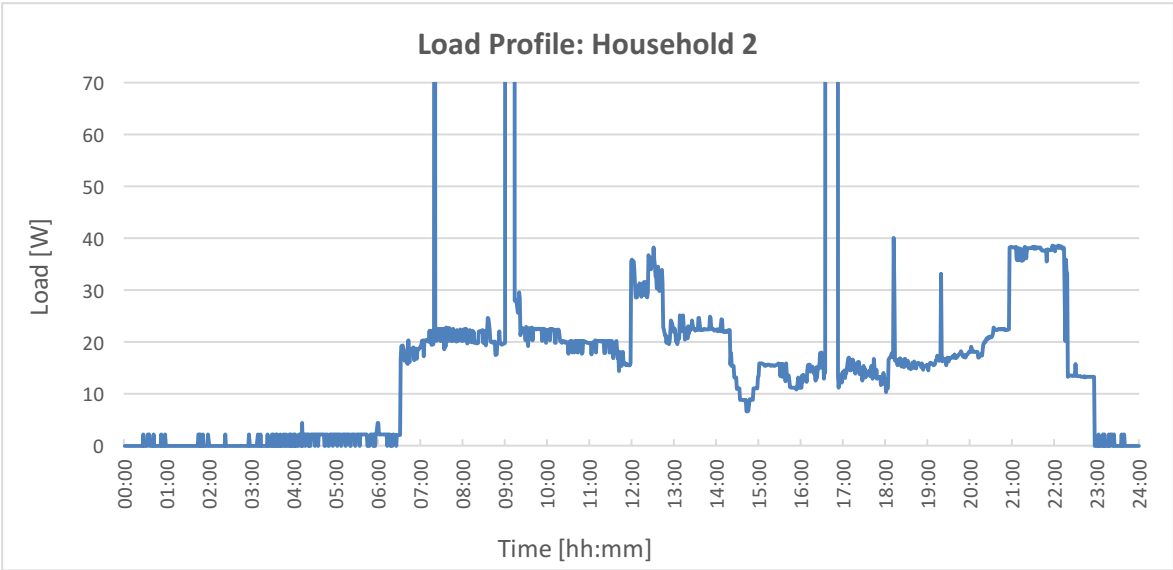


Figure 4-7: Household 2 – load profile. Values of the three cut-off peaks are 372 W, 1 694 W and 1 165 W. For a full-scale load profile of H2, see Appendix P. [Own Illustration]

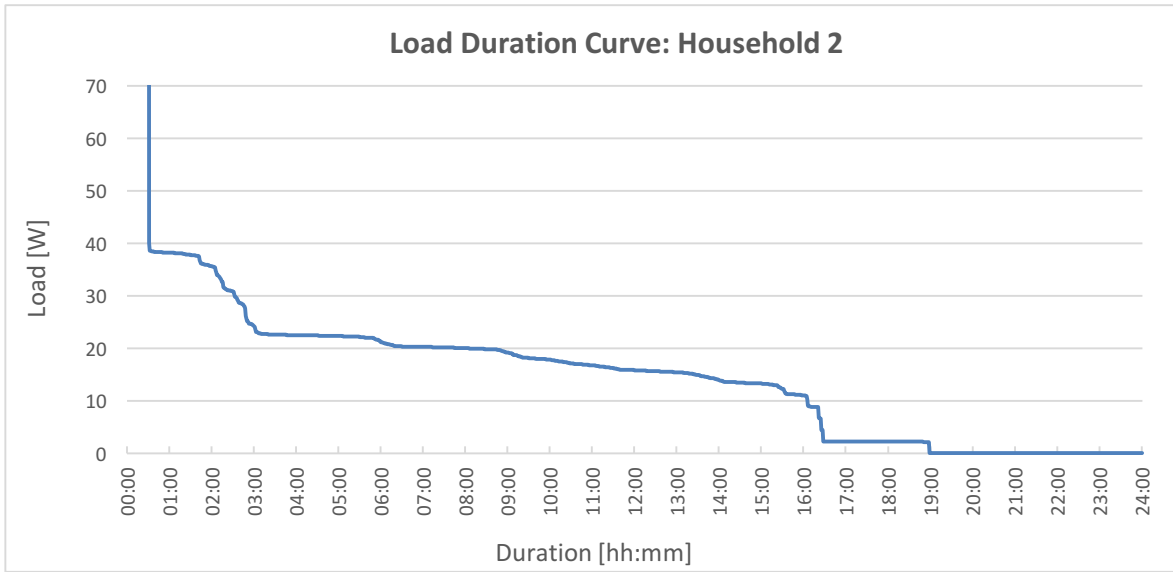


Figure 4-8: Household 2 – load duration curve. For a full-scale load profile of H2, see Appendix P. [Own Illustration]

Table 4-2: Household 2 – primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	1 010 Wh/d	Energy consumed (MB)	1.13 kWh/d
Mean load	42.0 W	Accordance	89%
Peak load	1 740 W		

Survey

<i>Family members:</i>	3 adults (father, mother & son)
<i>Income of the family:</i>	10 000 NPR / month on average
<i>Electric devices:</i>	- rice cooker (550 W); several times per week - water boiling jug (1.65 kW [measured]); twice per day - blender (350 W); once per day in the morning - radio (6 W); daily for 3-6 hours during evening times - 6 light bulbs (6 – 22 W); daily in the evening and morning - 3 mobile phones; charged daily
<i>Desired electric devices:</i>	1. Solar Photovoltaic Light
<i>Space heating:</i>	improved cooking stove (combined cooking and heating) 30 / 30 m ² living space is heated
<i>Cooking:</i>	- improved cooking stove; mainly - 2-burner LPG stove; when no heat needed - rice cooker - water boiling jug
<i>Energy consumption:</i>	firewood: ~ 4 285 kg / year LPG: ~ 15 kg / year electricity: 20 – 25 kWh / month (0.67 – 0.83 kWh/d)
<i>Desired heating / cooling devices:</i>	none

4.1.2.2 Discussion

Similar to H1, the electricity consumption of H2 can be classified as rather low, with a consumed electrical energy of 1 010 Wh/d. However, in contrast to H1 the peak load was comparatively high (1 740 W) due to the use of a water boiling jug. Apart from the water boiling jug and the medium-power blender (350 W), only low-power devices were in use, when measured.

In figure 4-7 three peaks exceed the ordinate axis (for a full-scale load profile of H2, see Appendix P). The first one (371 W) in the morning (7:20) represents the utilisation of the blender for preparing the traditional morning butter tea. During the early hours of the day, the improved cooking stove was used for both, heating up the living space and cooking, so no water boiling jug was needed in this case (same for late hours). The second (1 694 W; 9:00) and third peak (1 165 W; 16:45) mainly resulted from utilising the water boiling jug for preparing black tea, wherefore no blender was needed. During the day, space heating was not necessary, so tea water was boiled by using the water boiling jug. Apart from the above mentioned three slender peaks, power consumption did not exceed a level of 40 W. This is the reason for comparable power consumptions in H1 and H2, though the peak values differ a lot.

The distribution of load values varied strongly due to the big gap of short-term high-power level and residual low load level (see figure 4-8 and Appendix P).

A comparison of the measured power consumption (1 010 Wh/d) and the reported average electricity consumption (0.67 – 0.83 kWh/d) shows that, when measured, electricity demand was slightly higher than on an average day.

As H2 does not wish any additional electrical devices other than a small photovoltaic emergency light, there are no indicators of a rising electricity demand in future.

4.1.3 Household 3: Family Dolma

Due to the faultiness of one multimeter, no load measurements could be performed at H3. Nevertheless, survey and observation were conducted.

Results

In Family Dolma's household in Humde (altitude: 3 390 m; see figure 4-9), a large variety of electronic devices is used. With 80 m² their living space is also rather large. In comparison to the rather traditional ways of life of H1 and H2, the living standards of H3 can be classified as upscale.



Figure 4-9: Household 3 [Own Illustration]

Survey

<i>Family members:</i>	3 adults (grandmother, mother & daughter) 2 children
<i>Income of the family:</i>	28 000 NPR / month on average
<i>Electric devices:</i>	- refrigerator with freezer compartment (90 W); only during summer - rice cooker (400 – 700 W); daily in use - television (~ 65 W output); daily more than 6 hours - receiver (30 W); daily for 3 – 6 hours - DVD-player (20 W); daily for 1 – 3 hours - blender (280 W); once per day in the morning - water boiling jug (1.2 – 1.8 kW); daily 4-5 times - stereo setup (25 W); daily for 1-3 hours - 6 light bulbs (6 – 22 W); daily in the evening and morning - 3 mobile phones; charged daily
<i>Desired electric devices:</i>	1. Washing machine
<i>Space heating:</i>	improved cooking stove (combined cooking and heating) 28 / 80 m ² living space is heated
<i>Cooking:</i>	- improved cooking stove; mainly - 2-burner LPG stove; when no heat needed - rice cooker - water boiling jug - blender
<i>Energy consumption:</i>	firewood: ~ 24 000 kg / year LPG: ~ 15 kg / year electricity: ~ 70 kWh / month (~ 2.33 kWh/d)
<i>Desired heating / cooling: devices:</i>	1. Solar heater 2. Electric heater

4.1.4 General Conclusions for All Household Test Subjects

Total Energy Consumption

Being common in Nepal, the energy consumption of all household test subjects is dominated by fuelwood, while demand for LPG and electricity is relatively low (see figure 4-10). This derives from the fact that all three household test subjects use the same fuelwood driven device (improved cooking stove) for both, heating and cooking. Low LPG usage relates to cooking with LPG stoves only when no heat is needed for space heating and the improved cooking stove is not already in use. Due to using electricity mostly just for lighting and low-power entertainment devices, power consumption is rather low. However, H3 reported on an electricity demand of three times more than H1 or H2. This results from more devices in use and a higher number of family members.

Patterns of test subjects H1 and H2 are almost the same, possibly due to comparable living standards and ways of life. H3 shows extremely high fuelwood consumption, as H3's household head often prepares meals for the neighbouring police station.

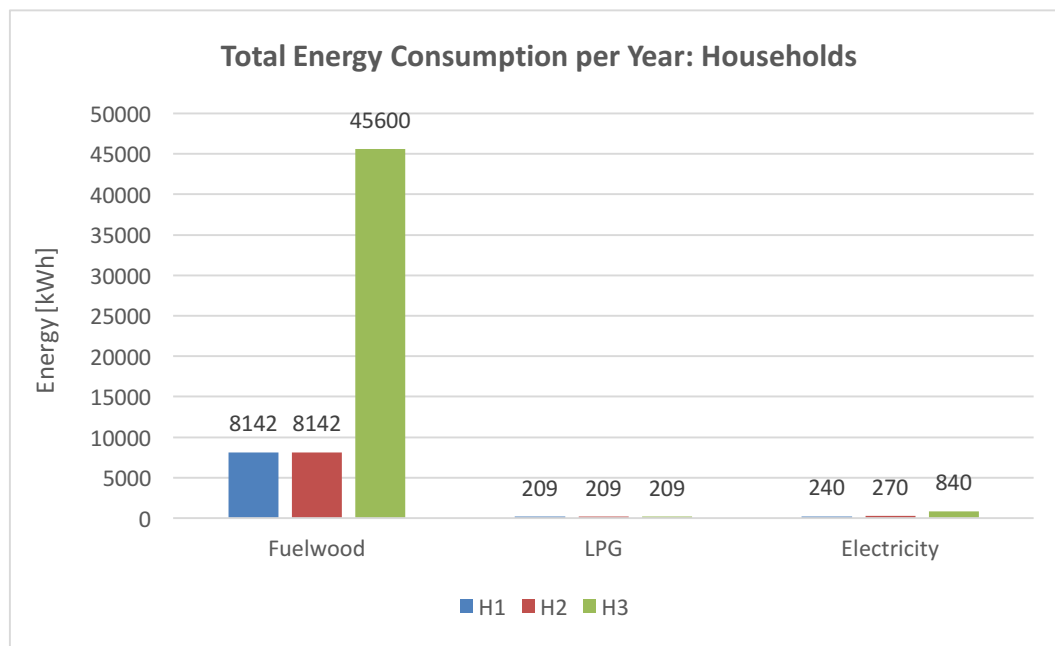


Figure 4-10: Households – total energy consumption per year. Data is based on questionnaire results. [Own Illustration]

When considering the energy prices in Manang Valley (see table 2-2), H1's annual expenses on fuelwood sum up to 277 USD (H3: 1551 USD), more than one third of the national average annual salary of 730 USD (World Bank 2015).

The electricity demand of test subjects H1 and H3 may rise, as they reported that they wish to use more electric devices in future. This matches with the ongoing growth of electricity consumption per capita (see figure 2-8). In general, household test subjects seem to be open to use more electricity driven devices in future times. However, they reported that completely switching from fuelwood to electricity to generate heat for cooking and space heating was currently not imaginable due to their habit of using wood.

Heat and Cooling Demand

In general, most of the energy at household test subjects is consumed for generating heat. Thereby, heat is needed for cooking and space heating. For space heating, all household test subjects use an improved cooking stove fueled by firewood (see Appendix N for a picture). Heat for cooking is mainly generated by combusting fuelwood in the improved cooking stove as well. Only a small proportion of the cooking heat is generated by LPG stoves (H1 – H3), rice cookers (H1 – H3) and water boiling jugs (H2 & H3). As the fuelwood driven stove is used for cooking only when it is already run for generating heat (H1 & H2), it can be stated that at H1 and H2 all the fuelwood consumption contributes to space heating. At H3 the stove is often fired just for cooking. To put the heat demand and the fuelwood consumption of the household test subjects into perspective, a comparison of the reported fuelwood consumption and the theoretical heating demand calculated according to DIN V 4108-6 is provided in figure 4-11. Scenario A refers to a set point indoor temperature of 20° C for the whole year, whereas scenario B refers to heating only during the three first and last months of the year and a set point indoor temperature of 18° C. However, it is important to point out that the calculated heating demand should be considered to be rather qualitatively than quantitatively relevant as a wide range of assumptions and simplifications were made. See Appendix Q for further details about the calculation.

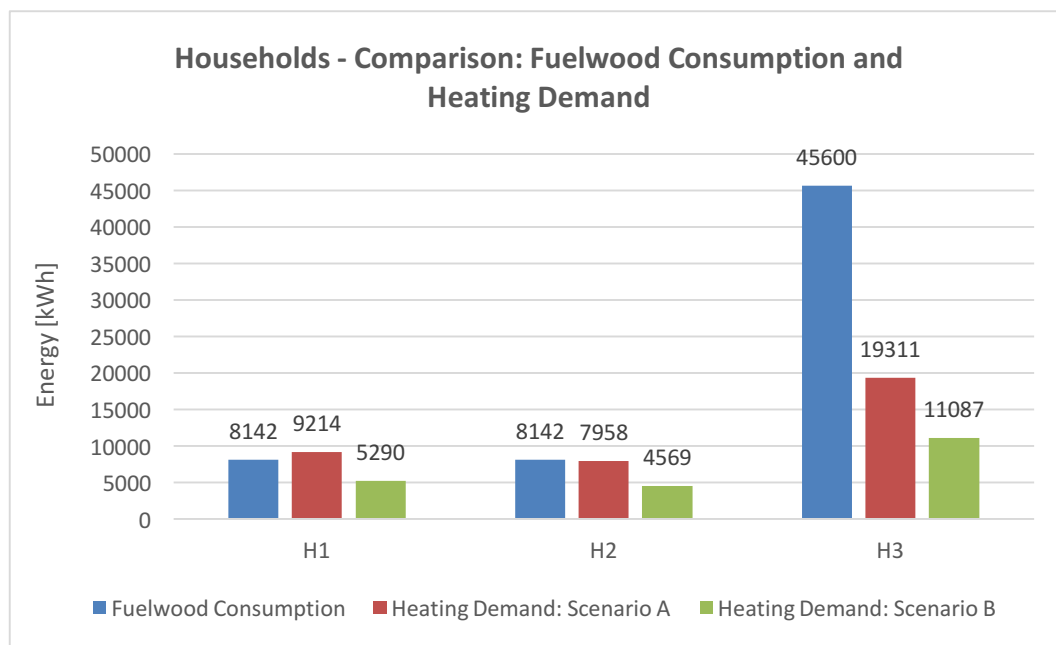


Figure 4-11: Comparison of the calculated heating demand of all household test subjects and their fuelwood consumption [Own Illustration]

For H1 and H2, the heating demand in either of the two scenarios ranks among a similar magnitude as their respective fuelwood consumption. At H3, fuelwood consumption exceeds the calculated heating demand distinctly, as H3 often prepares meals for the nearby police station. Thus, H3 uses wood not only mostly for heating but also for cooking when actually no heat for space heating is needed at the respective moment. The calculated heating demand of H3 is significantly higher than H1's and H2's due to the following reasons: H1 and H2 have thicker walls and they do not have windows in their heated room.

H1 and H2 show no cooling demand at all, while at H3 a refrigerator for chilling beverages is run during summer time. Therefore, the general cooling demand at household test subjects can be estimated as relatively low. However, as H1 would like to have a small fridge, it might rise slightly in future.

4.2 Lodges

During the load measurement at lodges L1 – L3 in Chame, voltage and current were measured simultaneously. All lodges were supplied by Chame's very own hydropower plant. For the voltage curves used for calculating the load profiles of L1 – L3, see Appendix R. Chame Hydropower Station is shut down from 09:00 to 11:00 in the morning, to “give the newly acquired generator some rest” (Maharjan 2016).

The energy consumption of lodges is highly dependent on the trekking season (Maharjan 2016). High season lasts for about five months in total during autumn and spring. Measurements were conducted during high season.

4.2.1 Lodge 1: Hotel Shangri-La

4.2.1.1 Results

Measurements at Hotel Shangri-La were performed on 15/10/2016. Family Maharjan, owner and operator of the lodge, consists of the two parents and their adult son and daughter residing in separate private rooms of the property. The little hotel (see figure 4-12) is located in Chame at an altitude of 2 670 m. In total, they only had few electric devices and reported that they wanted to save electricity because of the constant power shortage in Chame. The load profile is shown in figure 4-13, the load duration curve in figure 4-14. See section *Survey* for detailed information about the lodge's characteristics gained by using the questionnaire.

The mean load during measurements was 123.7 W, consequently the total power consumption sums up to 2 970 Wh/d. When compared to the main box meter readings of 2.86 kWh/d, an accordance of 96% results. A peak demand of 424 W was measured.



Figure 4-12: Lodge 1: Hotel Shangri-La in Chame [Own Illustration]

Load Measurements

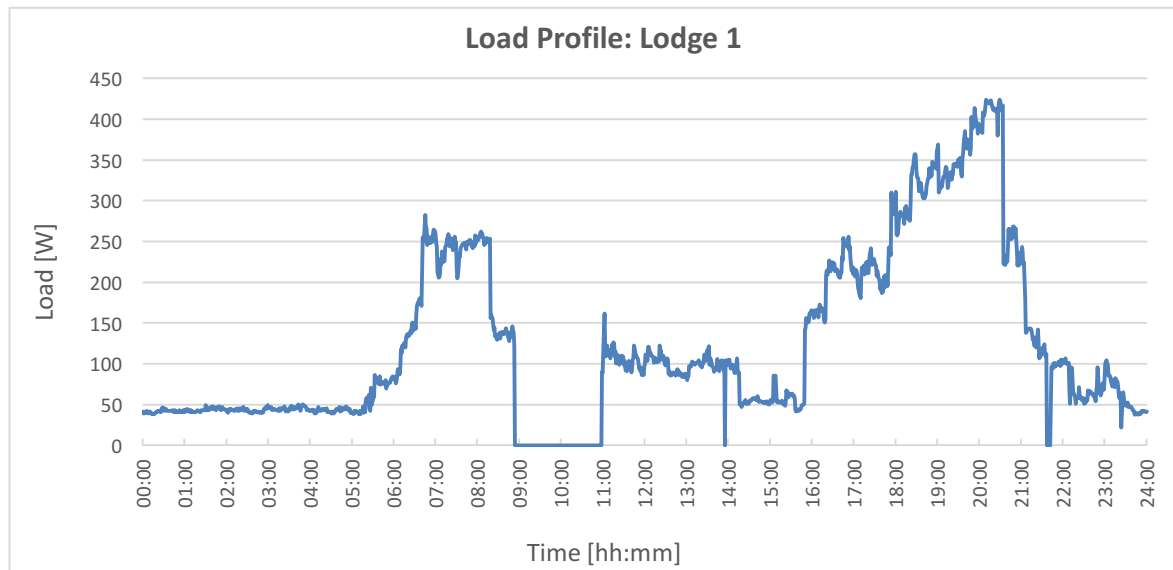


Figure 4-13: Lodge 1 – load profile [Own Illustration]

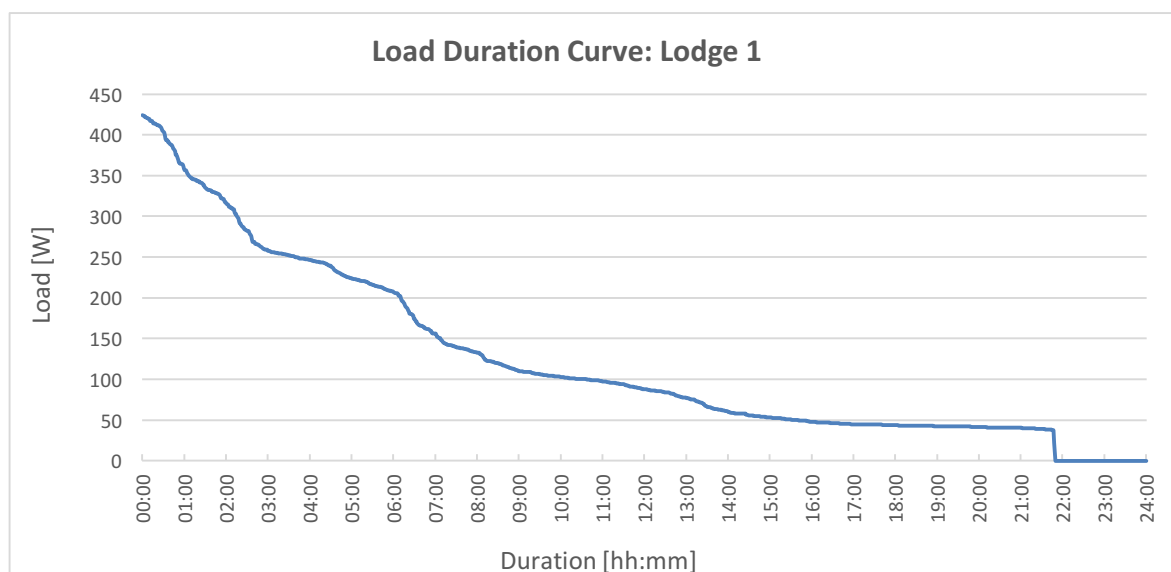


Figure 4-14: Lodge 1 – load duration curve [Own Illustration]

Table 4-3: Lodge 1 – primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	2 970 Wh/d	Energy consumed (MB)	2.86 kWh/d
Mean load	123.7 W	Accordance	96%
Peak load	424 W		

Survey

<i>Staff living at the lodge:</i>	4 adults (father, mother, daughter & son)
<i>Capacity:</i>	22 rooms with 32 beds 5 guests, when measured
<i>Electric devices:</i>	- refrigerator with freezer compartment (90 W); only for 2-3 hours in the afternoon - television (24 W) with receiver (10 W); daily for 0-1 hours- - fixed telephone (5 W); permanently plugged; rarely in use- - Wifi-router (5 W); permanently plugged - > 40 light bulbs (2 – 15 W); mostly during evening and night - 4 mobile phones; charges daily
<i>Desired electric devices:</i>	1. Electric heater 2. Electric air conditioning 3. Electric stove 4. Electric geyser 5. Washing machine
<i>Space heating:</i>	smokeless metal stove 48 m ² dining room is heated
<i>Water heating:</i>	LPG geyser solar thermal system
<i>Cooking:</i>	4-burner LPG stove; mainly improved cooking stove; not in use during summer
<i>Energy consumption:</i>	firewood: ~ 30 t / year LPG: ~ 400 kg / year electricity: ~ 60 kWh / month (~ 2 kWh/d)
<i>Desired heating / cooling devices:</i>	1. Electric heater 2. Electric air conditioning 3. Electric stove 4. Electric geyser

4.2.1.2 Discussion

When compared to test subjects L2 and L3, the electricity consumption of lodge 1 can be estimated as rather low. This applies for both, the peak value (424 W), as well as the mean load (123.7 W). These circumstances can be related to the lodge's small and low-power range of electrical appliances. Dharma Raj Maharjan, head of the lodge and supervisor of Chame Hydropower Station, reported that he was naturally aware of the power shortage. Therefore, he was trying hard to merely use low-power devices, so that there is enough electricity for all the residents of Chame. All the electric devices of L1 were carefully selected by Mr. Maharjan to save as much energy as possible despite the higher purchase prices of efficient appliances. As the refrigerator was only used in the evening in order to provide cooled beverages for trekking tourists, the most consumptive electrical application was lighting. For cooking purposes, heat is mainly generated through LPG stoves. Only very rarely the improved cooking stove is used. Not a single electric device was utilised for cooking and preparing food. The lodge's dining room is heated by using a smokeless metal stove (see Appendix N for pictures).

In general, electricity consumption at L1 was highest when the trekking tourists were present in the morning (06:00 – 09:00) and even more in the evening (16:00 – 21:30) (see figure 4-13). When the lodge's guests arrived after a day of hiking, they also might have charged their mobile devices, as every room was equipped with several power sockets. The base load during night times of around 50 W resulted from exterior lighting and permanently plugged devices, such as the Wifi-router and the fixed telephone.

As no peaks were measured at L1 and only low-power appliances were in use, the load duration curve can be classified reasonably even (see figure 4-14).

When contrasting the measured power consumption of 2.86 kWh/d with the reported average consumption of approximately 2 kWh/d, the demand can be ranked comparably high when measured. This may be due to the selected time for field work, corresponding to the high season in the local touristic sector.

During the questionnaire-based interview, L1 reported that if there was enough installed capacity for Chame, they would use much more electrical devices. L1 would prefer to completely switch to cooking as well as heating with electricity. When considering the lodge's high fuelwood demand, power consumption would rise excessively if they did so. Mr. Maharjan reported that in future, Chame's hydropower plant was likely to be upgraded to around 200 kW (Maharjan 2016). These circumstances clearly demonstrate how electricity demand and energy use patterns are influenced by supply when a certain form of energy, in this case electricity, is scarce.

4.2.2 Lodge 2: Hotel Mona Lisa

4.2.2.1 Results

At Hotel Mona Lisa in Chame (altitude: 2 670 m), load was measured on 16/10/2016. The hotel (see figure 4-15) is run by Laxmi Gurung and her assistant, living with two children at the lodge. In Hotel Mona Lisa there was a wide range of electric devices. However, Mrs. Gurung reported that she could not run some appliances, for example the microwave, because of the ongoing electricity scarcity. Load profile and load duration curve are shown in figure 4-16 and 4-17. In section *Survey*, general information about the lodge gained using the questionnaire can be found.

The mean load was 454.0 W, resulting in a total power consumption of 10 896 Wh/d during the measurement period of 24 hours. When compared to the main box meter readings of 11.98 kWh/d, an accordance of 91% was calculated. A peak load of 1 893 W was measured.



Figure 4-15: Lodge 2: Hotel Mona-Lisa in Chame [Own Illustration]

Load Measurements

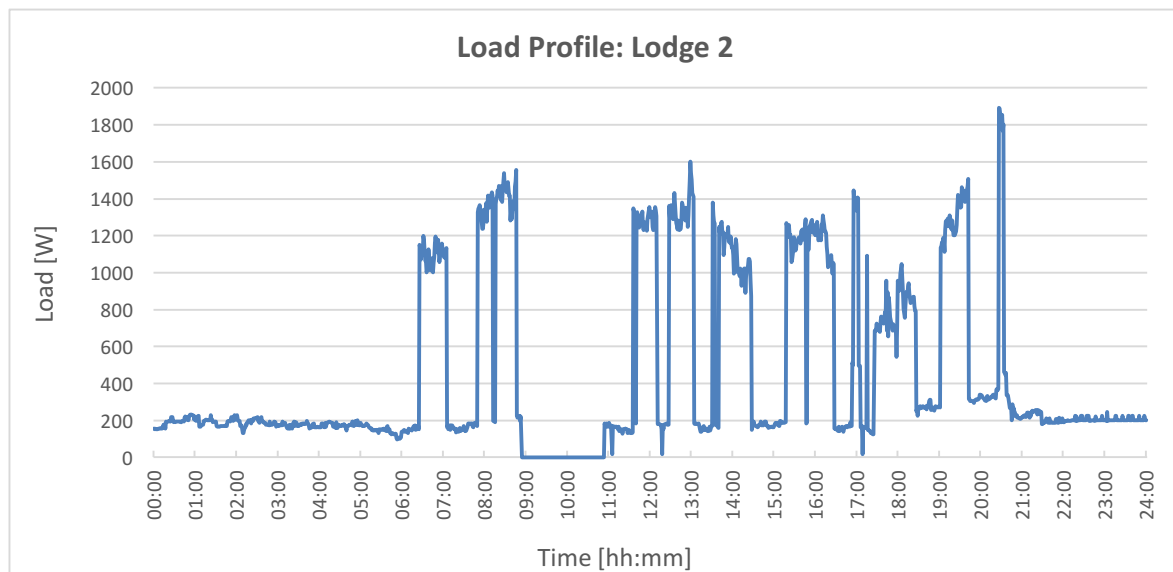


Figure 4-16: Lodge 2 – load profile [Own Illustration]

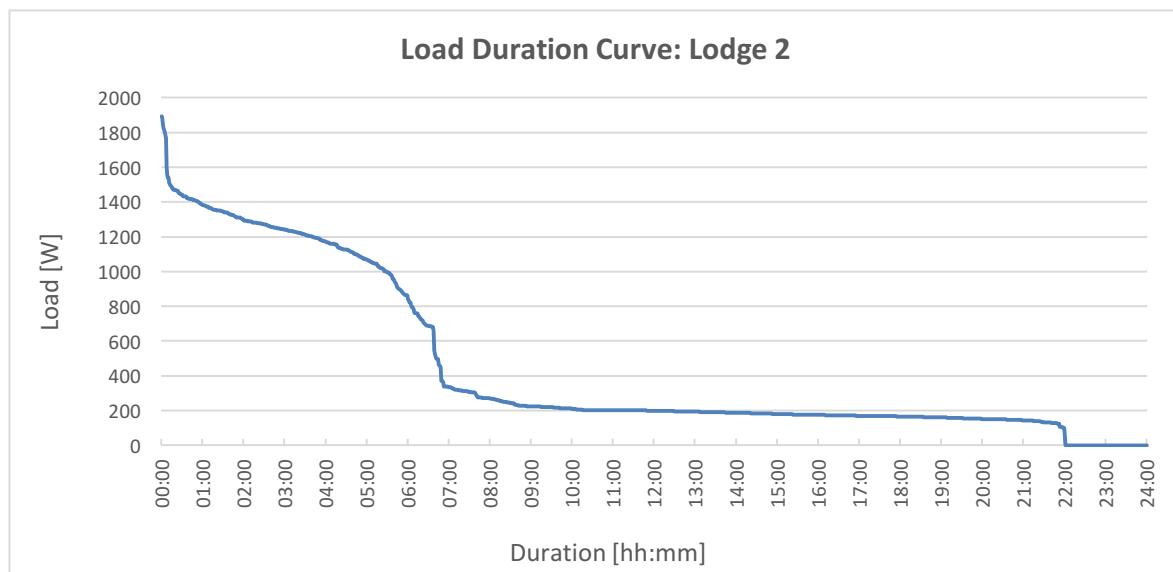


Figure 4-17: Lodge 2 – load duration curve [Own Illustration]

Table 4-4: Lodge 2 – primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	10 896 Wh/d	Energy consumed (MB)	11.98 kWh/d
Mean load	454.0 W	Accordance	91%
Peak load	1 893 W		

Survey

<i>Staff living at the lodge:</i>	2 adults (mother and assistant) 2 children
<i>Capacity:</i>	15 rooms with 30 beds 16 guests when measured
<i>Electric devices:</i>	- refrigerator with freezer compartment (100 W); permanently - rice cooker (900 W); daily for more than 6 hours - microwave (1 500 W); rarely - blender (400 W); unregularly - television with receiver (in total: 100 W); daily > 6 hours - water boiling jug (1 200 W [measured]); daily 4-6 times - fixed telephone (5 W); permanently plugged; rarely in use - Wifi-router (5 W); permanently plugged - > 40 light bulbs (~ 20 W); mostly during evening times - 2 mobile phones; charged daily
<i>Desired electric devices:</i>	1. Electric stove 2. Electric heater 3. Electric air conditioning 4. Washing machine
<i>Space heating:</i>	smokeless metal stove 36 m² dining room is heated
<i>Water heating:</i>	LPG geyser
<i>Cooking:</i>	- 4-burner LPG stove; mainly - improved cooking stove; rarely - rice cooker - water boiling jug
<i>Energy consumption:</i>	firewood: ~ 18 t / year LPG: ~ 650 kg / year electricity: ~ 120 kWh / month (~ 4 kWh / day)
<i>Desired heating / cooling devices:</i>	1. Electric stove 2. Electric heater 3. Electric air conditioning

4.2.2.2 Discussion

Test subject L2 showed the highest electricity consumption (10 896 Wh/d) as well as the highest peak load value (1 893 W) among all test subjects in this study. Mrs. Gurung reported that she considered electricity to be cheap in contrast to fuelwood and LPG, and that she, therefore, uses it for cooking purposes as much as possible. She would also boil water during the day when there was enough electricity available, and saved it in big thermos flasks for cooking in the evening, when power from the plant was low. In this way, the 5-liter water boiling jug contributed massively to L2's electricity demand.

When analysing the measured load profile (see figure 4-16), no comparably higher demand levels in the morning and evening can be recognized as observed at L1. Instead, primarily load peaked caused by the large water boiling jug are noticeable and spread across the day. Night time base load (mainly exterior lighting) amounted to around 200 W, being significantly higher than L1's average load of 123.7 W over the whole day. When L2's load graph dropped from 19:45 to 20:30, a higher demand level of around 300 W can be observed, compared to the 200 W base load during night times. This may be related to tourists lighting their rooms and charging their mobile devices.

Due to the frequent utilisation of the water boiling jug, the load duration curve (see figure 4-17) looks balanced to some extent. It is a remarkable fact that during less than 5.5 hours, electricity demand was higher than 1 000 W.

A comparison of the measured electricity consumption of 10 896 Wh/d and the reported average consumption of around 4 kW/d indicates that when measured, demand was much higher than on an average day. Again, this may result among other things from high season.

Like L1, Mrs. Gurung wished to substitute fuelwood and LPG for electricity driven devices for cooking and heating, if Chame's hydroelectric station was upgraded and, as a consequence, electricity wouldn't be short anymore. This would obviously lead to a massive increase in electricity demand.

4.2.3 Lodge 3: Moonlight Guest House

4.2.3.1 Results

Measurements at Moonlight Guest House (L3; see figure 4-18) were conducted on 17/10/2016. The lodge is run by family Lama, consisting of the two parents and their three children, two of them being adults. Family Lama lives in a private area of their little hotel in Chame (altitude: 2 670 m). They had several electric appliances. The lodge's load profile (see figure 4-19) and load duration curve (figure 4-20) was calculated using measured voltage and current. See section *Survey* for detailed information about the lodge's characteristics gained by use of the questionnaire.

During measurements, a mean load of 128.4 W was recorded, resulting in a total power consumption of 3 083 kWh/d, with a peak demand of 875.9 Wh. When compared to the main box meter readings of 2.90 kWh/d, an accordance of 94% results.



Figure 4-18: Lodge 3: Moonlight Guest House in Chame [Own Illustration]

Load Measurements

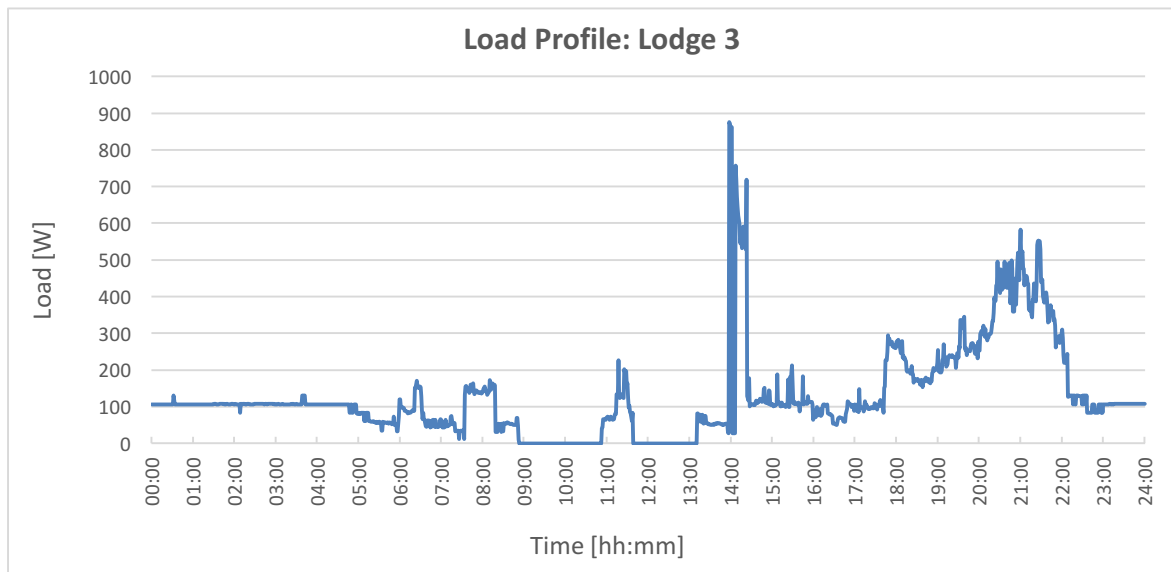


Figure 4-19: Lodge 3 – load profile [Own Illustration]

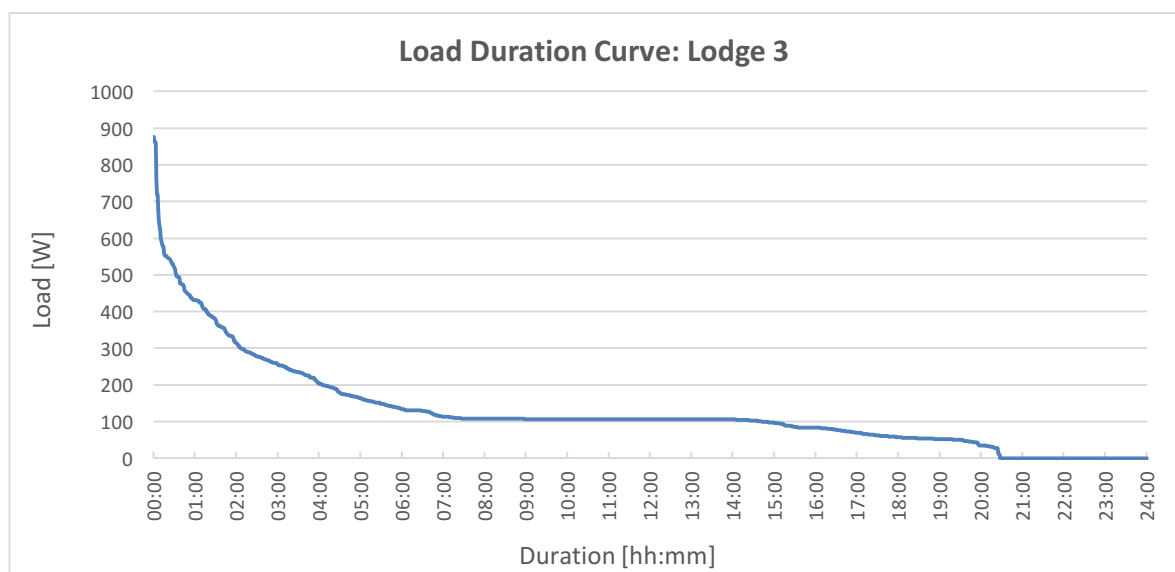


Figure 4-20: Lodge 3 – load duration curve [Own Illustration]

Table 4-5: Lodge 3 – primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	3 083 Wh/d	Energy consumed (MB)	2.90 kWh/d
Mean Load	128.4 W	Accordance	94%
Peak Load	875.9 W		

Survey

<i>Staff living at the lodge:</i>	- 4 adults (father, mother & 2 sons) - 1 children
<i>Capacity:</i>	- 10 rooms with 23 beds - 11 guests when measured
<i>Electric devices:</i>	- rice cooker (650 W); daily for 0 - 1 hours - water boiling jug (1 000 W); daily 3-4 times - television with receiver (in total: 75 W); daily for 3 – 6 hours - Wifi-router (5 W); permanently plugged - > 40 light bulbs (~ 20 W); mostly during evening times - 2 mobile phones; charged daily
<i>Desired electric devices:</i>	none
<i>Space heating:</i>	smokeless metal stove 17.5 m ² dining room is heated
<i>Water heating:</i>	- LPG geyser
<i>Cooking:</i>	- 4-burner LPG stove; mainly - improved cooking stove - rice cooker - water boiling jug
<i>Energy consumption:</i>	firewood: ~ 6 t / year LPG: ~ 540 kg / year electricity: ~ 110 kWh / month (~ 3.7 kWh/d)
<i>Desired heating / cooling devices:</i>	none

4.2.3.2 Discussion

In general, the measured electricity demand of lodge 3 can be classified rather low. The electric energy consumption (3 083 Wh/d) was slightly higher than L1's consumption. However, L3 showed an intermediate peak value (875.9 W) compared to L1 and L2. The two most consumptive appliances were the water boiling jug and lighting.

When examining the load profile (see figure 4-19), two circumstances seem remarkable: First, the electricity demand level ranked steadily below 200 W throughout the whole day until consumption rose to nearly 600 W, and then decreased again following a bell-shaped curve in the evening (17:45 – 22:00). High demand in the evening was related to trekking tourists arriving at the lodge, switching on room lights and charging their mobile devices. Secondly, the usage of the water boiling jug resulted in an 860 W peak at around 14:00.

The distribution of load values (see figure 4-20) can be described as rather unbalanced, due to the big contrast of short-term high and long-term low load.

Measured electrical energy consumption amounted to 3 083 Wh/d, while the reported consumption during the interview was 3.7 kW/d on average. In contrast to L1 and L2, the measured demand of L3 was lower than the reported consumption per day. The reason for this may be the frequency by which the water boiling jug was used. While measured, it was used once, whereas the owner reported a mean use of three to four times a day.

As test subject L3 does not wish any additional electrical devices for the future, no indicators of an increasing power consumption are evident.

4.2.4 General Conclusions for All Lodge Test Subjects

Total Energy Consumption

Similar to household energy use (compare section 4.1.4) fuelwood has the biggest share on total energy consumption (see figure 4-21). In all three lodges, fuelwood is used mainly for heating up the dining room for tourists during trekking season. Thereby, heating up the lodges' dining rooms is more consumptive than preparing food.

Though energy demand is also dominated by fuelwood use, lodges show more modern consumption patterns than households. The share of LPG is significantly higher due to using it as the main energy source for cooking. However, electricity consumption is, again, relatively low because of power scarcity in Chame.

At L1, fuelwood consumption has the biggest share, whereas demand for LPG and electricity is lowest compared to the other lodges. L3's low level of fuelwood use may arise from having the smallest dining room and the best thermal insulation (see Appendix Q).

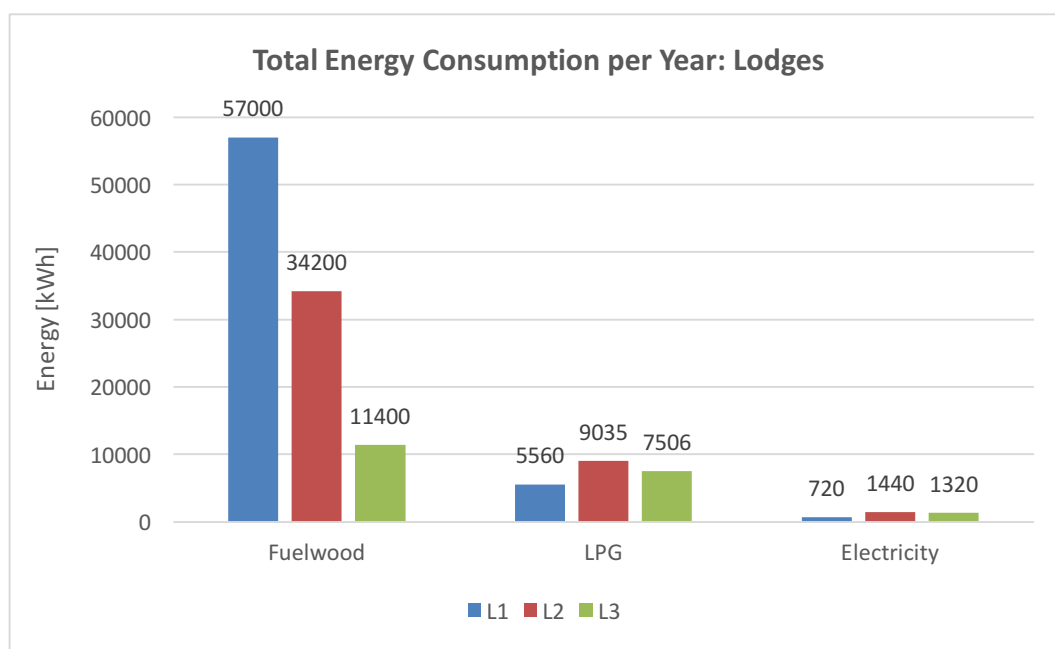


Figure 4-21: Lodges – total energy consumption per year. Data is based on questionnaire results. [Own Illustration]

When applying the energy prices given in table 2-2, L1 spends roughly 1 950 USD/a on fuelwood, 750 USD/a on LPG and 70 USD/a on electricity. When considering the 2015 national average annual salary of 730 USD (World Bank 2015), the expenses on energy can be estimated as considerably high.

The electricity demand of test subjects L1 and L2 may rise in future, as they wish to use additional electric device, especially for heating and cooking. To be able to power those additional highly consumptive devices, Chame's hydroelectric power plant needs to be upgraded to overcome the ongoing power shortages. In general, during the interview of L1 and L2, a strong desire for switching from fuelwood and LPG to electricity driven devices could be determined.

When comparing the measurements and the questionnaire-based reports regarding electricity demand, different conclusions can be derived. While the consumption of L1 and L3 seems similar when comparing measurement data, the consumption data collected through the interviews shows similarities between L2 and L3. These findings may call for repeated measurements, when conducting further studies, as the measurements often do not represent the average pattern of test subjects. Load profiles collected in the present study only display a small snapshot of the test subjects' energy consumption patterns. To get a total overview, repeated measurements on both, weekdays and weekends as well as during different seasons of the year would be necessary.

Heat and Cooling Demand

Like at the household test subjects, the most consumptive application at the lodges L1 – L3 is generating heat for space heating. For this, all lodge test subjects utilise a smokeless metal stove (see Appendix N) fueled by firewood. For cooking, 4-burner LPG stoves are used predominantly. A minor share of the heat for cooking is generated by combusting fuelwood in improved cooking stoves (L1 – L3) and by using electricity for water boiling jugs (L2 & L3) and rice cookers (L1 – L3). At all lodge test subjects, fuelwood is mostly only used for space heating. Thus, it can be stated that almost the complete fuelwood consumption contributes to space heating. To provide a comparison to the fuelwood use, the theoretical heating demand for two different scenarios was calculated according to DIN V 4108-6 (see figure 4-22); on the one hand based on a set point indoor temperature of 20° C for the whole year (scenario A), on the other hand based on a set point indoor temperature of 18° C and the assumption that the buildings are only heated during the three first and last months of the year and (scenario B). However, as a wide range of simplifications and assumptions were made (see Appendix Q), this calculation should be considered rather qualitatively than quantitatively relevant.

Findings for all three lodge test subjects show the same pattern, with a decreasing level of values from L1 and L2 to L3. Fuelwood consumption exceeds the calculated heating demand by far. Heating demand at L2 ranks on a slightly lower level than the one at L1 because the heated space is 12 m² bigger. L3's heating demand is only a fraction of L1's and L2's due to a much smaller heated space (17.5 m² compared to 48 m² (L1) and 36 m² (L2)) and significantly better insulation with wooden planks at the inside walls.

Cooling demand can be classified relatively low at L1 and L2 as they only run one refrigerator for chilling beverages for trekking tourists. L3 shows no cooling demand at all.

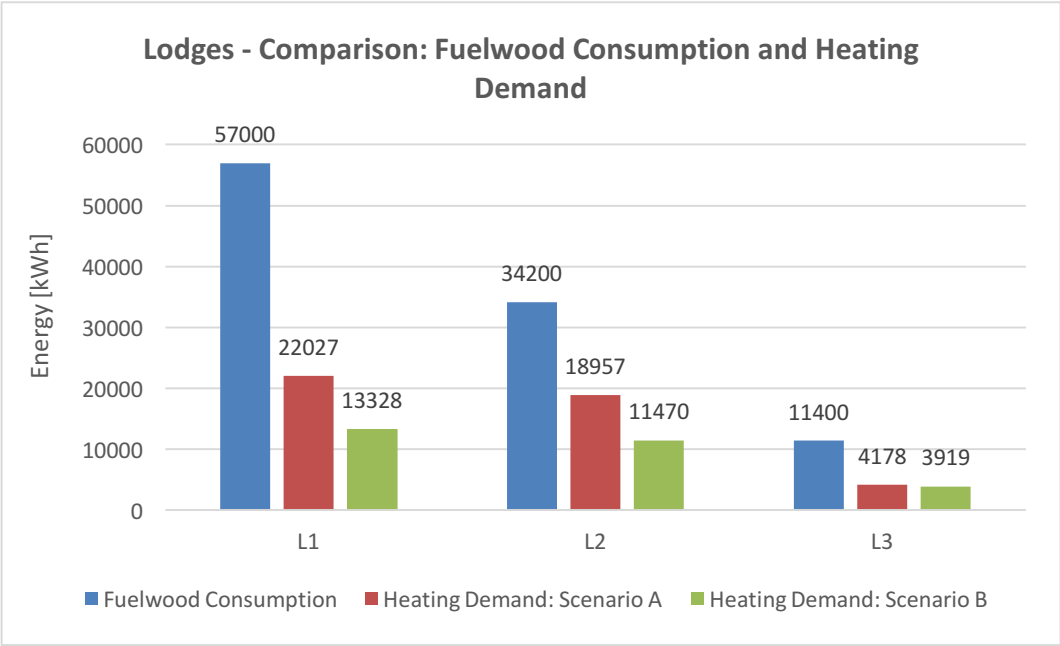


Figure 4-22: Comparison of the calculated heating demand and the reported fuelwood consumption [Own Illustration]

4.3 Schools

Load Measurements at schools S1 (Lophelling Boarding School) and S2 (Braga Primary School) were performed after measurements at households H1 and H2. Thus, again, only one multimeter was working faultlessly, so no simultaneous measurement of voltage and current was possible. Only current could be logged with solely one working multimeter left. Voltage for calculating load was taken from voltage measurements for H1, also supplied by Sabje Hydropower Station.

4.3.1 School 1: Lophelling Boarding School

4.3.1.1 Results

Measurements at Lophelling Boarding School (LBS) were performed on 25/10/2016. As LBS is a boarding school, students are living on campus. The staff consisted of five people living at school, and five teachers, who leave school after classes. LBS is a private school supported by several non-governmental organisations from abroad and, thus, standards in terms of equipment are rather high compared to public schools (see Braga Primary School in section 4.3.2). The school (see figure 4-23 and 4-24) is located between Humde and Braga in the plains of Manang Valley at an altitude of 3 430 m. The load profile is shown in figure 4-25, the load duration curve in figure 4-26. See section *Survey* for detailed information about the school's characteristics gained through the questionnaire.

Mean load during measurements was 179.8 W. Consequently, the total power consumption amounted to 4 319 Wh/d. When compared to the main box meter readings of 4.65 kWh/d, an accordance of 93% results. A peak demand of 1636.5 W was measured.



Figure 4-23: School 1 – Lophelling Boarding School: Classrooms [Own Illustration]



Figure 4-24: School 1 – Lophelling Boarding School [Own Illustration]

Load Measurements

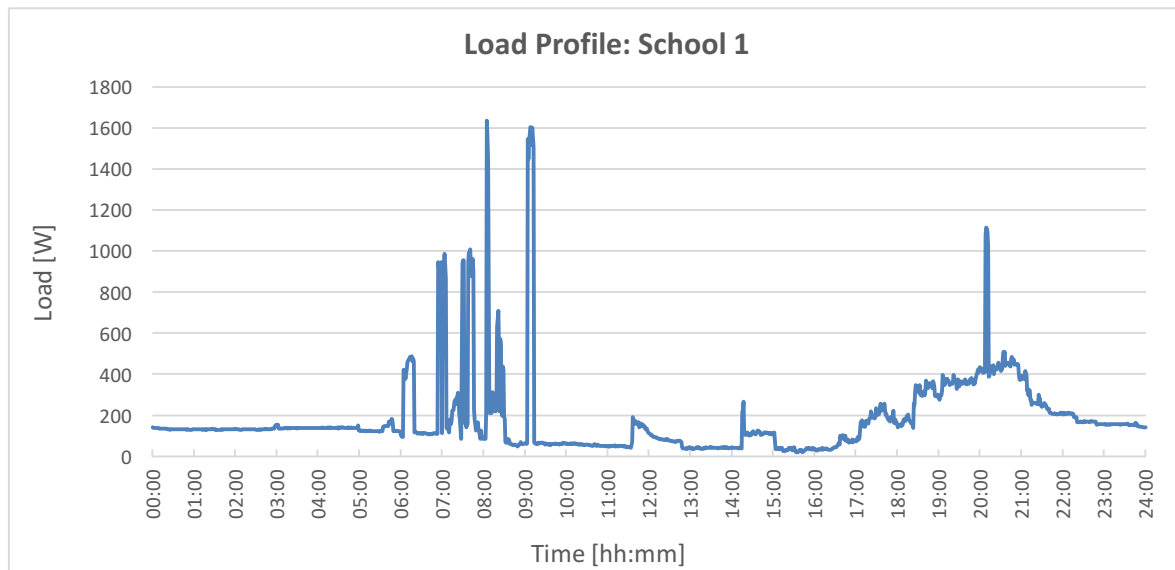


Figure 4-25: School 1 – load profile [Own Illustration]

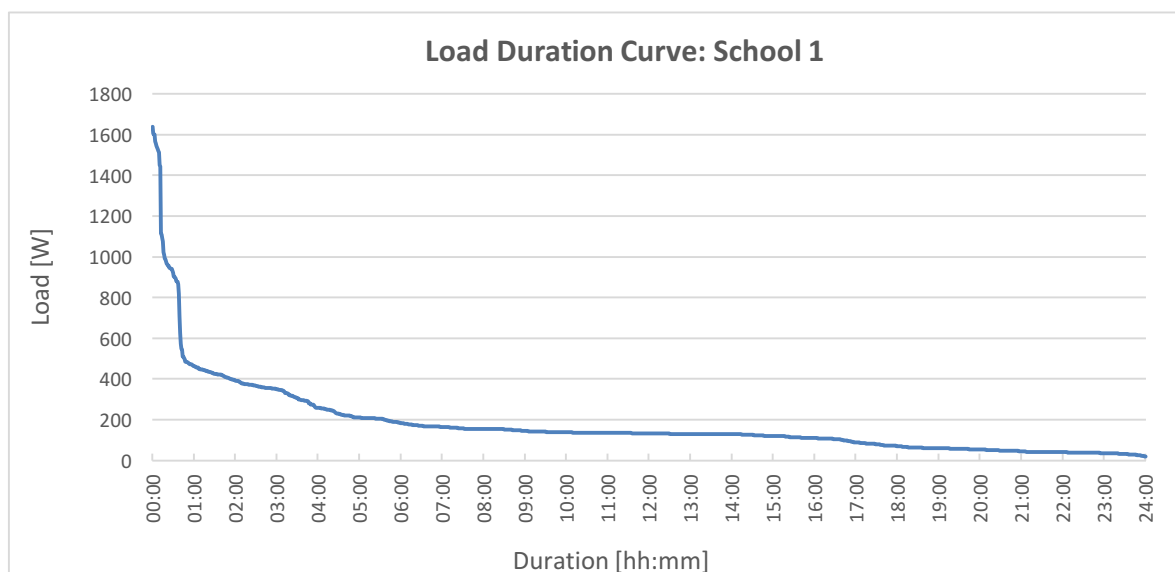


Figure 4-26: School 1 – load duration curve [Own Illustration]

Table 4-6: School 1 – primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	4 319 Wh/d	Energy consumed (MB)	4.65 kWh/d
Mean load	179.8 W	Accordance	93%
Peak load	1 636.5 W		

Survey

<i>Type of school:</i>	private boarding school
<i>Staff:</i>	5 adults, 1 child (living at school) 5 teachers (not living at school)
<i>Students:</i>	43 (boarding school)
<i>Electric devices:</i>	- television (57 W) with receiver (30 W) and DVD-Player (15 W); on weekends, 1 – 3 hours - computer (~ 200 W) with monitor (70 W) and printer (60 W); daily for 1 – 3 hours - 4 laptops (~ 50 W); unregularly - blender (250 W); once per day in the morning - 4 water boiling jugs (2 x 1 000 & 2 x 1 500 W); daily, mainly in the morning - > 50 light bulbs (~ 20 W); mainly in the evening - 10 mobile phones; charged daily
<i>Desired electric devices:</i>	1. Television (for staff) 2. 4 – 5 additional laptops 3. Portable microphone and loudspeaker (for dancing shows)
<i>Space heating:</i>	none
<i>Water heating:</i>	solar heating system
<i>Cooking:</i>	- big improved cooking stove; mainly - kerosene stove; very rarely - water boiling jug
<i>Energy consumption:</i>	firewood: ~ 25 t / year electricity: ~ 180 kWh / month (~ 6 kWh/d)
<i>Desired heating / cooling devices:</i>	none

4.3.1.2 Discussion

Test subject S1 had an electricity consumption of 4 319 Wh/d and a peak load of 1 636.5 W during the 24-hour measurements. Compared to S2 (Braga Primary School) both values can be ranked very high. The most consumptive appliances were the water boiling jugs, mostly during morning times, and lighting during evening times. The significantly higher level of electricity demand of S1 compared to S2 may be due to the following two circumstances: On the one hand, S1 is a boarding school, so students and some of the staff sleep and live in situ, whereas at S2, a day school, students go home after classes. On the other hand, the economic situation of S1 can be estimated as better, as it is a private school while S2 is a public school. In addition, more students attend Lophelling Boarding School, than Braga Primary School, so a higher demand level seems plausible.

When analysing the load profile (see figure 4-25), power demand seems to be concentrated at two times of the day. In the morning (06:00), butter tea was prepared with the blender resulting in a little load peak. Furthermore, from 07:00 to 09:15, four peaks can be noted in the load profile representing the use of the water boiling jugs, also for preparing tea. The first two correspond to the 1 000 W jugs, the last two to the 1 500 W jugs. In the evening at around 20:00, again a 1 000 W jug was used for preparing tea. From 17:00 until around 21:15, lighting results in a roughly bell-shaped load curve progression. Base load during the day ranked on a very low level of around 30 – 50 W. During the night, lighting caused a constant load of around 130 W.

Due to the big contrasts of long-term low-level load during day and night, the moderate load during the evening from lighting and the short-term high-level load in the morning and evening, the load duration curve can be classified as very uneven (see figure 4-26).

A comparison of the measured electricity consumption (4 319 Wh/d) and the reported average consumption value (around 6 kWh/d) gained using the questionnaire indicates that demand was lower than on an average day.

The headmaster of S1, Mr. Gonpo Wangchuck, reported during the interview that he considered acquiring a few additional electric devices in future. As those devices, such as a TV and Laptops, do not consume a lot of energy, electricity consumption may rise only slightly in future times.

4.3.2 School 2: Braga Primary School

4.3.2.1 Results

At Braga Primary School (S2; see figure 4-27), a public day school, measurements were conducted on 23/10/2016. Students do not live on campus, but go home after classes. Staff living at school consists of five people. As Braga Primary School is a public school, standards in terms of equipment and, thus, electric devices are rather low. The school, located on the outskirts of Braga, is situated at an altitude of 3 470 m. The school's load profile (see figure 4-28) and load duration curve (figure 4-29) was calculated based on measured voltage and current. See section *Survey* for detailed characteristics of Braga Primary School evaluated with the questionnaire.

A mean load of 13.8 W was measured, resulting in a total 24-h power consumption of 330 Wh/d, with a peak demand of 79.2 W. During measurements, construction works were ongoing. However, electrical tools were supplied by a second phase of the main box, so the school's electricity consumption could be measured separately. A comparison with the main box meter readings was not possible.



Figure 4-27: School 2 – Braga Primary School [Own Illustration]

Load Measurements

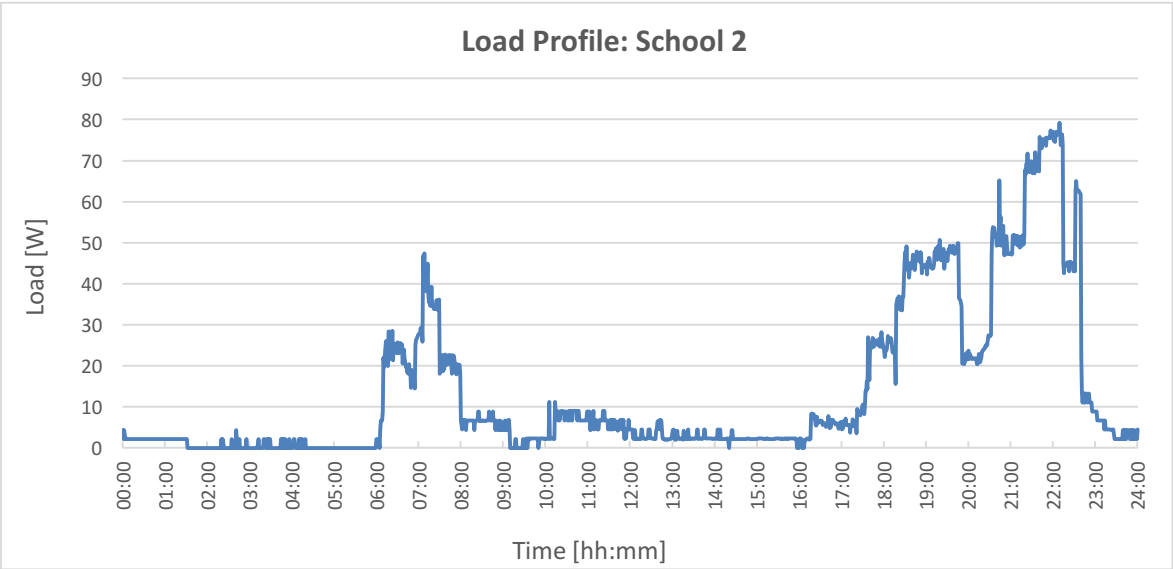


Figure 4-28: School 2 – load profile [Own Illustration]

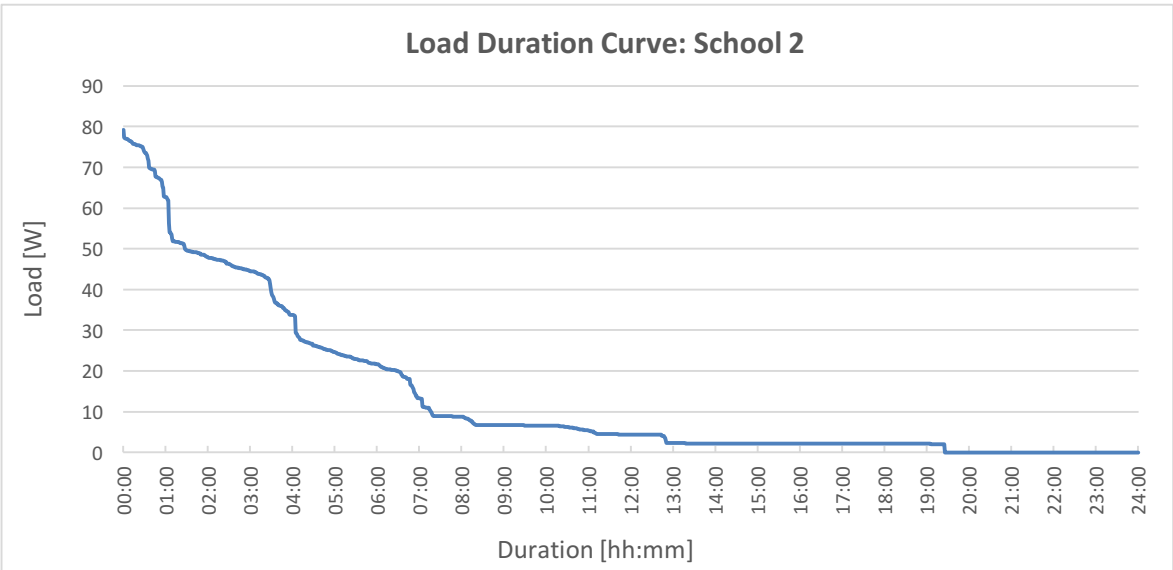


Figure 4-29: School 2 – load duration curve [Own Illustration]

Table 4-7: School 2 – primary load measurement data (left) and accordance of the measured and main box (MB) derived consumption (right)

Energy consumed	330 Wh/d	Energy consumed (MB)	-
Mean Load	13.8 W	Accordance	-
Peak Load	79.2 W		

Survey

<i>Type of school:</i>	public day school
<i>Staff living at school:</i>	5 adults
<i>Students:</i>	25
<i>Electric devices:</i>	- computer (~ 200 W) with monitor (60 W); unregularly - laptop (~ 30 W); unregularly - photocopy machine (80 W); unregularly - radio (10 W); daily for 1 – 3 hours during evening - 7 light bulbs (9 – 25 W); mainly in the evening - 5 mobile phones; charged daily
<i>Desired electric devices:</i>	1. Television (for staff) 2. Wifi (for staff) 3. More computers
<i>Space heating:</i>	none
<i>Water heating:</i>	none
<i>Cooking:</i>	improved cooking stove
<i>Energy consumption:</i>	firewood: ~ 7 t / year electricity: ~ 19 kWh / month (~ 0.6 kWh/d)
<i>Desired heating / cooling devices:</i>	1. Rice cooker 2. Water boiling jug 3. Electric heater

4.3.2.2 Discussion

In general, the electricity demand of S2 was very low, when measured. That applies for the overall electrical energy consumption (330 Wh/d) as well as for the peak load value (79.2 W). S2's average demand level (13.8 W) was the lowest among all test subjects. The most consumptive appliance was lighting. Especially when contrasting the load profiles of S1 and S2, completely different consumption patterns can be observed. As mentioned before, this derives from S2 being a public day school and not an externally financed boarding school as S1. During the interview, the headmaster of test subject S2 reported that the school was not allowed to consume more electricity due to strict budget constraints.

As electricity consumption was mostly due to lighting, the load profile (see figure 4-28) shows the highest demand during morning (06:00 – 08:00) and especially evening (17:30 – 23:00) times. In the evening, radio use by the staff was noticed during observation. Base load throughout day classes and night was between 0 and 10 W.

The load duration curve (see figure 4-29) shows a balanced shape to some extent as mainly only light bulbs were in use. It is noticeable that for almost 15 hours of the 24-hour measurement period, load remained below 10 W.

A comparison of the measured electricity consumption of 330 Wh/d and the via questionnaire reported average consumption of around 0.6 kWh/d indicates that, when measured, demand was slightly lower than on an average day. Still, mean electricity demand of S2 can be estimated as very low.

Though the headmaster reported a few desired devices, it can be assumed that the consumption level will not rise significantly in future. This seems transparent, when considering that the lately acquired electric heater was not in use because of its high-power consumption and the school's budget constraints.

4.3.3 General Conclusions for All School Test Subjects

Total Energy Consumption

Total energy consumption patterns of school test subjects S1 and S2 (see figure 4-30) are comparable to those of household test subjects (see figure 4-10). The pattern of S1 looks comparable to H3's, the distribution of S2 shows parallels to the ones of H1 and H2, with the difference that in schools no LPG is consumed at all. Apart from that, fuelwood use dominates the total energy consumption, as it serves as energy source for generating heat for cooking. In both school test subjects, heat from combusting wood is only used for cooking, not for space heating. The annual fuelwood expenses of S1 sum up to around 1 600 USD per year.

When comparing the total energy consumption of S1 to that of S2, the only difference is the amount of energy consumed. Again, this arises out of the circumstance that S1's economic situation is better and, therefore, the budget for energy consumption is higher. In addition, more students attend S1 and students spend more time at S1. Therefore, electricity consumption is higher than at S2.

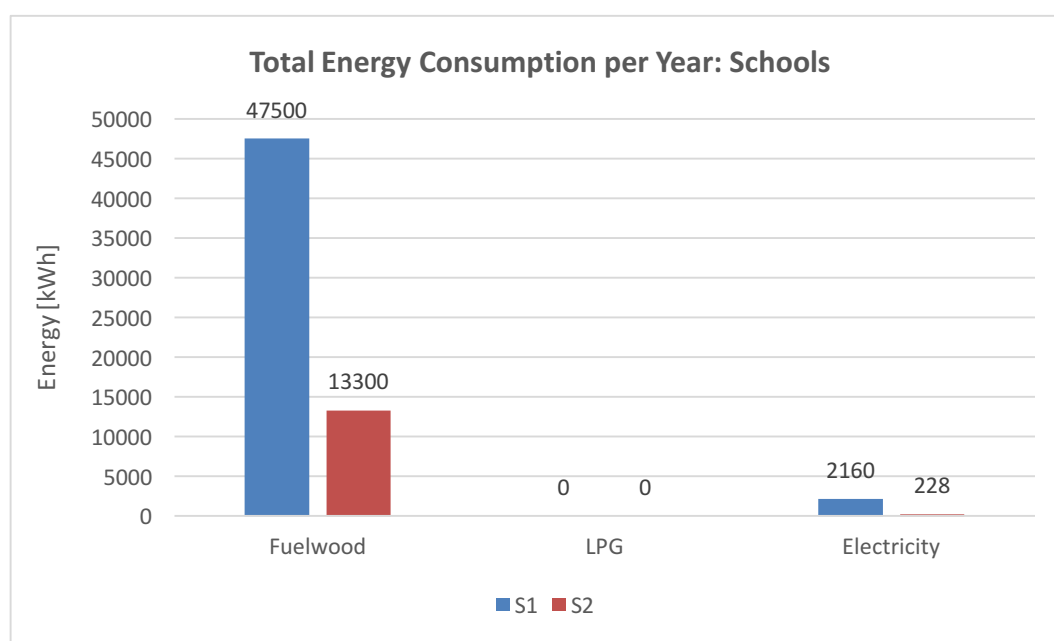


Figure 4-30: Schools – total energy consumption per year. Data is based on questionnaire results. [Own Illustration]

Electricity demand of test subject S1 may rise slightly in future, as its headmaster reported that he would like to acquire a few additional low-power devices. S2's consumption level may stay constant, due to budget limitations. However, if the schools budget rises in future, also S2's demand may rise. In general, both school test subjects reported that they were highly concerned about their electricity bills. Thus, no significant increase of their demands can be assumed, if their economic situation remains unchanged.

Heat and Cooling Demand

Both school test subjects' heat demand mainly consists of heat for cooking generated by combusting fuelwood. In addition, at S1, heat is also generated with water boiling jugs, using electricity. Space is heated neither at S1 nor S2. Therefore, no comparison of the theoretical heating demand and the fuelwood consumption is presented.

Both school test subjects show no cooling demand at all.

4.4 Manang Healthcare Station

Results

In Manang District, there are two main healthcare stations, a bigger one in Chame, a smaller one in Manang Village, operated by the Himalayan Rescue Association of Nepal. Like in whole Manang Village, the healthcare station (HC1; see figure 4-31) has two separate power connections. One coming from Sabje Hydropower Station (single phase), the other one from the village's own hydropower plant (three-phase). Additionally, HC1 is powered by an off-grid solar system, making it impossible to measure power consumption with the available equipment during fieldwork. Nevertheless, a questionnaire-based survey was performed with the following results.



Figure 4-31: Manang Village healthcare station [Own Illustration]

Survey

<i>Opening times:</i>	during trekking season (5 months per year)
<i>Staff living on-site:</i>	5 adults
<i>Electric devices:</i>	- 3 laptops (~ 30 W); daily for 3-6 hours - television (65 W [measured]) with receiver (15 W) and DVD-player (12 W); unregularly - water boiling jug (670 W; [measured: 570 W]); daily for 1 – 3 hours - refrigerator with freezer compartment (90 W); permanently plugged - induction cooker (2 000 W; [measured: 1 560 W]); daily for 0 – 1 hours - electric geyser (1 500 W; [measured: 1 210 W]); daily for more than 6 hours - 2 electric heaters (1200 W [measured]); in use for around 30 days per year for 3 hours each on average - ~ 30 light bulbs; mostly LED - 5 mobile phones; charged daily Very rarely used medical equipment: - needle burner (60 W) - autoclave (2 000 W) - oxygen concentrator (450 W)
<i>Desired electric devices:</i>	1. Washing machine 2. Additional induction cooker 3. Additional electric heaters
<i>Space heating:</i>	2 electric heaters
<i>Water heating:</i>	electric geyser
<i>Cooking:</i>	electric stove (Induction); mainly 2-burner LPG stove
<i>Energy consumption:</i>	LPG: ~ 45 kg / year electricity: ~ 450 kWh / month (~ 15 kWh/d)
<i>Desired heating / cooling devices:</i>	1. Additional induction cooker 2. Additional electric heaters

Discussion

Total Energy Consumption

With no fuelwood use at all and most of the total energy consumption being electricity, Manang Healthcare Station shows the most modern energy consumption pattern among all test subjects (see figure 4-32). Heat for cooking and space heating is generated mainly with electricity driven devices. Those devices are highly consumptive, so HC1's electricity demand is by far the highest among all test subjects, especially when considering that it is open for only five months per year. This consumption pattern is only possible because of the current massive overcapacities of Manang Village's very own hydropower plant. The fact that the induction cookers usually cannot be run, when Manang Hydropower Plant is off duty due to maintenance, shows that only with a sufficient power supply, electric devices can serve as practicable alternatives to fuelwood combustion to generate heat for cooking and heating.

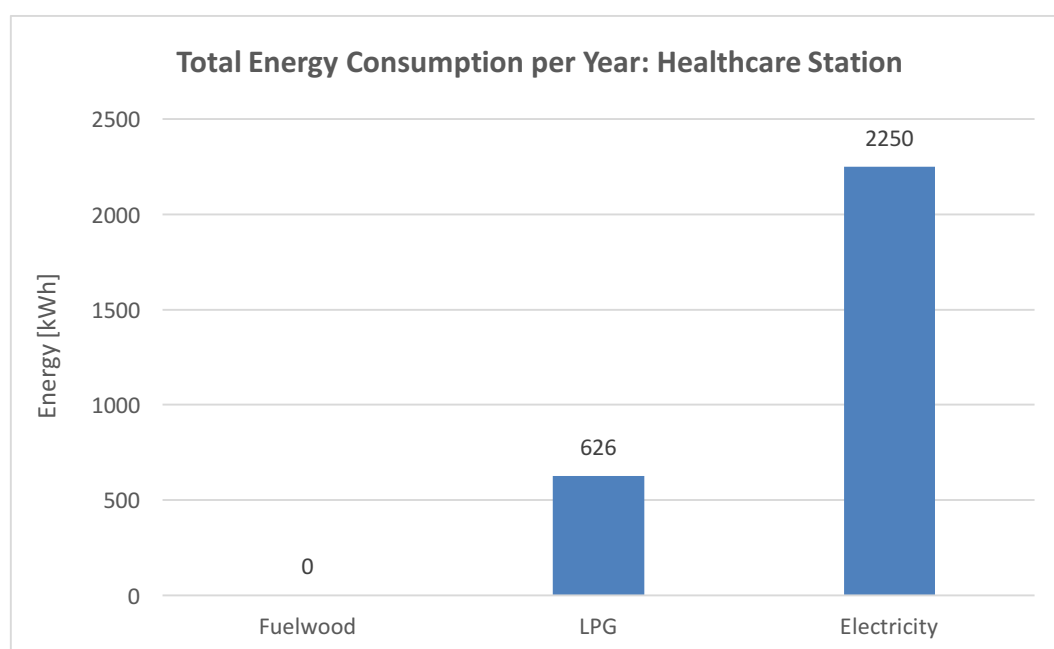


Figure 4-32: Manang healthcare station – total energy consumption per year. Data is based on questionnaire results. [Own Illustration]

During the questionnaire-based interview, the staff's head of HC1 reported that they recently replaced their LPG driven geyser with an electric one. In addition, they would like to acquire additional electric heaters and induction cookers. Therefore, it can be assumed that electricity demand may rise significantly in future, as it did recently in the past by switching from LPG to electricity driven hot water production.

Heat and Cooling Demand

At Manang Healthcare Station, heat for cooking (LPG and electricity) and space heating (electricity only) represents the most consumptive appliance. It exceeds the energy consumed for medical purposes by far. Thereby, no particular space is heated on a regular

basis. Simply those rooms are heated up, where the staff is staying at the respective moment. Therefore, no heating demand was calculated for HC1.

Cooling demand is comparable to the ones of the lodge test subjects, as a small refrigerator is run for chilling beverages, food and a small number of vaccines.

5 Conclusions for Practice

As domestic consumption has the highest share in TPEC in Nepal, this chapter focuses on conclusions regarding households. Nevertheless, it is important that also electricity consumption data on other types of consumers, such as lodges and schools, was collected to provide an overview of the electricity demand of remote areas in Nepal and to allow a comparison among different kinds of consumers.

5.1 General Conclusions

Methodology

In general, it can be noted that with the simple and low-cost equipment used in this study, load measurements can be performed in a satisfactory manner. The minimum setup consisted of a digital multimeter with an USB connector and an AC current clamp adapter. It sums up to a total retail price of only around 130 USD (laptop excluded). Therefore, the cost-effectiveness of this method can be classified as decent. In addition, as the method allows contactless current measurements, it is safe and convenient for both the investigator and the test subjects. Therefore, the load measurement method applied in this study is recommended for further practical use afield. For recommendations on how to still improve the method, see section 6.3.

Study Results

In general, the results and data gained by the present study can be used to validate load profiles generated by simulations and models. In this way, the simulations can be optimized and off-grid systems can be designed in a more consumer-oriented and valid manner.

Except L2, all test subjects showed similarities regarding their load profiles during the 24-hour measurement period. High-power applications, if in use at all, were utilised only for a short period. Most of the time, rather low-power appliances, such as lighting, entertainment devices (television or radio) or communication devices (internet or mobile phones) were in use.

For both household test subjects, load level was below 100 W for a minimum of 23.5 hours during the measured day. Thus, peak loads beyond 100 W were required for 30 minutes only. The accordance of the measured 24-hour consumption and the average daily power consumption calculated from the reported annual demand is considerably high. Therefore, it can be assumed that the incidence of merely short-time peak load is common among households' consumption pattern. When analysing the load duration curves of the other test subjects, comparable circumstances of only short-time peak levels can be observed among all subjects, except for L2.

This often resulted in rather unbalanced load duration graphs. Highly uneven demand means an ineffective exploitation of the constant capacity provided by an off-grid hydroelectric system. Especially when designing very small hydropower systems of up to just a few Kilowatts, these findings should be considered, as the chance of a balancing effect drops with a decreasing number of individuals supplied.

In section 2.3, two approaches of providing a certain fixed amount of power per household were presented. AEPC currently grants 125 W and considers upscaling to 200 W. Prof. Dr. Maskey calls for at least 700 W per household, to be able to power heat generating cooking appliances (Maskey 2016). In conclusion, it can be stated that considering the study's results, a compromise of those two approaches may be the best trade-off in terms of usability, customer satisfaction and cost-efficiency. In section 5.3, this compromise is presented in the form of a brief concept for the supply of households in remote areas, based on the conclusions mentioned above. This supply concept may pave the way for the reduction of the ecologically problematic fuelwood consumption, by using more electricity for cooking appliances.

5.2 Future Projections on the Electricity Demand

Electricity Consumption Level

Future projections on the electricity demand are of importance for two reasons. On the one hand, they can be used, for adapting load profiles generated by Monte Carlo Simulations to changing circumstances. On the other hand, when designing energy systems, not only the current consumption should be considered. To be sustainable in every sense, a renewable energy system should meet current as well as future demands. Therefore, in this section conclusions about possible future trends on the electricity demand based on the study's findings are presented.

As carved out in chapter 2, electricity consumption per capita has risen continuously in the last years. NPC projected an even higher growth rate for the near future (NPC 2007), (NPC 2015). However, there is a need to clarify if this consumption growth also applies for remote areas such as Manang District.

The present study's results indicate that in general, electricity demand of individuals in Manang District is likely to rise, as most of the test subjects reported that they would like to acquire additional electric devices. However, some limiting factors of an electricity demand growth and the use of additional electric devices were found out through the questionnaire-based interviews:

Electricity scarcity: Lodge test subjects L1 and L2 reported that they would completely like to switch to electricity for generating heat for cooking and space heating. Especially for them, electricity scarcity represents the biggest obstacle for doing so and, hence, for consuming more power. Other test subjects as well estimated the supply with electricity as too insufficient to represent a serious alternative to fuelwood. Without upgrading the capacity of the overloaded hydroelectric plants, such as the Chame and Sabje ones, electricity consumption is inhibited to rise. Only in Manang Village, a sharp increase in electricity consumption did and will happen due to adequate overcapacities.

Budget constraints: Both school test subjects, S1 and S2, reported that they simply could not consume more electricity due to budget limitations regarding their electricity bill. Thus, the running expenses constitute a bigger obstacle for consuming more electricity than the devices' acquisition costs.

Tradition and habit-related circumstances: Household test subjects H1 and H2 stated that they did not use a wide range of electrical devices, as they lived a rather traditional life. However, they could imagine that things might change and using more electricity driven devices may become customary. The fact that H3 seems to be a few steps ahead of H1 and H2 on the path of becoming a rather modern household and, therefore, uses a lot more electric devices leaves a similar impression. In the past, tradition and habit-related circumstances may have curbed a rise in household electricity consumption, but these inhibitions are likely to be overcome eventually.

In conclusion, it can be stated that electricity demand is likely to rise in Manang District as it does for whole Nepal. Pace and steadiness of this growth is dependent on the limitations mentioned above. Demand is most likely to go up, when the supply situation improves, the economic level increases or tradition and habit-related obstacles break down more and more.

Switching from Fuelwood and LPG to Electricity

As explained in chapter 2, fuelwood use results in environmental issues, while LPG as a fossil fuel contributes to climate change with its GHG emissions.

Fuelwood was used among test subjects for space heating and cooking, while LPG mostly served as fuel for cooking. Generating heat with electricity for both, cooking and space heating purposes is highly consumptive. As seen at test subject HC1, only in Manang Village it is possible to generate heat mostly with electricity driven devices due to sufficient overcapacities of Manang Hydropower Plant. However, such fairly oversized off-grid systems come with rather high specific costs.

When surveyed, test subjects reported that electricity driven devices were more convenient to use than fuelwood driven appliances and cheaper in terms of operation than LPG driven ones. Hence, when there is enough electricity, people tend to switch from fuelwood and LPG to electricity resulting in a rise of the electricity demand. Therefore, it may seem reasonable to design off-grid systems considering a future rising demand with a certain amount of overcapacities. However, as those overcapacities are costly and peak load often is only short-timed as the present study shows, new concepts for an effective exploitation of installed capacities must be developed.

To address cost-effectiveness, it is suggested to use electricity as complementary energy source for cooking and heating purposes as a first step on the path towards sustainable energy use. Completely switching to electricity driven devices for cooking and heating can currently not be estimated to be feasible.

5.3 An Off-Grid Supply Concept for Households

In this section, a brief hydroelectric supply concept for households, based on the study's findings is presented.

In AEPC's current approach on rural electrification through off-grid hydropower systems, only an amount of 125 – 200 W of electrical power per household is provided (Maskey 2016). To make the first step on the path of switching from excessive fuelwood consumption to using electricity generated from renewable energies, a bigger amount of available capacity per household is needed to power cooking appliances. Prof. Dr. Maskey of Kathmandu University therefore calls for a minimum of 700 W per household. In this way, low-power rice cookers and water boiling jugs could be run.

However, measurements performed in the present study show that test subjects used those devices mostly only for a short period throughout the day. When considering mean loads of 26.4 W (test subject H1) and 42.0 W (H2) when measured, utilisation factors of 3.7% (for H1) and 6.0% (H2) can be calculated if supplied with 700 W each. Low exploitation of the constant hydroelectric power output during the day or in other words, high overcapacities result in high specific system costs. Therefore, the aim of the following concept is to lower fuelwood and LPG consumption by providing enough capacity to run low-power cooking devices and, in addition, address cost-effectiveness with higher utilisation rates.

Supply Concept

In general, the concept consists of a certain base capacity for each household and, on top, a shared peak capacity. To make this kind of load management method practicable, the concept is designed to supply a maximum of three households to avoid anonymity effects. These effects were observed, when Prof. Dr. Maskey conducted a study, where significantly more than three individuals had to share a certain amount of power and people did not obey their schedule.

For lighting and low-power entertainment, information and communication appliances, such as radios, televisions and mobile phones, a base capacity of 200 W per household is provided. This base capacity is available throughout the whole day. To supply three households, a total base capacity of 600 W is needed.

To power cooking appliances, such as low-power water boiling jugs (500 – 700 W) and rice cookers (450 – 700 W), a minimum capacity of 700 W is suggested. However, electrical measurements performed for this study showed that the total period of daily use of that type of devices is short. Therefore, for better utilisation rates, 700 W of peak load capacity is provided for all the three households combined and is available chronologically. To organise peak load capacity sharing, a load management concept is needed. Before, several options should be developed and evaluated with regard to their sociocultural suitability. However, as the maximum number of three households is suggested, no automatic and technically sophisticated load management may be required. The distribution of the available power may happen based on an agreement among the connected individuals in a self-administrated manner and according to their respective current demands.

To provide electricity for three households by implementing this supply concept, a total capacity of 1 300 W is needed, 3 x 200 W of base capacity and 700 W of shared peak load

capacity. Figure 5-1 shows an exemplary occupancy schedule of these 1 300 W. Thereby, the shared peak load capacity of 700 W is divided into availability periods of 60 minutes for each household. How the sharing is best implemented in the end has still to be assessed. The segmentation into periods of 60 minutes may also not be the most applicable option. Hereby evaluation is needed as well. The schedule can be modified arbitrarily. Figure 5-2 depicts another possible schedule: Household 1 is provided with a base capacity of 300 W, whereas Household 2 and Household 3 are supplied with a base capacity of 150 W each. In addition, during mealtimes, the sharing periods are reduced to 30 minutes each.

This concept combines the possibility of powering heat generating devices for cooking and cost-efficiency via the shared capacity approach. 200 W of base load capacity is available at each household throughout the day, while in certain periods a total power of 900 W is available per household (for schedule example 1). Thus, for three households a total installed capacity of 1 300 W is needed. If every household was supplied with a constant available power of 900 W individually, a total capacity of 2 700 W would be necessary. Therefore, if the usability of the shared capacity concept was assumed equal, the required installed capacity would be reduced by more than 50%. This results in significantly lower specific costs, or more electrified households with the same investment amount.

One option of generating and providing those 1 300 W would be the low-tech water wheel, developed at the Chair of Renewable and Sustainable Energy Systems of the Technical University of Munich (see figure 5-3). All the water wheel's components can be produced and assembled locally except for the generator with gearbox. However, Prof. Dr. Maskey developed a *Low-Speed Direct-Drive Axial-Flux Permanent Magnet Alternator* fully manufacturable in Nepal that may be operable with the water wheel (Maskey, et al. 2006). By combining the supply concept explained above with the low-tech water wheel design, a wide range of today's problems of rural Nepal can be approached. First, electricity can be produced by renewable energy in a cost-efficient way. Thus, power scarcity and the dependency on energy imports from India can be reduced and the nation's economy can be boosted by a reliable and modern energy supply. Second, rural poverty and a reduction of the excessive fuelwood use can be addressed to enter the path of ecological development.

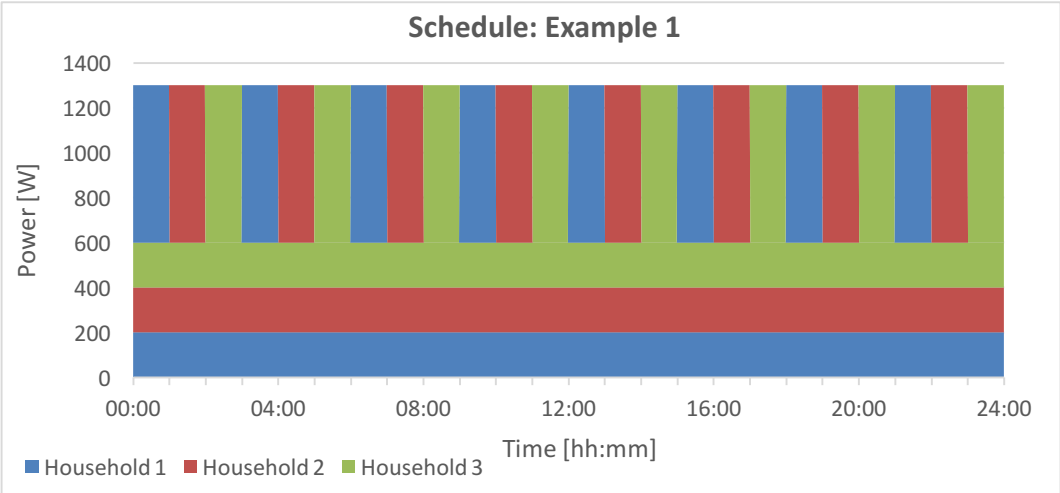


Figure 5-1: Supply concept – exemplary schedule 1 [Own Illustration]

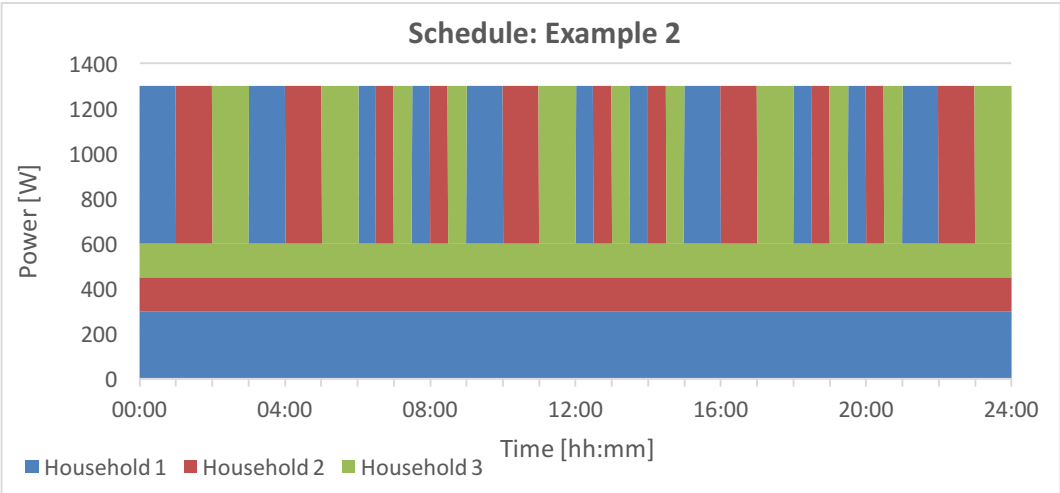


Figure 5-2: Supply concept – exemplary schedule 2 [Own Illustration]



Figure 5-3: Prototype of a low-tech water wheel set up in the Solo Khumbu area in Nepal [Stephan Baur]

6 Critical Reflection

In this chapter, the methods applied and their performance during fieldwork is reflected critically. To measure the electricity demand of individuals and buildings in remote areas of Nepal, simple equipment was used. The requirements regarding measurement accuracy were moderate, as data was collected for rather application-oriented research.

6.1 Methodology

Load Measurements

Measuring the electricity consumption for a period of only 24 hours represents just a snapshot of the test subjects' consumption pattern. For a better insight and more solid conclusions, a longer measurement period and measurements during different seasons of the year would be necessary. This was not possible in the present study due to time limitations for fieldwork.

The equipment used was rather simple calibrated according to the factory standard only. The basis accuracies of the equipment used are $\pm 0.9\%$ (digital multimeter) and $\pm 2.5\%$ (current clamp adapter). It can be assumed that its measuring accuracy was limited and an impact on measurement results is imaginable.

For calculating load profiles, voltage and current were measured simultaneously. This was done with two separate measurement setups consisting of digital multimeters and laptops, by which the equivalent value was logged every 60 seconds. An influence on the measurement results by discretisation on the one hand and by a possible asynchrony of separately logged voltage and current on the other hand is possible.

Due to the faultiness of one multimeter, measuring voltage and current simultaneously for load measurements at household and school test subjects was not possible. It was decided to record one load profile at S1 and use it for calculating the load profiles of the household and school test subjects, as they were all supplied by the same hydroelectric station. As observed during the measurements in Chame, voltage profiles at individuals connected to the same off-grid hydroelectric plant do not differ significantly during a small time frame of a few consecutive days (see Appendix R). Furthermore, accordance of load measurements with main box meter readings at the equivalent test subjects was still high. Nevertheless, an impact on measurement results due to the above described circumstances seems imaginable.

During the preliminary tests, the data logging software malfunctioned several times. This incidence is described in Appendix S. However, malfunction did not occur during data collection afield.

6.2 Performance of the Study

Load Measurements

Especially when performing measurements at public test subjects, such as lodges and schools, a safe spot for placing the equipment had to be found. This resulted in different wiring lengths of the current clamp adapter and the multimeter. Although, no influence on measurement data could be found during preliminary tests, it cannot be excluded that the different cable lengths had an influence on the measurement results.

A possible disruptive element, a so-called interfering artefact, when conducting the measurements may be represented by the investigator. Several direct or indirect influences on the measurement results are possible. On the one hand, measurement data was influenced by power consumption of the investigator and instrumentation. Impacts were avoided if possible, for example by charging the investigator's mobile phone with power banks or by using a torch instead of switching on light bulbs throughout the night. The laptops' electricity consumption was determined in a preliminary test, and the effect was eliminated during data processing as described in chapter 3. On the other hand, the investigators presence during the measurements while performing observations may have had an influence on the test subjects' behaviour of device use and, therefore, electricity consumption. Thus, it cannot be ruled out that the investigator sometimes directly or indirectly influenced the measurement results.

During the measurements at the test subjects connected to Sabje Hydropower Plant, Manang Hydropower Plant was under maintenance. The Sabje grid, therefore, was loaded exceptionally strong by the residents of Manang Village, as they couldn't use the Manang power connection. This circumstance may have had an impact on the measurements performed at household and school test subjects.

Survey and Observation

In general, surveying was done in English. However, some test subjects' knowledge of the English language ranked qualitatively at a level, where misunderstandings cannot be ruled out. For surveying H2, an individual of H1 helped as Nepali translator. When compared, the answers given during the interview by H1 and H2 show noticeable parallels. Therefore, an impact on the results arising from communication issues is imaginable.

6.3 Recommendations for Further Studies

As pointed out, load measurements for a period of only 24 hours merely deliver a snapshot of the test subjects' consumption pattern. When considering the available time for performing the measurements in the present study, repeated measurements to cover the weekly or seasonal fluctuation effects were not feasible. Consequently, it is recommended to take more time for future studies. In this way, repeated measurements and / or more test subjects can be managed.

The method for load measurements applied in this study combine the use of simple and cost-efficient equipment and satisfactory measurement data quality. It can, therefore, be

recommended for further related studies. However, taking only one laptop to the field and replacing additional laptops with small-sized single-board computers, such as the Raspberry Pi, would make the overall hardware setup more lightweight and handy. In this way, more backup equipment could be carried.

As one multimeter showed evidence of faultiness during fieldwork, only one working multimeter was left. Due to this fact, voltage and current could not be measured simultaneously for all household and school test subjects. Therefore, it is recommended to provide backup devices of essential equipment.

To avoid communication issues, a translator with good knowledge of both, English and Nepali is recommended. The translator should be independent and should not have any personal relations with the test subjects, to minimize artefacts.

7 Summary and Outlook

As the current literature is lacking of such data, the present study's objective was to assess the electricity demand in remote areas of Nepal based on electrical measurements. This was performed by using very basic and simple consumer equipment, namely a digital hand-held multimeter and an AC only current clamp adapter to measure the load at the test subjects' main box for a period of 24 hours each. With two measurement setups and laptops, current and voltage was logged simultaneously once per minute. Using this measurement data, load profiles were calculated afterwards. The test subjects were two households, three lodges and two schools in the study area of Manang District. A secondary aim of the present study was to assess, whether it was possible to gain measurement-based load profiles with such simple and affordable equipment.

In conclusion, it can be stated that the applied method for collecting load data delivers excellent results. It is simple, easy and safe to handle and, data quality is highly adequate for application-oriented purposes. Thus, the objectives of the present study have been achieved. The main difficulties during field work were the faultiness of one multimeter and occasionally language-related communication problems. In general, the approach and methodology of the present study is recommended for further research. Nevertheless, it is suggested to take an independent translator and additional backup equipment afield.

The collected measured data can be used for verifying simulation-based load profiles. The 24-hour load data gained during the present study only represents a snapshot of the user's consumption pattern. With Monte Carlo Simulation methods, load profiles can be adapted to changing and evolving circumstances and patterns, but data measured afield is essential to provide a solid foundation for those simulations. Therefore, this study contributes to a more consumer-oriented and valid way of designing off-grid energy systems. However, the measurements performed in the present study were locally and temporally strongly limited. To gain a solid overview of the detailed electricity demand of individuals residing in remote areas in Nepal based on load profiles, repeated measurements have to be performed in different areas in terms of touristic influence, climate and socio-economic factors. In this way, simulation-based data could be complemented even better.

Based on the analysis of each test subject's electricity and total energy consumption, general conclusions for practice were derived. As most of the test subjects only use high-power devices for a short total period during the day, a shared capacity supply concept was developed. Thereby, three households are provided with 200 W of base capacity each, and an additional peak capacity of 700 W is distributed and available at each household chronologically. In this way, the excessive fuelwood consumption could be reduced, by at least partly utilising electricity for generating heat for cooking appliances.

However, with an available maximum power of 900 W, only rather low-power water boiling jugs and rice cookers can be run. Most of the widely common appliances imported from China are inefficient and need more power than stated by the producer. This calls for developing and offering a combined and bundled solution of off-grid electricity supply and the devices to be run. However, for understanding that only low-power appliances would fit with the presented supply concept, awareness among society needs to be built. Thereby, education and schools play an essential role. The nation needs utilize its human

potential and own rich renewable energy sources. In this way, it will be highly capable of inherently solving the problematic energy situation and setting the foundations for a brighter economic future on an ecological path – “with their own hands and minds” (Maskey 2016).

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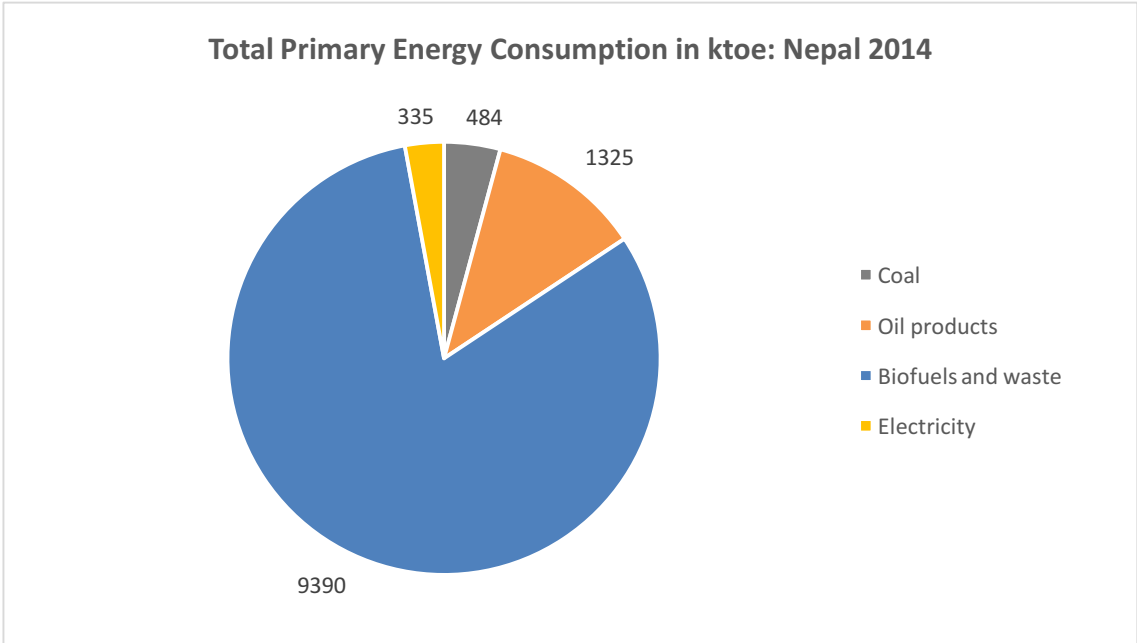
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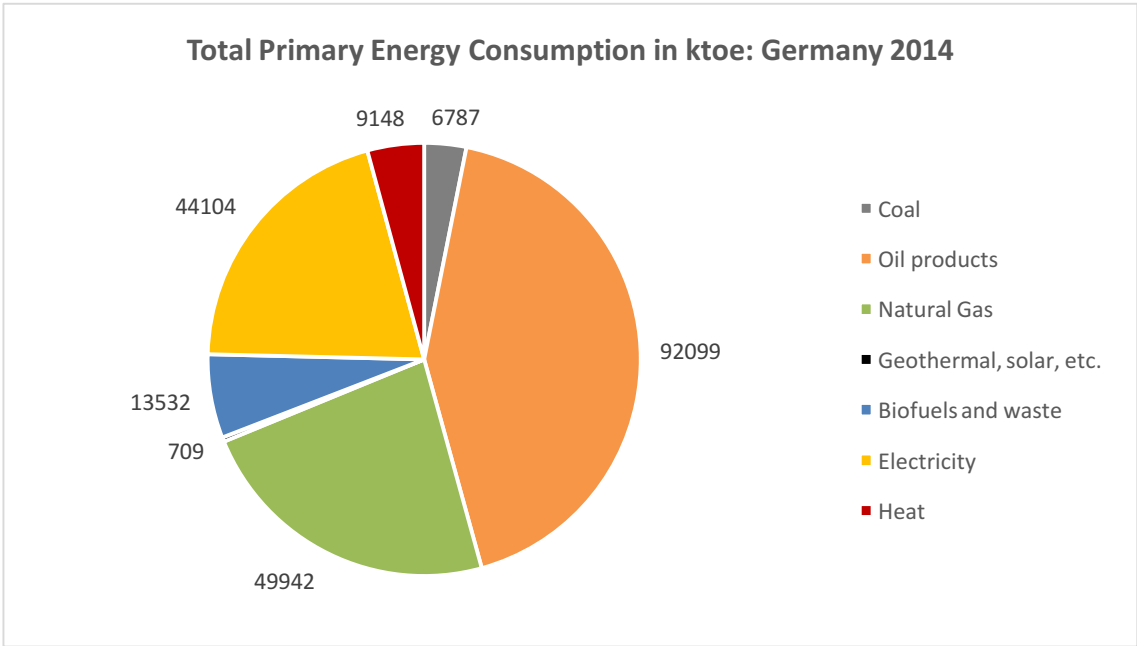
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Appendix

A) Total Primary Energy Consumption in Nepal Compared to Germany

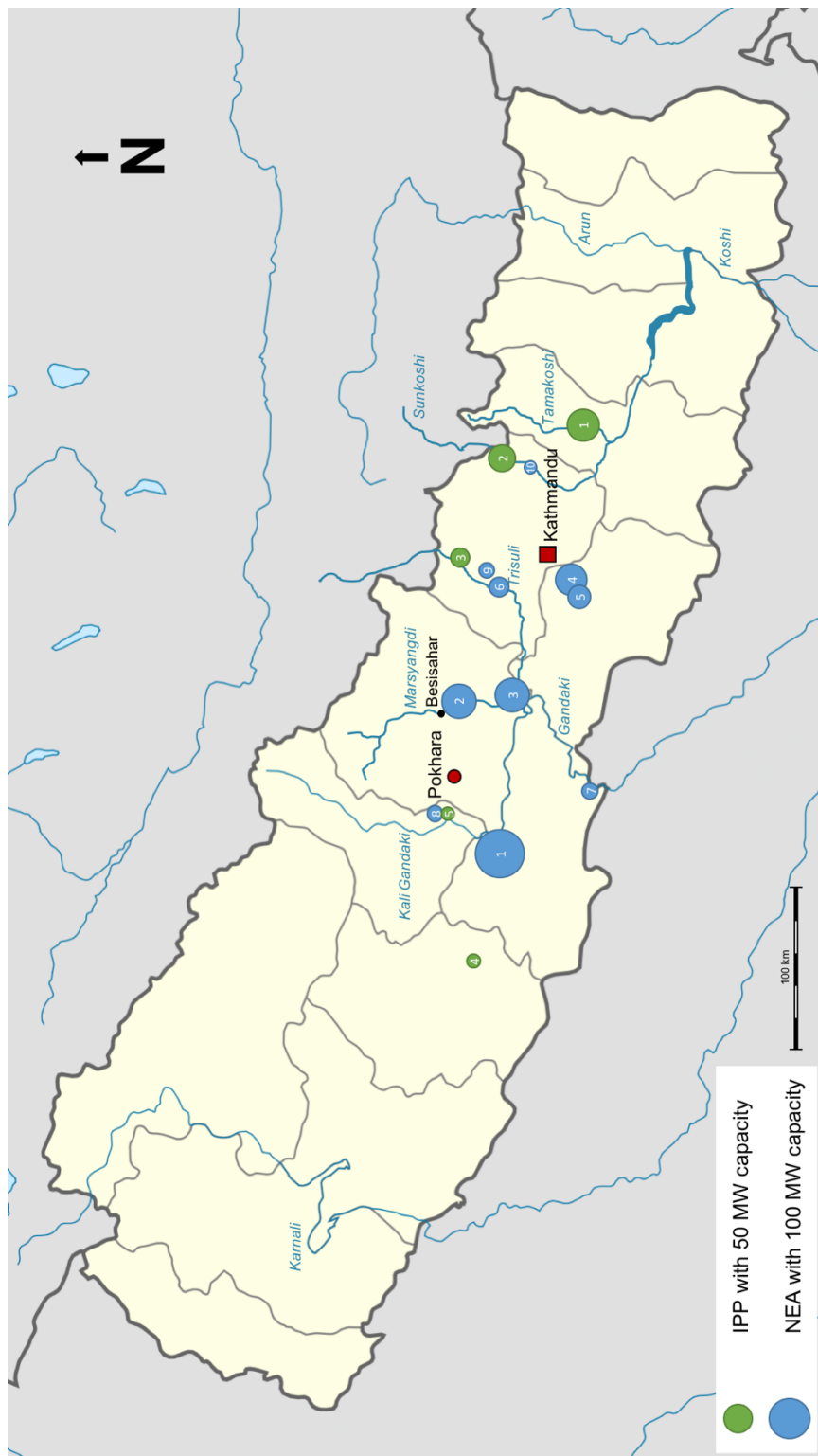


Total Primary Energy Consumption of Nepal for the year 2014 [Own Illustration; Data based on IAE (2014)]



Total Primary Energy Consumption of Germany for the year 2014 [Own Illustration; Data based on IAE (2014)]

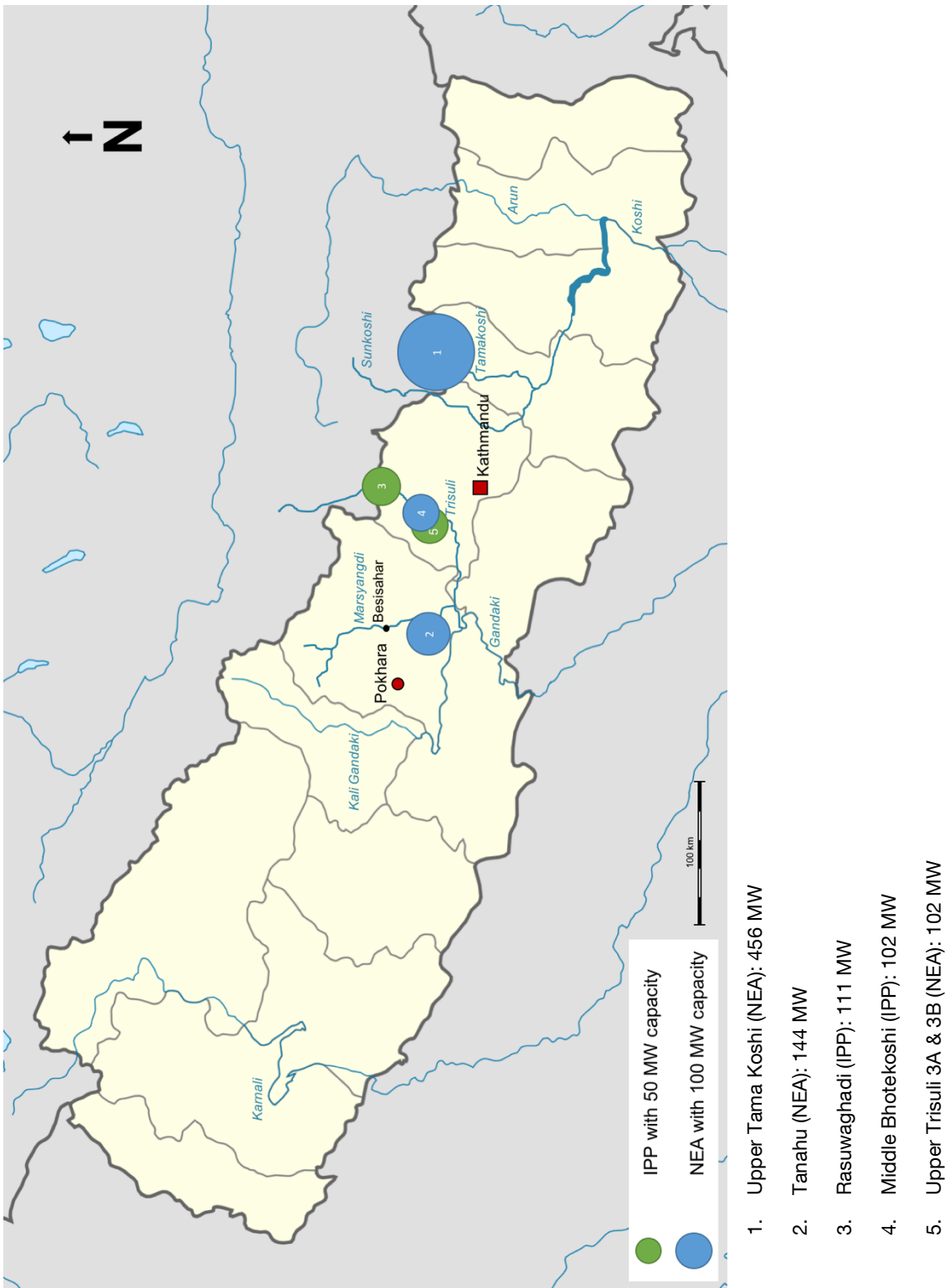
B) Nepal's Major Hydropower Plants in Operation



[Own Illustration]

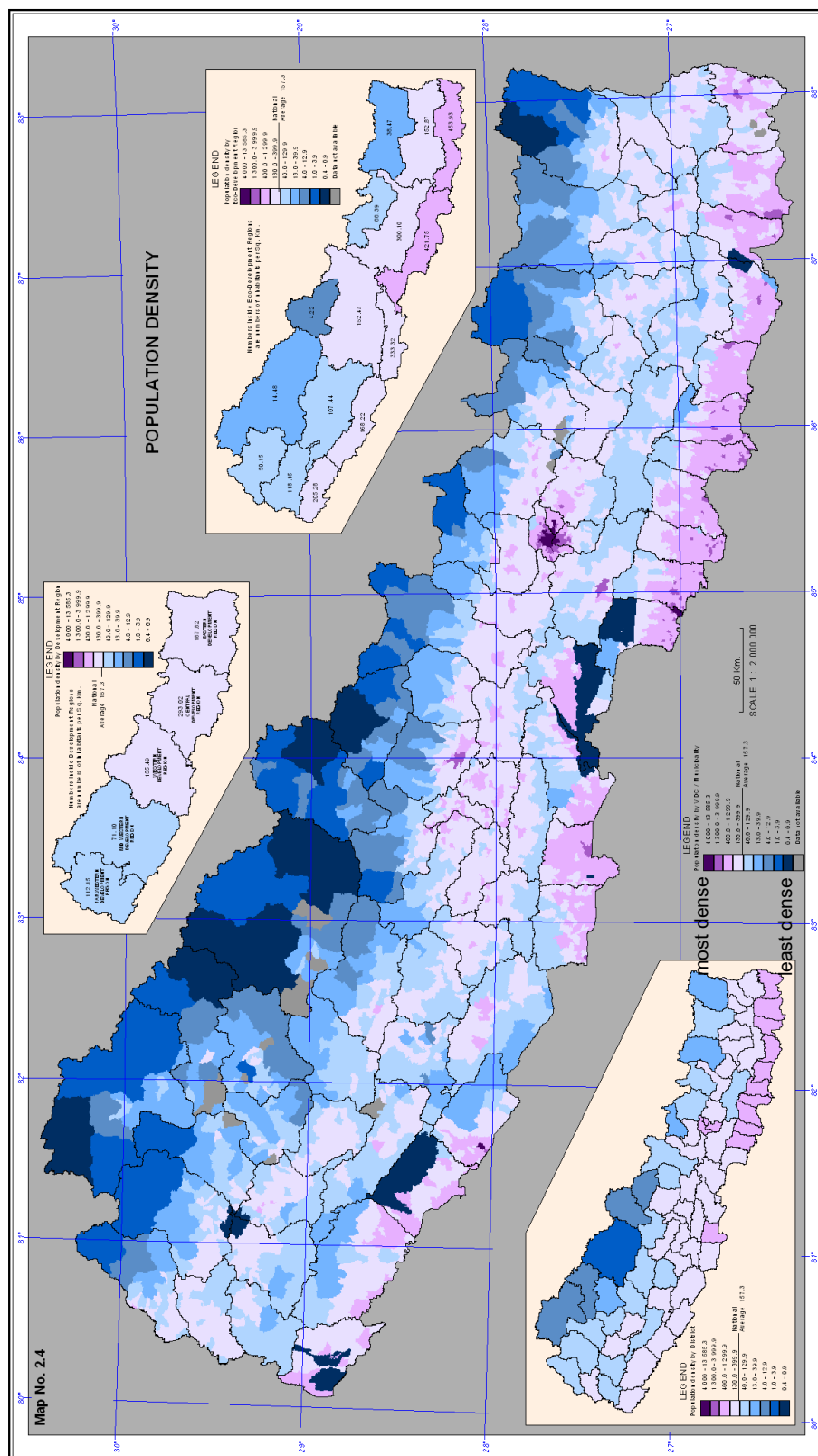
NEA-owned:		IPP:	
1. Kali Gandaki A: 144 MW	6. Trisuli: 24 MW	1. Khimti Khola: 60 MW	
2. Middle Marsyangdi: 70 MW	7. Gandaki: 15 MW	2. Bhotekoshi Khola: 45 MW	
3. Marsyangdi: 69 MW	8. Modi Khola: 14.8 MW	3. Chilime: 22 MW	
4. Kulekhani I: 60 MW	9. Devighat: 14.1 MW	4. Jhmruk Khola: 12 MW	
5. Kulekhani II: 32 MW	10. Sunkoshi: 10.05 MW	5. Lower Modi: 9.9 MW	

C) Nepal’s Five Major Hydropower Plants Under Construction



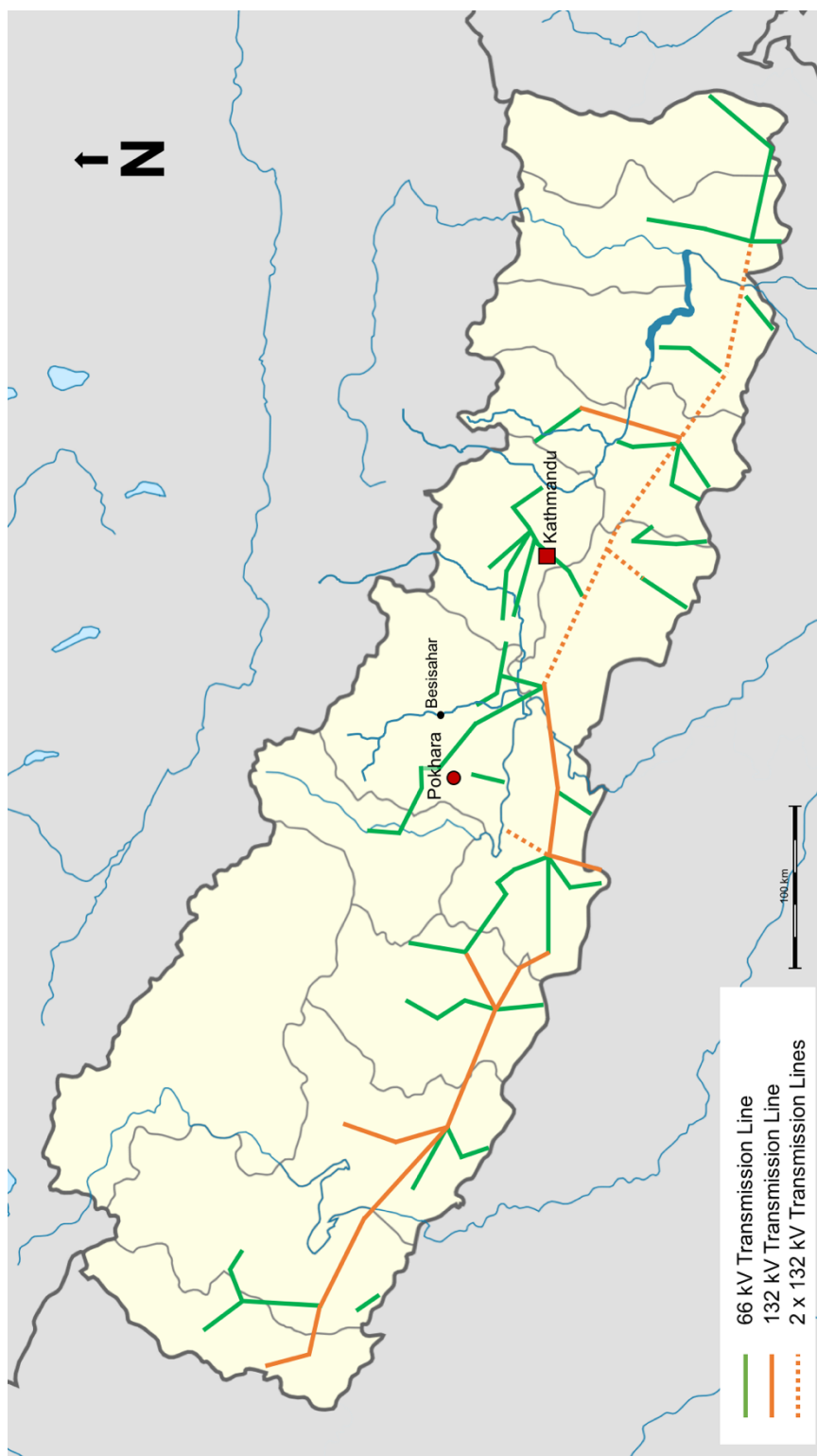
[Own Illustration]

D) Regional Population Density of Nepal



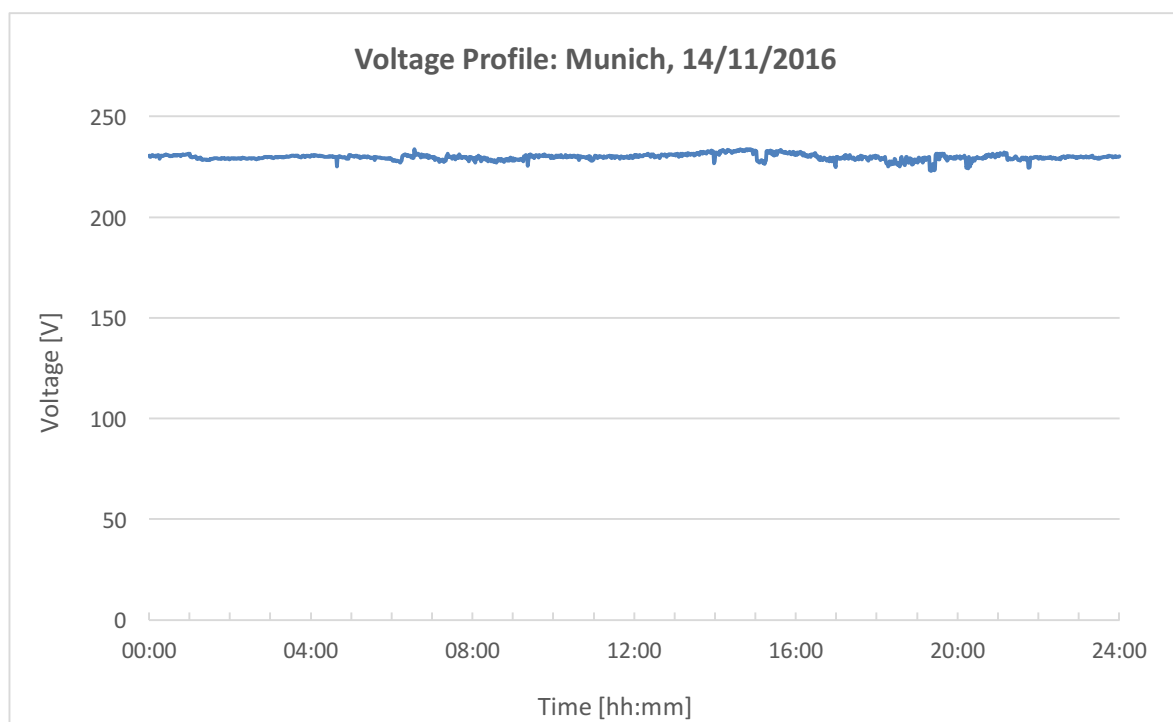
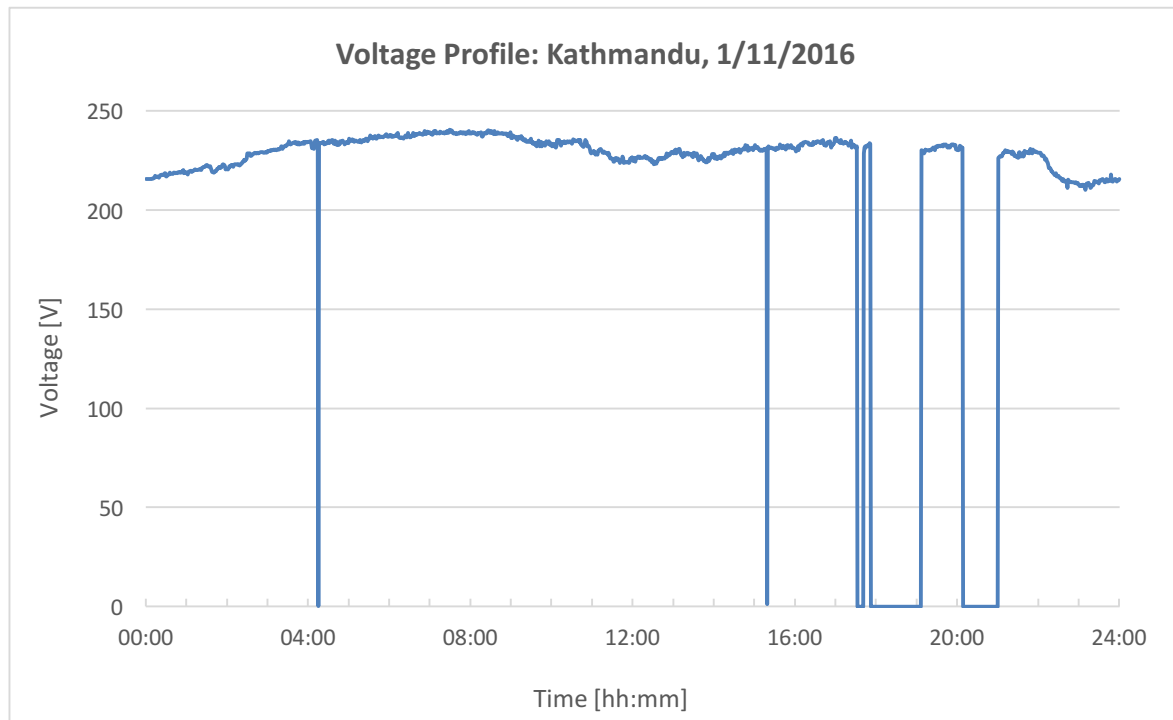
[http://cbs.gov.np/photo_gallery_photo_gallery_photo_gallery_population]

E) Nepal's National Grid



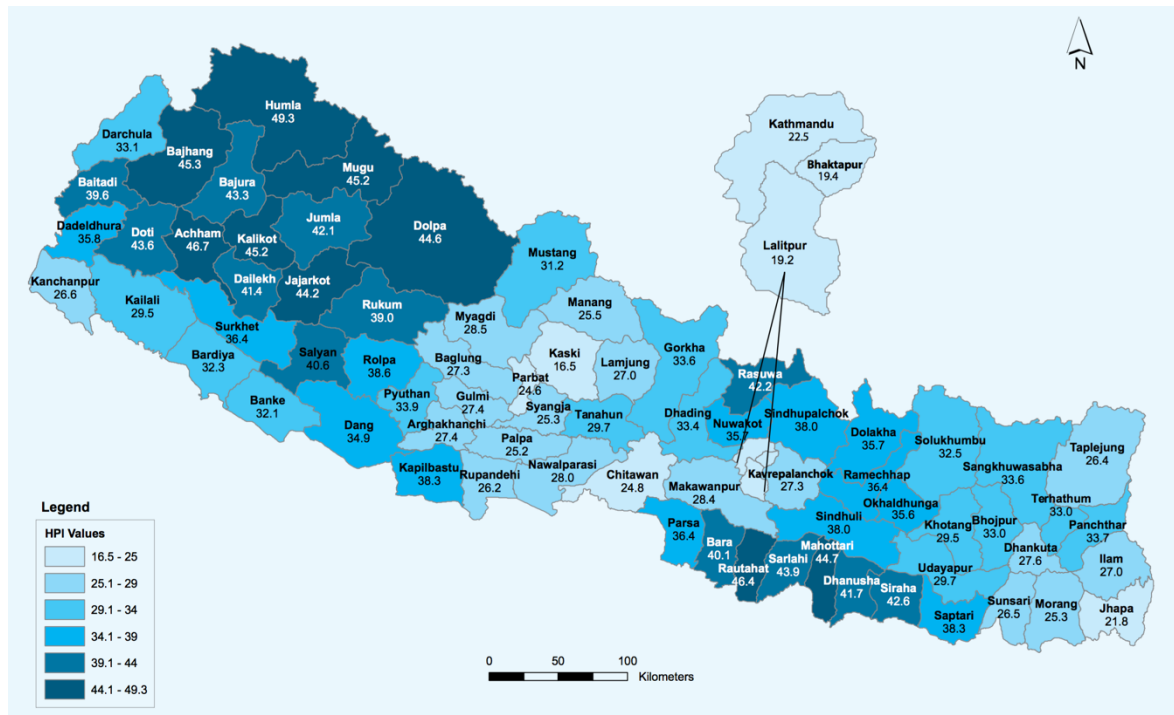
[Own Illustration; Data based on energydata.info]

F) Voltage Graphs of Kathmandu, Nepal and Munich, Germany



[Own Illustrations]

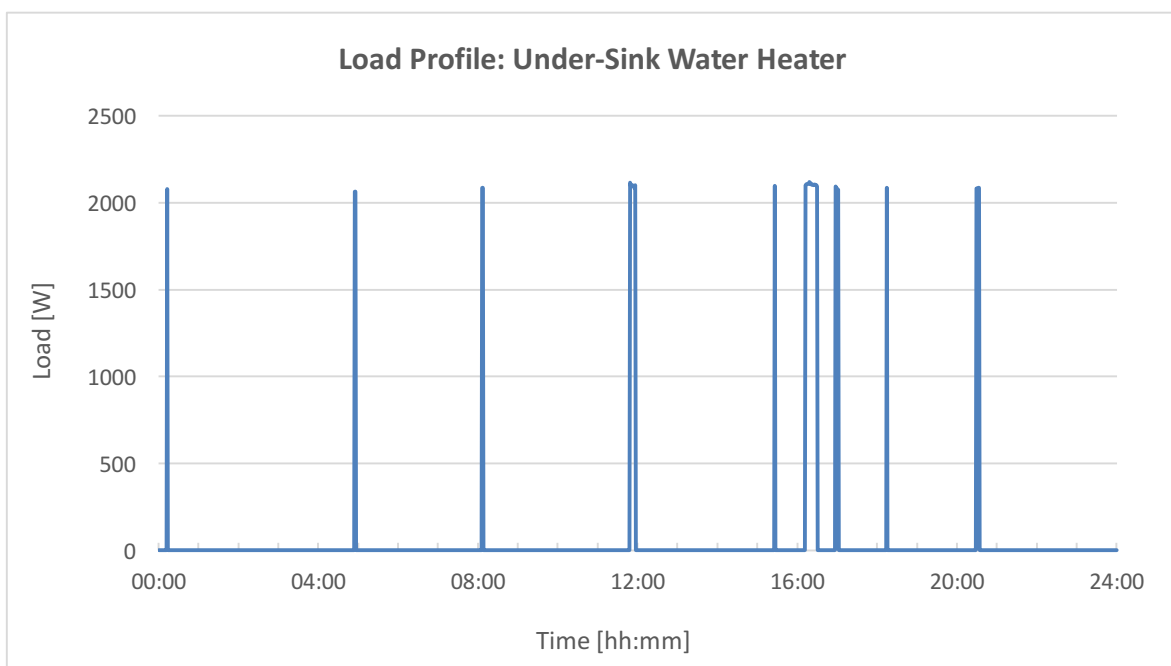
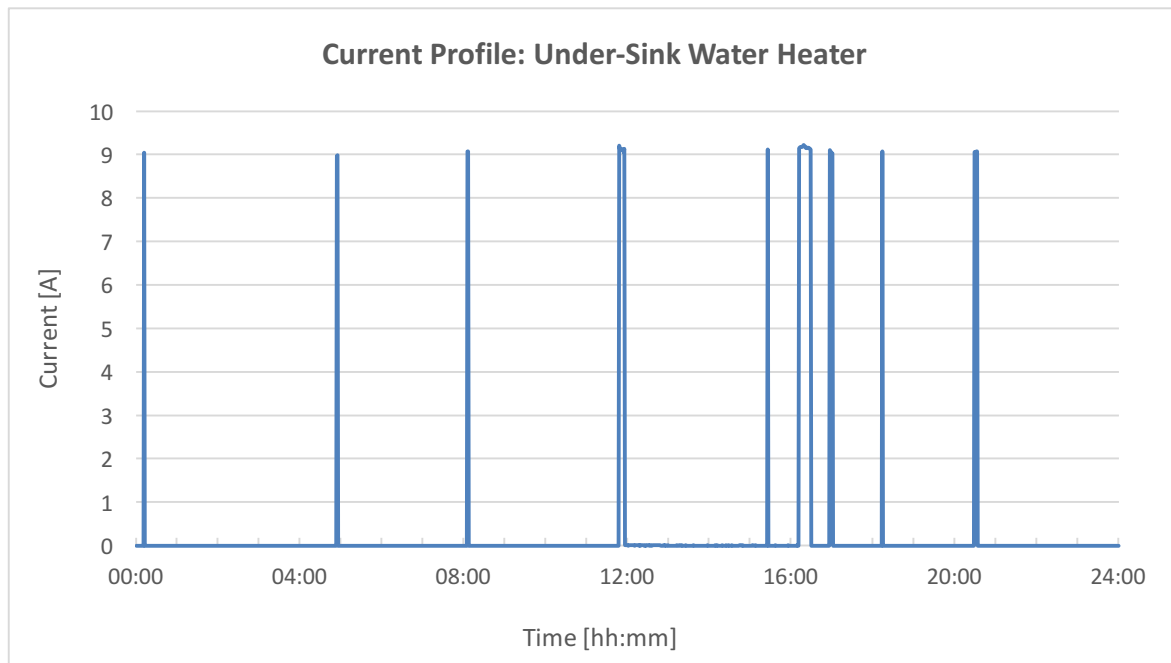
G) Human Poverty Index (HPI) Distribution in Nepal's 75 districts



[NPC 2014]

H) Current and Load Profile of an Under-sink Water Boiler Powered by the 230 V National Grid in Germany

The voltage was assumed constant (230 V), as voltage fluctuations in Germany (see Appendix F) are negligible for a wide range of applications.



[Own Illustration]

I) Full List of the Hardware

Main Hardware:

Type of Equipment	Model	Retail Price ¹	Amount
Digital hand-held multimeter	Voltcraft VC 820-1 CAT III	59.99€	2
AC current clamp adapter	Voltcraft VC-510 AC	29.99€	2
AC/DC current clamp	Voltcraft VC-521 CAT III	74.99€	1
Laptop	Lenovo ThinkPad X220	-	1
Laptop	MacBook Pro Early 2015	-	1
Infrared/USB cable	Voltcraft USB-Interface adapter	30.99€	1

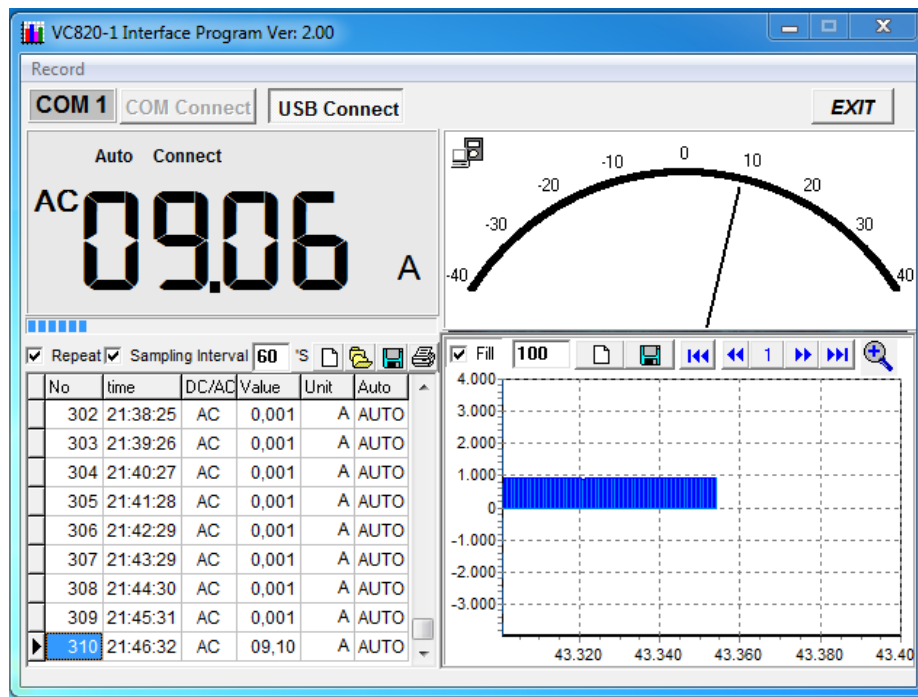
¹ Retail price refers to <http://www.conrad.de>

Auxiliary Hardware:

Equipment	Amount
Soldering iron with solder	1
Quick release luster terminals (3-way)	15
XT Power 15600 mAh 12 V power bank (for mobile devices & laptops)	2
Measuring lead	6
2 core cable 10 m	2
1 core cable 5 m	2
Cable stripper	1
Flat nose pliers	1
Victorinox multitool with a screwdriver bit set	1
Victorinox pocket knife	1
Screwdriver	2

Phase tester	1
Insulating tape	1
Duct tape	1
Shrinking tube with lighter	1
AAA battery	16
9 V battery	8
Spare fuse for multimeters	6
Tape measure 2 m	1
Banana plug	16
Type C plug (Nepal)	2
Type D plug (Nepal)	4
Type F plug (Germany)	3
Type F socket (Germany)	4
Type F power strip with type D plug	1
Nepali power socket	1

J) Interface of the Data Logging Software VC820 V2.00 with an Example of an Exported Excel Data Sheet

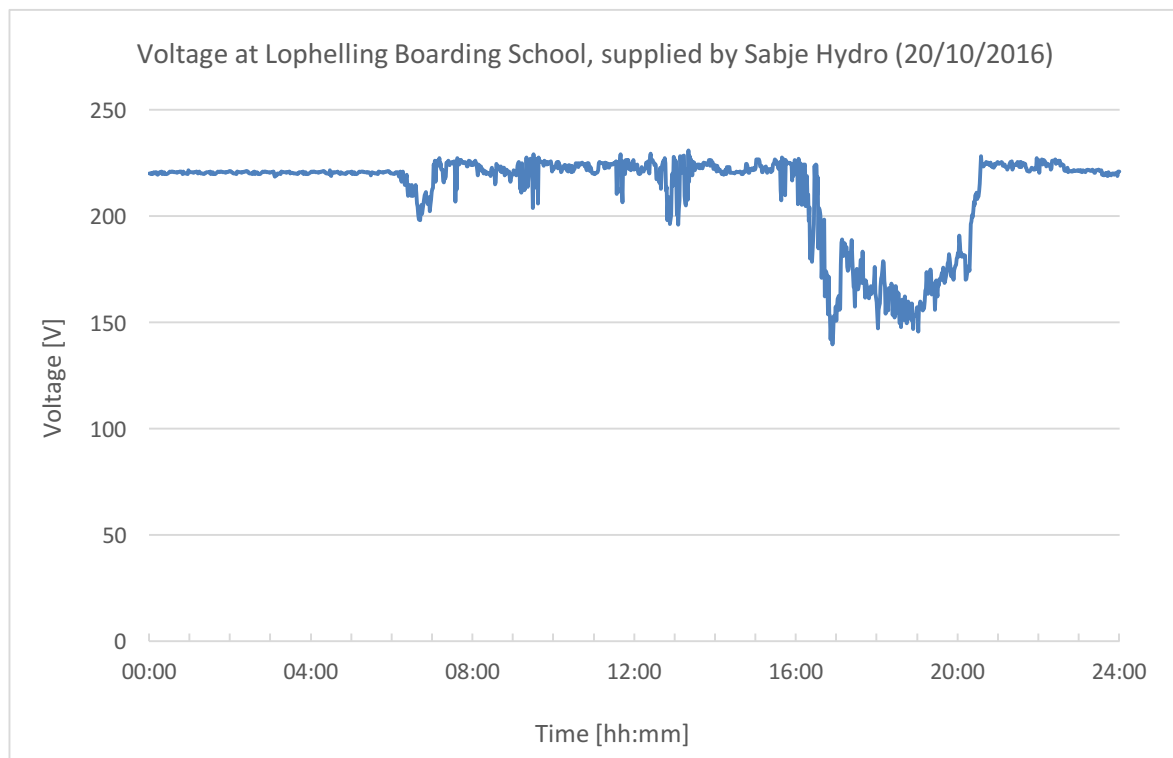
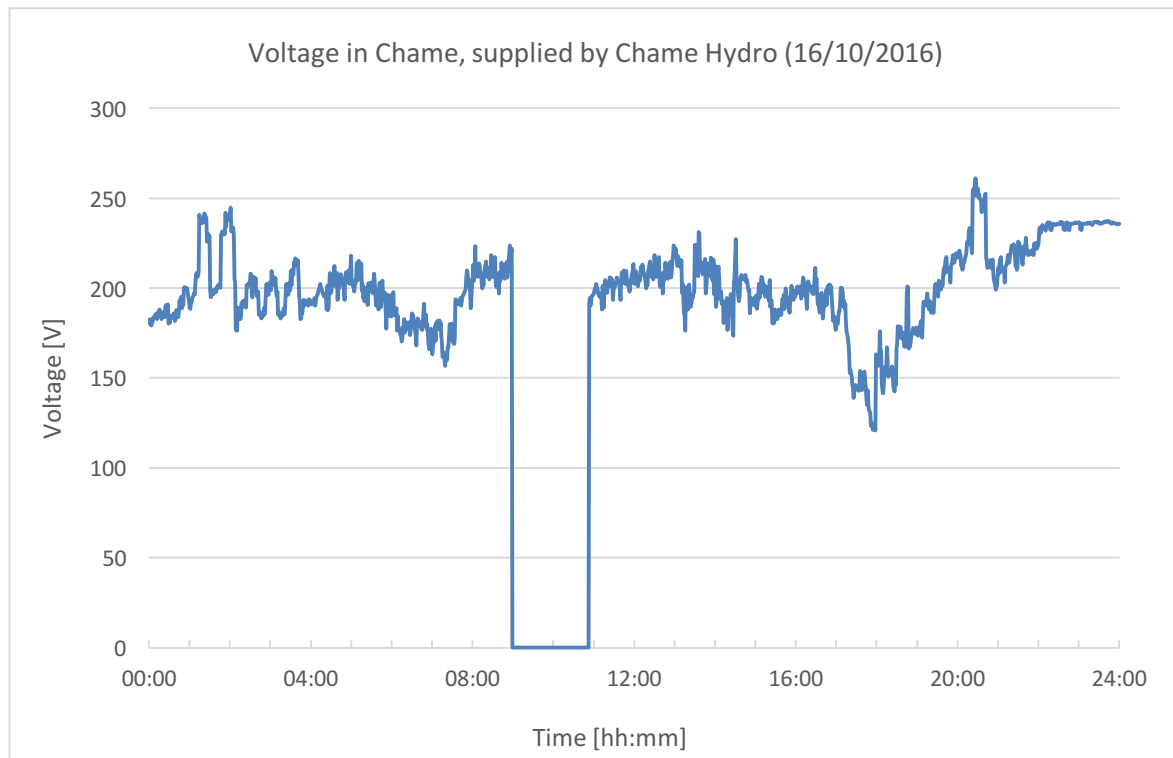


Data logging software interface [Own Illustration]

No	Time	DC/AC	Value	Unit	AUTO
1	06:27:58	AC	232,5	V	AUTO
2	06:28:58	AC	233,2	V	AUTO
3	06:29:58	AC	230	V	AUTO
4	06:30:58	AC	227,3	V	AUTO
5	06:31:58	AC	236,7	V	AUTO
6	06:32:58	AC	236,8	V	AUTO
7	06:33:58	AC	234,3	V	AUTO
8	06:34:58	AC	237,6	V	AUTO
9	06:35:58	AC	237,5	V	AUTO
10	06:36:58	AC	236,3	V	AUTO
11	06:37:58	AC	236,2	V	AUTO
12	06:38:58	AC	234,6	V	AUTO
13	06:39:58	AC	232,6	V	AUTO
14	06:40:58	AC	233,6	V	AUTO

Exported Excel data sheet [Own Illustration]

K) Voltage Curves of Chame and Sabje Hydro



[Own Illustrations]

L) Questionnaire

1

SURVEY BACKGROUND

RESPONDENT NO: ____ / ____ / ____
Location: _____

Date: _____
Time: _____

Research Objective:

Collect Information and understanding of the present energy demand, such as electricity, heating and cooling, of households, lodges, healthcare facilities and schools in remote areas in Nepal. Find out, how the energy demand could change during the next years, to have reliable and forward-looking data to be able to adequately design off-grid energy systems.

Target Audience:

Residents or managers of households, lodges, healthcare facilities and schools from villages along the Marsyangdi River from Besisahar to Manang, both with or without access to electricity.

SCREENER

Hello, my name is Johannes Eisner and I am a master student at the Technical University of Munich in Germany. I am currently doing a survey about the energy demand of households and schools in Nepal. Would you be willing to answer a few questions? It would no longer take than 30 minutes. All answers will be kept confidentially and will be used in aggregated form.

Before we proceed with questions regarding your energy consumption, I would like to ask you a few questions about the characteristics of your "XXX"

- ☐ Household
- ☐ Lodge
- ☐ Healthcare Facility
- ☐ School

Declaration of consent:

I, _____, hereby confirm, that the data collected with this questionnaire can be published in aggregated form. All personal details will be kept confidentially. Pictures taken of my ground or my belongings can also be published. If I don't like a picture to be published, I will tell the interviewer to do so after looking through the pictures.

Date: _____

Signature: _____

Survey about the Energy Demand of Domestic Households

DEMOGRAPHIC QUESTIONS

D1 What is the Sex (m/f) and Age of the household head/-s?

First household head: Sex: _____ Age: _____

If there is a second household head:

Second household head: Sex: _____ Age: _____

D2 In total, how many adults and kids live in the household?

Number of adults: _____ Number of kids: _____

D3 Income of the family

Important: Do the individuals have several jobs? Is the salary constant over the year or are there seasonal differences? Please specify!

Example:

Earning family member: Father Profession: Teacher, Farmer

Salary: As a teacher: 5000 Rupees per month constantly. As a farmer: 4000 Rupees in total for the period of May-September

First earning family member: _____ Profession: _____
Salary: _____

Second earning family member: _____ Profession: _____
Salary: _____

Third earning family member: _____ Profession: _____
Salary: _____

Space for indirect question:

D4 How much living space [m²] does the household have?

_____ m²

3

Survey about the Energy Demand of Lodges

DEMOGRAPHIC QUESTIONS

D1 What is the Sex (m/f) and Age of the head of the lodge?

Head of the lodge: Sex: _____ Age: _____

D2 In total, how many adults and kids live in the household belonging to the lodge?

Number of adults: _____ Number of kids: _____

D3 In total, how many rooms and beds does the lodge have?

Number of rooms: _____ Number of beds: _____

4

Survey about the Energy Demand of Schools

DEMOGRAPHIC QUESTIONS

D1 What is the Sex (m/f) and Age of the headmaster?

Headmaster: Sex: _____ Age: _____

D2 In total, how many students, teachers and staff members live at school?

Number of students: _____ Number of teachers: _____

Number of staff members: _____

Survey about the Energy Demand of Healthcare Facilities

DEMOGRAPHIC QUESTIONS

D1 What is your Sex (m/f) and Age?

Respondent: Sex: _____ Age: _____

D2 In total, how many adults and kids live at the healthcare facility?

Number of adults: _____ Number of kids: _____

D3 How much living space [m^2] does the healthcare facility have? _____ m^2

6

POWER CONSUMPTION

P1 Do you use any electricity in/at XXX?☐ YES☐ NO*If NO, only ask P9, P10, P12, P13, P14 & P15***P2 Where do you get your electricity from? (several answers possible)**☐ Central Power Grid (NEA)☐ Local Power Grid

Location of the Power Plant: _____

☐ Diesel Genset☐ Renewable Energy Technology: _____☐ _____ Location of the Power Plant: _____**P3 On average, what is the amount of hours of load shedding per day?**

_____ hours

P4 Are there seasonal differences with load shedding? If yes, please specify the differences?☐ YES, _____
_____☐ NO**P5 How does load shedding affect your everyday life (and business)?**_____

_____**P6 Did the problem of load shedding change over the last years?**☐ More load shedding☐ Less load shedding☐ No Change**P7 What kind of electricity tariff do you have?**☐ _____ NPR / kWh☐ _____ NPR / _____ W (Flatrate)**P8 How much money [NPR] do you spend on electricity per month? Please report if you spend the money on electricity itself or for example on diesel for your Diesel Genset.**

_____ NPR per month, for _____

7

P9 Do you consider using any off-grid electricity source, other than the electricity source/-s currently in use (if so)? If yes, please specify.

☐ YES, _____ ☐ NO

If YES, why so?

P10 If you had reliable electricity, what changes would that bring to your life and business?

P11 What electric devices do you have and use? (several answers possible)

☐ Refrigerator with (☐) /without (☐) Freezer Compartment Power: _____ W

Do you use this device in every season of the year and constantly during the day? If No, please specify, when the device is in use!

☐ YES ☐ NO, _____

Notes: (e.g. measured power consumption)

☐ Freezer Power: _____ W

Do you use this device in every season of the year? If No, please specify, when the device is in use!

☐ YES ☐ NO, _____

Notes: (e.g. measured power consumption)

☐ Rice Cooker Power: _____ W

How often do you use this device?

☐ Daily ☐ Several times per week ☐ Once a week or less

For how much time do you use this device per day when in use?

☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hours

Notes:

8

☐ Light Bulbs Quantity: _____ Main type of bulbs: _____

When do you use this device?

Notes:

☐ Washing Machine Power: _____ W

How often do you use this device?

☐ Daily ☐ Several times per week ☐ Unregularly

Do you use this device in every season of the year? If No, please specify, when the device is in use!

☐ YES ☐ NO, _____

For how much time do you use this device per day when in use?

☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hours

Notes:

☐ Television with ... Power: _____ W

☐ Receiver Power: _____ W

☐ DVD Player Power: _____ W

How often do you use this device?

☐ Daily ☐ Several times per week ☐ Unregularly

For how much time do you use this device per day when in use?

☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hours

Notes (e.g. measured power consumption):

☐ Personal Computer Power: _____ W

How often do you use this device?

☐ Daily ☐ Several times per week ☐ Unregularly

For how much time do you use this device per day when in use?

☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hours

Notes (e.g. measured power consumption):

9

☐ Radio

Power: _____ W

How often do you use this device?☐ Daily ☐ Several times per week ☐ Unregularly**For how much time do you use this device per day when in use?**☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hoursNotes (e.g. measured power consumption):

_____☐ Mobile Phone Quantity: _____**How often do you charge this device?**☐ Daily ☐ Several times per week ☐ Once a week or less**For how much time do you use this device per day when in use?**☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hoursNotes (e.g. measured power consumption):

_____☐ Water Boiling Jug

Power: _____ W

How often do you use this device?☐ Daily ☐ Several times per week ☐ Unregularly**For how much time do you use this device per day when in use?**☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hoursNotes (e.g. measured power consumption):

_____☐ Blender

Power: _____ W

How often do you use this device?☐ Daily ☐ Several times per week ☐ Unregularly**For how much time do you use this device per day when in use?**☐ 0-1 hours ☐ 1-3 hours ☐ 3-6 hours ☐ More than 6 hoursNotes (e.g. measured power consumption):

10

P12 What at the present time in/at XXX non-existing electric devices would you like to use in the future? Why don't you have these devices in/at XXX yet? (several answers possible)

- ☐ Device 1: _____
- ☐ Can't afford the device
 - ☐ Don't have enough electricity for the device
 - ☐ _____
- ☐ Device 2: _____
- ☐ Can't afford the device
 - ☐ Don't have enough electricity for the device
 - ☐ _____
- ☐ Device 3: _____
- ☐ Can't afford the device
 - ☐ Don't have enough electricity for the device
 - ☐ _____

Note: Possible devices: Television, Mobile Phone, Radio, Washing machine, _____

P13 Put the mentioned devices of question P12 in order of desire!

1. _____
2. _____
3. _____

P14 What lighting method/-s do you use? (several answers possible)

Electricity / Light Bulbs

- ☐ Candles
- ☐ Kerosene Lamps
- ☐ Emergency light (Torch)
- ☐ _____

P15 What changes in general or other changes than mentioned before regarding electricity or electronic devices would you wish for XXX?

11

HEATING / COOLING

E1 Do you ... in/at XXX? (several answers possible)

- ☐ ... have a water heating device ...
☐ ... use a space heating method ...
☐ ... have a space cooling device ...
☐ ... have a food cooling device ...

E2 What space heating method do you use? (several answers possible)

- ☐ Wood / open fire
☐ Smokeless metal stove of the following kind: _____
☐ Improved cooking stove of the following kind: _____
☐ LPG Gas with the following device: _____
☐ Electric heater
☐ _____

Usage of space heating method:

E3 Could you image switching to an electric space heating method?

- ☐ YES, _____
☐ NO, _____

E4 How much of the space [m²] is heated?_____ m²**Measurements:**

Ceiling height: _____ m
 Insulation classification: _____
 Outside temperature: _____ °C
 Inside temperature: _____ °C

E5 What cooking method do you use? (several answers possible)

- ☐ Open fire / Three stone cooking stove
☐ Improved cooking stove
☐ LPG Gas
☐ Electric stove
☐ Rice Cooker
☐ _____

12

Usage of cooking method:

E6 Could you image switching to an electric cooking method?

- ☐ YES,

- ☐ NO,

E7 What water heating method do you use? (several answers possible)

- ☐ Same as cooking method
- ☐ Gas driven geyser
- ☐ Electricity driven geyser
- ☐ Immersion coil
- ☐

Usage of water heating method:

E8 Could you image switching to an electric water heating method?

- ☐ YES,

- ☐ NO,

E9 How much of the following resources do you use?

<i>Resource</i>	<i>Quantity with Unit (e.g. [€/month])</i>	<i>Costs per kilo</i>	<i>Consumption per month</i>
Firewood			
LPG			
Electricity			
Kerosene			

E10 Would you consume more resources if they were cheaper?

- ☐ YES ☐ NO
- If NO, don't ask E8*

13

E11 Of which resource would you consume more, if it was cheaper? (several answers possible)

- ☐ Firewood
- ☐ LPG
- ☐ Electricity
- ☐ Kerosene
- ☐ _____

E12 Do you use any space cooling method? If yes, which one? (several answers possible)

- ☐ Electricity driven air conditioning ☐ None
- ☐ Fan
- ☐ _____

E13 Do you use any food cooling method? If yes, which one? (several answers possible)

- ☐ Refrigerator with Freezer Compartment ☐ None
- ☐ Refrigerator without Freezer Compartment
- ☐ Freezer
- ☐ Other: _____

E14 What at the present time in/at XXX non-existing heating or cooling devices would you like use in the future? Why don't you have these devices in/at XXX yet? (several answers possible)

- ☐ Device 1: _____
 - ☐ Can't afford the device
 - ☐ Don't have enough electricity for the device
 - ☐ _____
- ☐ Device 2: _____
 - ☐ Can't afford the device
 - ☐ Don't have enough electricity for the device
 - ☐ _____
- ☐ Device 3: _____
 - ☐ Can't afford the device
 - ☐ Don't have enough electricity for the device
 - ☐ _____

E15 Put the mentioned device of question E14 in order of desire!

1. _____
2. _____
3. _____

E16 What changes in general or other changes regarding heating and cooling solutions would you wish for XXX?

Notes:

[illegible]

M) Protocol of Expert Interviews

E1: Expert Interview: Prof. Dr.-Ing. Ramesh Kumar Maskey (Kathmandu University)

Basic Topic: Rural electrification in Nepal in general

Date: 12/10/2016

Location: Mr. Maskey's Home, Kathmandu

- Touristic remote areas in Nepal have similar consumption patterns
- NEA is providing only 125 W per customer in remote areas. This was upgraded from 100 W and will be upgraded in the future to 200 W
- Prof. Dr. Maskey's approach: Provide 700 W or 1 000 W for cooking as fuelwood consumption is around 85% of total primary energy consumption
- "You can live without lighting electricity, but you can't live without cooking energy"
- Nepal Blockade was a big problem because no LPG was available for cooking
- Nepal has to find ways to end the dependency on India
- Used for cooking currently: LPG (mostly cities), fuelwood (mostly rural)
- Problems with LPG: GHG-Emissions, High Expenses (especially during Nepal Blockade), Availability (Fuel Crisis → Dependency on India)
- Problems with Fuelwood: GHG-Emissions, black carbon aerosols cause glacier melting, deforestation

E2: Expert Interview: Dharma Raj Maharjan (Manager Hotel Shangri-La, Chame)

Basic Topic: Chame Hydro, Energy Efficient Devices

Date: 14/10/2016

Location: Hotel Shangri-La

- Load shedding is a big problem in Kathmandu, in Manang Valley it is not so much of a problem, but no load shedding at all would of course be better
- Chame Small Hydropower Station delivers 45 kW (River: Marda Khola)
- Generator comes from India and now is three years old.
- For 29 years, Chame Hydro was NEA-owned. Then, NEA handed it over to the community of Chame 8 years ago. NEA cared about Chame Hydro with two men being always present at the powerhouse. Now, the community does not care and is weak in this regards.
- Efficient and rather low-power devices are very expensive: Cheap and inefficient washing machine costs 13 000 NPR, while an efficient one with only 365 W (Brand: LG) costs around 85 000 NPR

-
- Mr. Maharjan is the only one who cares about Chame's Hydropower Plant. He is disappointed that the community does not care. The community should be involved more in the management and maintenance of the plant, so that some kind of consciousness evolves and people learn how to behave to deal with the power shortage situation
 - There always are two qualities of electric devices available in Nepal, namely Cheap Quality and Export Quality. Cheap Quality: Plate says 450 W, however, actual power is 1 000 W. Export Quality: Plate says 450 W, actual power is 450 W indeed, but export quality also is more expensive.
 - Many lodges have the desire to switch to electricity, because it is cheaper than LPG and more convenient than wood.
-

E3: Expert Interview: Chirring Lopsang Gurrang (Manager Hotel Tilicho)

Basic Topic: Manang and Sabje Hydro

Date: 23/10/2016

Location: Hotel Tilicho

Manang Hydro (MH):

- Before building Manang Hydro in 2012, Sabje Hydro (SH) was the only power supply for Manang
- Now: Manang is supplied by MH and SH
- Normally, Manang supplied around 100 kW, but it can supply up to 140 kW
- Peak demand: Off-Season around 30 kW; Season around 50 kW
- Manang Hydro only supplies Manang Village
- MH was paid and is run by Manang Community
- Voltage measurements not possible due to maintenance works
- Voltage very stable: 220 V
- Demand is rising quickly year by year, therefore costly connecting other villages to
- near future

Sabje Hydro (SH):

- SH used to supply Manang as only supply
- SH was constructed 27 years ago by NEA, but given to Private Hands 6-7 years ago for a total of 25 years
- Private Hands: 60% President of Youth Society Manang, 10% each Owners of Hotels Yak, Tilicho, Thorong La, 80)
- SH can deliver 70 kW
- Canal is not properly built
- Sabje Hydro supplies all Villages from Pisang to Khangsar: Pisang, Gyaru, Ngawal, Braga, Manang, Khangsar, Humde

E4: Expert Interview: Bir Bahadur Ghale (Employee at Hydro Energy Concern Pvt. Ltd.)

Basic Topic: Chame Hydro, Sabje Hydro, Manang Hydro

Date: 23/10/2016

Location: Manang Hydro Site

Manang Hydro (MH):

- MH was built in 2012
- Vertical Francis Turbine, Low Head (11 m), Flow Rate: 1 300 l/s
- Imported from China
- Initial Design: 100 kW, but can deliver more than 140 kW
- AEPC: 25 million rupees subsidy
- Demand increasing every year. Now at high season: more than 60 kW
- Manang Community paid for MH, therefore only Manang is supplied
- 140 kW Dump Load (Electrical Heating System)

Chame Hydro (CH):

- Supply: 45 – 50 kW
- Peak Demand: 75 kW
- Crossflow Turbine: Made in Nepal, but designed by Swiss company ENTEC (ENTEC T15)

Sabje Hydro (SH):

- Crossflow Turbine: Made in Nepal, but designed by Swiss company ENTEC (ENTEC T15)

Email (11/11/2016)

Project costs of Manang Hydro:

- Electro mechanical costs with underground distribution:	153 027.33 \$
- Civil construction costs without cement transportation:	135 298 55 \$
- Transportation costs of electro mechanical parts by helicopter:	46 654 67 \$
- Transportation of civil construction & other electro mechanical material:	60 651 08 \$

Total Costs: 395 631 63 \$

Note: Costs for MH calculated with exchange rates of the 11.11.16: 1 USD = 107.1704 NPR

E5: Expert Interview: Chatur Gurung (Supervisor of Sabje Hydro)

Basic Topic: Sabje Hydro

Date: 23/10/2016

Location: Sabje Hydro Site

Sabje Hydro:

- Was built in 1971
- Head height: almost 200 m
- 2 * 40 kW, but output is around 80 kW in summer time
- Now: Output is around 48 kW, because of less melt water
- Not planned to upgrade the Hydro

N) Typical Devices Used by Test Subjects



Improved cooking stove [Own Illustration]



Smokeless metal stove [Own Illustration]



LPG-stove with 4 burners [Own Illustration]

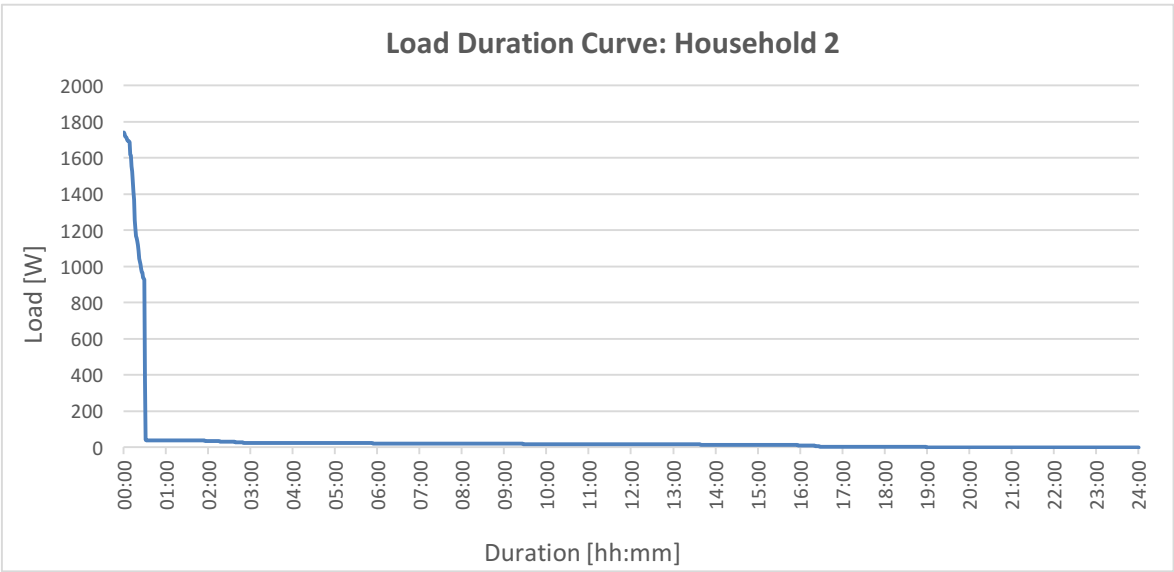
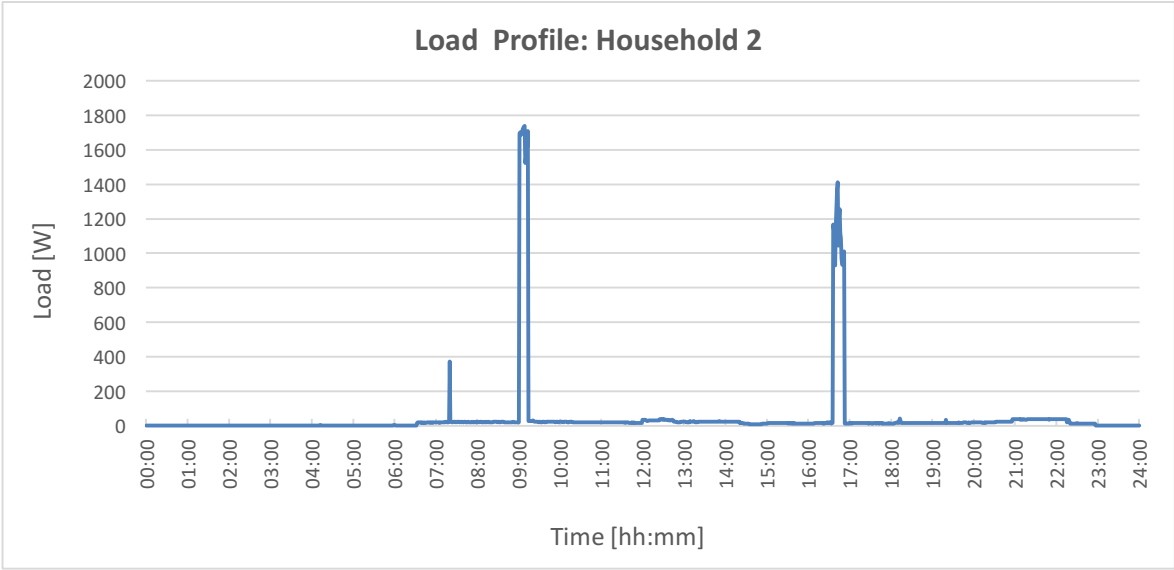
O) Faulty Multimeter

While performing voltage measurements at test subject H1, one multimeter malfunctioned. This became apparent when reading out the logged data. The figure below shows data logged by the malfunctioned multimeter compared to data logged by the faultless multimeter.

02:35:52	AC	202,9 V	AUTO	17:58:48	AC	227,5 V	AUTO
02:36:52	AC	202,1 AVHz	AUTO	17:59:48	AC	229,1 V	AUTO
02:37:52	NULL	41,99 Hz	AUTO	18:00:48	AC	229,1 V	AUTO
02:38:52	NULL	42,53 Hz	AUTO	18:01:48	AC	228,2 V	AUTO
02:39:52	NULL	14,46 Hz	AUTO	18:02:48	AC	228,3 V	AUTO
02:40:52	NULL	14,24 AVHz	AUTO	18:03:48	AC	229,2 V	AUTO
02:41:52	NULL	13,9 AVHz	AUTO	18:04:48	AC	231 V	AUTO
02:42:52	NULL	13,83 AVHz	AUTO	18:05:48	AC	233,3 V	AUTO
02:43:52	NULL	13,75 AVHz	AUTO	18:06:48	AC	230,3 V	AUTO
02:44:52	NULL	13,64 AVHz	AUTO	18:07:48	AC	232,7 V	AUTO
02:45:52	NULL	14,04 AVHz	AUTO	18:08:48	AC	220,8 V	AUTO
02:46:52	NULL	14,3 AVHz	AUTO	18:09:48	AC	209,2 V	AUTO
02:47:52	NULL	14,53 Hz	AUTO	18:10:48	AC	209,7 V	AUTO
02:48:52	NULL	17,35 Hz	AUTO	18:11:48	AC	211,6 V	AUTO
02:49:52	NULL	44,42 Hz	AUTO	18:12:48	AC	210,7 V	AUTO
02:50:52	NULL	17,02 Hz	AUTO	18:13:48	AC	216,1 V	AUTO
02:51:52	NULL	16,84 Hz	AUTO	18:14:48	AC	216,3 V	AUTO
02:52:52	NULL	16,57 Hz	AUTO	18:15:48	AC	218,8 V	AUTO
02:53:52	NULL	16,3 AVHz	AUTO	18:16:48	AC	227,5 V	AUTO
02:54:52	NULL	15,99 AVHz	AUTO	18:17:48	AC	230,1 V	AUTO
02:55:52	NULL	41,95 AVHz	AUTO	18:18:48	AC	230,1 V	AUTO
02:56:52	NULL	40,65 AVHz	AUTO	18:19:48	AC	230,3 V	AUTO
02:57:52	NULL	14,86 AVHz	AUTO	18:20:48	AC	229,3 V	AUTO
02:58:52	NULL	14,82 AVHz	AUTO	18:21:48	AC	230,2 V	AUTO
02:59:52	NULL	14,5 AVHz	AUTO	18:22:48	AC	231 V	AUTO
03:00:52	NULL	409,1 m%MF*AVH	AUTO	18:23:48	AC	230,8 V	AUTO
03:01:52	NULL	409,1 m%MF*AVH	AUTO	18:24:48	AC	230,9 V	AUTO
03:02:52	NULL	409,1 m%MF*AVH	AUTO	18:25:48	AC	231,4 V	AUTO

Data logged by the malfunctioned multimeter (left) compared to data logged by the faultless multimeter (right) [Own Illustration]

P) Full Scale of the Load Profile and Load Duration Curve of H2



[Own Illustrations]

Q) Comparison of the Reported Fuelwood Consumption of Household and Lodge Test Subjects and the Theoretical Heating Demand Calculated According to DIN V 4108-6:2003-06

When calculating the theoretical heating demand, the monthly balance method based on DIN V 4108-6 was used. Due to time constraints and some undeterminable data, it was not possible to collect all the data needed to calculate the heating demand *exactly* according to this norm. In addition, the norm originally applies for German housing and material standards. Therefore, it is important to point out at this juncture that the calculation of the theoretical heating demand in the following has to be considered rather qualitatively than quantitatively relevant. To provide as much transparency as possible the assumptions and simplifications made are presented in detail below.

Assumptions

- The room temperature should be a constant 20 °C for the whole year (Scenario A)
- The room temperature should be a constant 18°C for the first and last three months of the year (Scenario B)
- Outside temperature of test subjects L1, L2 and L3 (all in the town of Chame) are according the monthly average temperature of Odar, a town near Chame, as no temperature data of Chame was available. Climate data of Odar are based on (<https://en.climate-data.org/location/969034/>)
- Outside temperature of test subjects H1 and H2 (both in the town of Braga) are according the monthly average temperature of Braga based on (<https://en.climate-data.org/location/214972/>)
- As all windows were single-glazed, a U-value of $U_{windows} = 5.8 \frac{W}{m^2 K}$ was chosen for all windows
- All lodges were built with solid bricks. Therefore, a thermal conductivity of $\lambda_{walls,lodges} = 0.99 \frac{W}{m K}$ was chosen (based on DIN V 4108-4).
- The lodges' plaster material was assumed to be cement mortar (DIN V 4108-4: $\lambda_{plaster,lodges} = 1.4 \frac{W}{m K}$). Its thickness was assumed to be 1 cm.
- All households were built using a mixture of clay and interwoven branches. The thermal conductivity of the walls was assumed $\lambda_{walls,households} = 0.8 \frac{W}{m K}$ (based on the value for a clay and straw mixture derived from DIN V 4108-4)
- The inside and outside heat transfer coefficients were assumed as follows (according to a sample calculation in DIN V 4108-6):

$$\alpha_{inside} = 7.69 \frac{K m^2}{W}$$

$$\alpha_{outside} = 25 \frac{K m^2}{W}$$

Simplifications

- Heat losses through the roof and the floor were not considered
- Solar heat generation was not considered
- Ventilation heat losses were not considered
- Unheated walls of adjacent rooms were considered as exterior walls
- Heat losses through thermal bridges were not considered, as this only applies for buildings with good thermal insulation. Buildings in this study all had bad thermal insulation
- Heat gains through individuals present in the room or electrical devices, such as refrigerators are not considered, as those heat gains were assumed negligibly small compared to the heat losses

The dimensions of the rooms and walls were measured.

When considering the above-mentioned assumptions and simplifications, the annual heating demand Q_h according to the monthly balance method based on DIN V 4108-6 is calculated as follows:

$$Q_h = \sum_M Q_{h,M} \quad (\text{A.1})$$

$$Q_{h,M} = Q_{l,M} = 0,024 \cdot H (\theta_i - \theta_{e,M}) t_M \quad (\text{A.2})$$

$$H = H_T = \sum_i U_i A_i \quad (\text{A.3})$$

with:

Q_h Annual heating demand

$Q_{h,M}$ Monthly heating demand

$Q_{l,M}$ Monthly heat losses

0.024 in kWh = 1 Wd

H specific heat losses

θ_i Indoor temperature

$\theta_{e,M}$ Outdoor temperature

t_M Days of the respective month

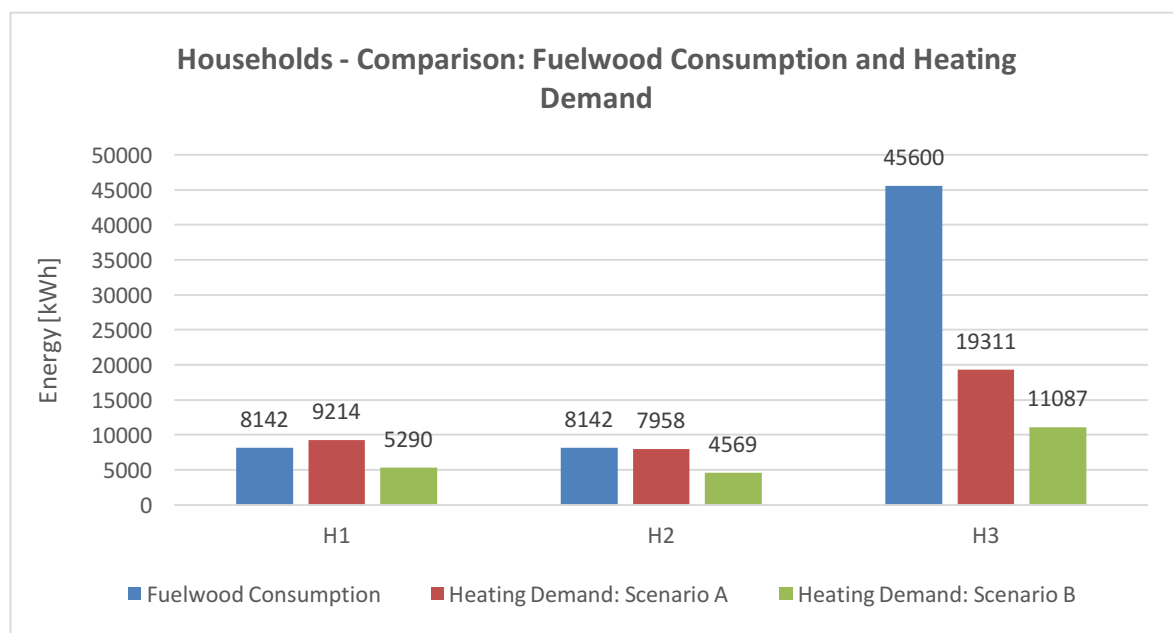
H_T Heat losses through heat transfer

Using formulas A.1 – A.3 the theoretical heating demand was calculated for all lodge (L1 – L3) and household (H1 – H3) test subjects for the rooms that were reported as heated. At household test subjects, only the living room is heated, at lodge test subjects only the dining room is heated. For school test subjects, no heating demand was calculated, as they reported not to heat any space. As Manang Healthcare Station did not heat any specific space, but only those rooms, where the staff stays at the respective time, no heating demand was calculated likewise.

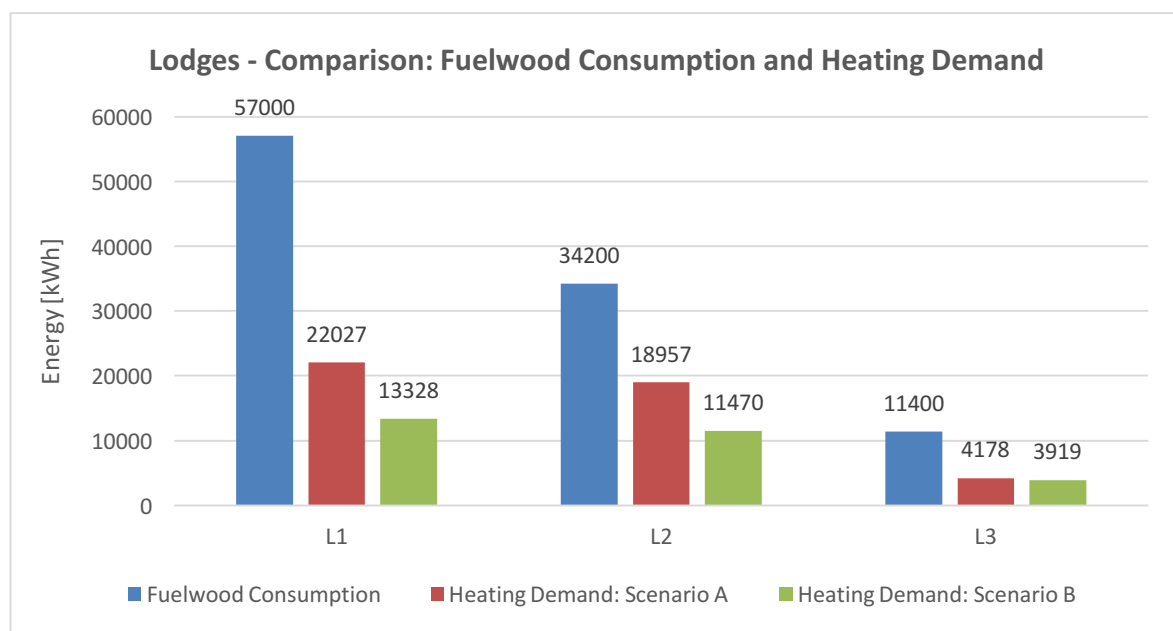
At household tests subjects, all the consumed fuelwood contributes to space heating, as it is combusted with the improved cooking stove in the living room only when heat is

needed for space heating. At lodge test subjects, most of the fuelwood contributes to space heating. Only a small amount is used for cooking purposes in another room than the heated one.

The results of the theoretically calculated heating demand in comparison with the respective fuelwood consumption for household and lodge test subjects is presented in the two figures below.



[Own Illustration]



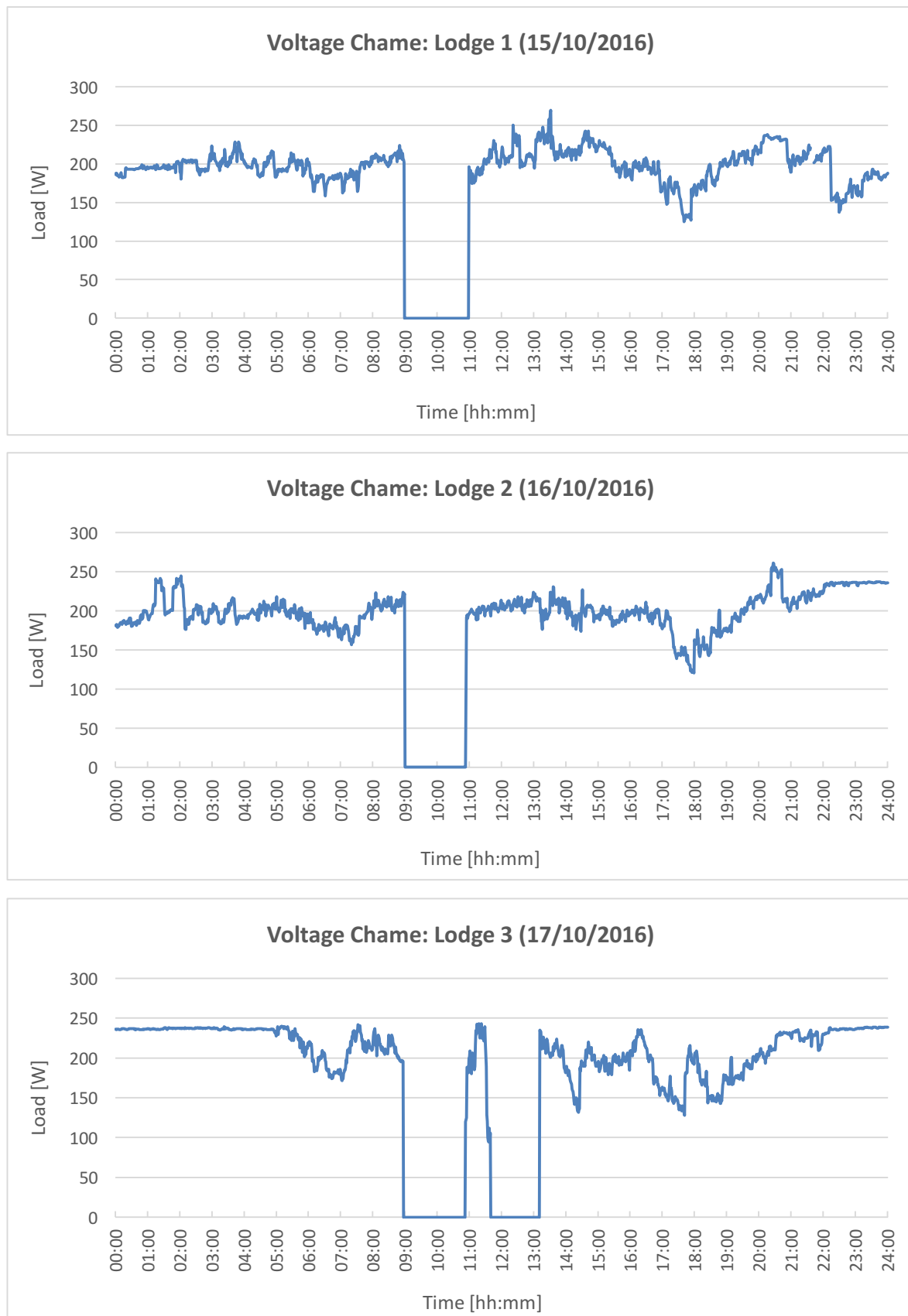
[Own Illustration]

As mentioned above, the results can be estimated to be rather qualitatively applicable due to several assumptions and simplifications. As throughout all test subjects of one kind the

same simplifications and assumptions were applied, the results can be used for relative comparisons among each other.

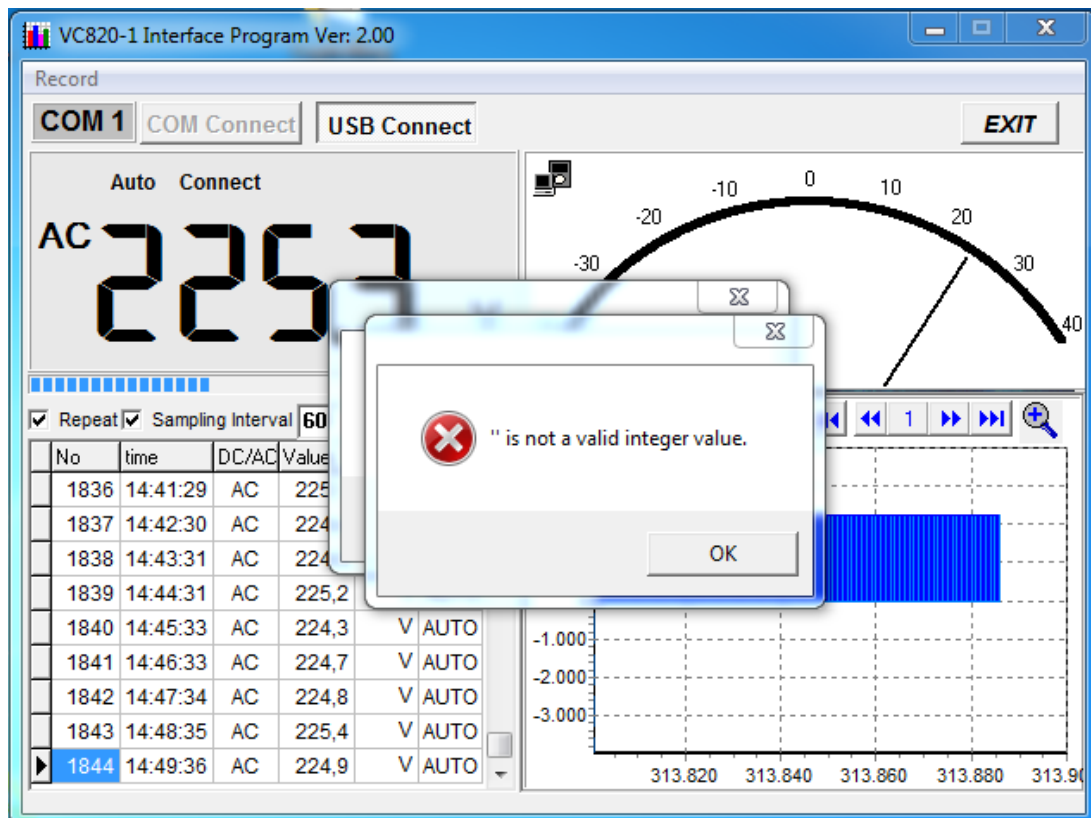
However, at least two incidents may indicate that these calculated heating demands also are quantitatively relevant to some extent. First, L3 shows by far the lowest heating demand among all lodge test subjects. This seems comprehensible, when considering that L3 showed the smallest and best isolated heated room (wooden planks on the inside of the walls). Second, the above calculated values match quite well with the findings of a study about household energy use conducted at Kathmandu University (Bhochhibhoya 2012).

R) Voltage Curves Used for Calculating the Load Profiles of L1 – L3



S) Data Logging Software Malfunction

Very rarely the data logging software malfunctioned for inexplicable and unpredictable reasons. When malfunctioning the pop-up notification depicted in Figure 8-2 is shown. In some cases, this led to a freeze of the data logging software and even the data logged in the particular session was lost, in other cases the data logging was still ongoing and the pop-up notifications could be closed by clicking the OK-Button.



[Own Illustration]

T) Data CD

Content of the Data CD:

1. Thesis
2. Data
3. Bibliography
4. Figures