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ABSTRACT

In Nepal, the share of biomass in total energy consumption is about 88 % and of biomass for cooking and heating about 90 % in 76 % of the households. Fuelwood, crop residues and dung are the three main biomass types. The lack of an integrated biomass inventory is hindering the formulation of effective policies and programs for sustainable resource management. This study evaluates the spatial variation of biomass supply and demand for cooking and heating in Nepalese rural households in three districts representing the country's main topographic regions lowland, hills, and mountains. The analysis is based on information from household survey, field studies, laboratory analyses, national statistics and application of GIS. Only those households adopting at least one type of biomass for cooking and heating are considered. The household survey was conducted in 240 households to evaluate biomass consumption, whereas the use of crop residues and dung is assessed in field studies in 27 households for the three seasons in 2013/14. By considering the five main staple crops (paddy, wheat, corn, millet and barley), the residues were evaluated, while cattle and buffalo were taken as a basis to assess the dung. The residue-to-product ratio (RPR) is the evaluation basis of crop residue supply, while the dung supply was assessed by determining the daily dung yield. The supply module of the GIS-based wood fuel supply and demand model (WISDOM) was taken as reference for the estimation of the fuelwood supply.

The annual per capita demand of biomass (dry matter) in terms of "fuelwood equivalent" in the lowland, hill and mountain districts is 435 kg, 660 kg, and 653 kg, respectively, where of the households only 57 %, (lowland district), 50 % (hill district) and 3 % (mountain district) have a surplus biomass supply. The fuelwood equivalent of crop residues (1 kg DM), dung (1 kg DM), LPG (1 kg) and biogas (1 m^3) are 0.40 kg, 0.93 kg, 23 kg and 4.57 kg, respectively. The households in the mountain district only use fuelwood whereas multiple energy sources with different combinations exist in the hill and lowland districts. The average annual per capita dung (dry matter) supply potential is 262 kg (lowland district), 278 kg (hill district) and 93 kg (mountain district). Despite the higher crop residue (dry matter) production (954 kg $capita^{-1}$ yr^{-1}) in the lowland than in the hill (547 kg $capita^{-1}$ yr^{-1}) district, the net usable amount of crop residues for energy generation is observed to be higher in the hill (207 kg $capita^{-1}$ yr^{-1}) than in the lowland (152 kg $capita^{-1}$ yr^{-1}) district. The lowest production (263 kg $capita^{-1}$ yr^{-1}) of crop residues was observed in the mountain district of which only 10 % is available for energy production.

Because of the relatively easier accessibility of forests in the hills and mountains, the households there do not burn crop residues or dung for energy production, and here the fuelwood exploitation rate is three times higher than the production potential. The fuelwood exploitation rate in the lowland district is double the production potential where about 66 % of the households utilize crop residues and dung for energy generation. The fuelwood deficit is the main reason for the use of crop residues and dung in the lowland district. The primary focus there should be on converting crop residues with bio-briquettes and dung with biogas. Awareness programs to prevent overexploitation of fuelwood by making balanced use of biomass should be initiated in all regions, while the use of other herbaceous materials for bio-briquettes and dung of small ruminants for biogas production should be initiated to fill the biomass supply gap in the mountains. Given the highly uneven distribution of biomass in all districts, the transportation of biomass from surplus to deficit areas could be one of the potential solutions to reduce overexploitation of fuelwood.

Räumliche Variation des Angebots und der Nachfrage für Biomasse zur Energieerzeugung im ländlichen Nepal

KURZFASSUNG

In Nepal beträgt der Anteil der Biomasse am gesamten Energieverbrauch ca. 88 %. In 75% der Haushalte wird fast ausschließlich (90%) mit Biomasse gekocht und geheizt. Feuerholz, Ernterückstände und Dung sind dabei die drei wichtigsten Biomasseformen. Das Fehlen einer integrierten Biomassenbestandsaufnahme erschwert die Formulierung effektiver Strategien und Programme für nachhaltiges Ressourcenmanagement. Die vorliegende Studie bewertet die räumliche Verteilung des Biomassenangebots und -bedarfs für Kochen und Heizen in ländlichen Haushalten in drei Distrikten, die die wichtigsten topographischen Regionen des Landes repräsentieren: Tiefland, Hügelland, und Bergregionen. Die Analyse nutzt Informationen aus Haushaltbefragungen, Feldstudien, Laboranalysen, nationalen Statistiken und wendet GIS an. Nur diejenigen Haushalte, die mindestens eine der eingangs aufgeführten Biomasseformen zum Kochen und Heizen einsetzen, wurden berücksichtigt. Um den Biomassenverbrauch zu erfassen, wurden Befragungen in 240 Haushalten durchgeführt. Die Nutzung von Ernterückständen und Dung wurde durch Felderhebungen in 27 Haushalten während der Vormonsun- und Monsunzeit sowie im Winter 2013/14 ermittelt. Ernterückstände der fünf Hauptnahrungsmittelpflanzen (Reis, Weizen, Mais, Hirse und Gerste) sowie die Dungproduktion von Rindern und Büffeln wurden erfasst. Das Verhältnis von Ernterückstände zu Produkt (RPR) ist die Berechnungsgrundlage für die Ernterückstände, während die Dungmenge empirisch pro Tag ermittelt wurde. Das Feuerholzangebot wurde mit dem GIS-basierten Feuerholzangebots- und Nachfragemodell WISDOM berechnet.

Der jährliche Pro-Kopf-Verbrauch an Biomasse (Trockenmasse/TM als "Feuerholzäquivalent") beträgt in den Tiefland-, Hügel- und Bergdistrikten 435kg, 660 kg, bzw. 653 kg. Das Feuerholzäquivalent der Ernterückstände (1 kg TM), Dung (1 kg TM) bzw. Biogas (1 m^3) beträgt 0.4 kg, 0.93 kg bzw. 4.57 kg. Im Tiefland haben 59 % der Haushalte, im Hügelland 53 % und in den Bergregionen nur 3 % einen Biomasseüberschuss aufzuweisen. Die Haushalte im Bergdistrikt nutzen ausschließlich Feuerholz, während verschiedene Energiequellen in unterschiedlicher Kombination in den Hügel- und Tieflanddistrikten genutzt werden. Das durchschnittliche jährliche Pro-Kopf-Angebotspotential von Dung beträgt 262 kg im Tiefland, 278 kg im Hügelland und 93 kg in der Bergregion. Die Haushalte mit Biogasanlagen in den Hügel- (10%) und Tieflanddistrikten (4%) nutzen nur 50 % ihrer Dungproduktion, die ca. 25 % des Energieverbrauchs abdeckt. Trotz der höheren Produktion an Ernterückständen im Tiefland (954 kg pro Kopf und Jahr) im Vergleich zum Hügelland (547 kg) zeigt sich, dass die netto nutzbare Menge für die Energieerzeugung im Hügeldistrikt höher (207 kg pro Kopf und Jahr) als im Tiefland ist (152 kg). Die niedrigste Produktion (265 kg pro Kopf und Jahr) wurde im Bergdistrikt beobachtet, wovon nur 10 % für die Energieproduktion zur Verfügung steht.

Durch den relativ leichteren Zugang zu den Wäldern in den Hügeln und Bergen nutzen die Haushalte dort weder Ernterückstände noch Dung zur Energieproduktion, was zu einem Feuerholzverbrauch führt, der dreimal höher als das Produktionspotential der Wälder ist. Der Feuerholzverbrauch im Tiefland ist doppelt so hoch wie das Produktionspotential, wo der Anteil von Ernterückstände und Dung am gesamten Energieverbrauch 43 % beträgt. Das Feuerholzdefizit ist der Hauptgrund für den Einsatz von Ernterückständen und Dung im Tiefland. Dementsprechend sollte dort über die Produktion von Biobriketts aus Ernterückständen und von Biogas aus Dung nachgedacht werden. Aufklärungsprogramme zur Verhinderung einer Übernutzung von Feuerholz und zur ausgewogenen Nutzung von Biomasse sollten in allen Regionen Nepals initiiert werden. In den Bergregionen sollten Biobriketts aus krautigen Pflanzenmaterialien sowie Biogas aus dem Dung von Kleinwiederkäuern verwendet werden, um das dortige Biomassedefizit auszugleichen.

LIST OF ACRONYMS AND ABBREVIATIONS

^0C	Degree celsius
ADBL	Agricultural Development Bank Limited of Nepal
AEPC	Alternative Energy Promotion Center
AGB	Above ground biomass
ANOVA	Analysis of variance
BEFS	Bio-energy and food security approach
BEST	Biomass energy strategy
BET	Biomass energy technologies
BSP	Biogas Support Program
CBS	Central bureau of statistics
DEM	Digital elevation map
DFI	District forest inventory
DM	Dry matter
EJ	Eta joule
FAO	Food and Agriculture Organization of the United Nations
FRA	Forest resource assessment
FRISP	Forest resource information system project
GHG	Greenhouse gas
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GJ	Giga joule
ha	Hectare
HDI	Human development index
HRT	Hydraulic retention time
ICIMOD	International centre for integrated mountain development
ICS	Improved Cook Stove

IEA	International energy agency
Kg	Kilogram
L	Liter
LPG	Liquefied petroleum gas
LRMP	Land resource mapping project
m	meter
m^3	Cubic meter
MAI	Mean annual increment
MJ	Mega joule
Mtoe	Million tons of oil equivalents
NEA	Nepal Electricity Authority
NEEP	Nepal energy efficiency programme
NFI	National forest inventory
NPR	Nepali rupees
OECD	Organization for economic cooperation and development
PJ	Peta joule
RPR	Residue-to-Product Ratio
SD	Standard deviation
SNV	Netherlands development organization
t	Tons
TJ	Tera joule
USD	United States Dollar
VDC	Village development committee
WECS	Water and energy commission secretariat
WHO	World health organization
WISDOM	Woodfuel integrated supply/demand overview mapping

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1 BACKGROUND AND INTRODUCTION

1.1 Introduction

In Nepal, the share of biomass in total energy consumption is about 88 % and the share of the domestic sector for cooking and heating in total energy consumption is about 90 % in 76 % of the households in the country. The prevailing utilization of biomass in open hearths or traditional stoves in poorly ventilated spaces is highly inefficient and time consuming, and has severe impacts on both health and environment. Hence, in order to make a progressive shift from the inefficient use of biomass to an efficient use, different programs for promotion of various biomass energy technologies (BET), mainly biogas and improved cooking stoves, are being implemented.

At the same time, under the framework of NEEP[1] (Nepal Energy Efficiency Program), the Government of Nepal initiated the Biomass Energy Strategy (BEST) on the national level to explore integrated solutions that aim to maintain balanced and sustainable supply-demand systems for biomass energy. However, among the major pitfalls, the lack of information on the potential biomass supply for energy generation had a negative impact on existing biomass programs. Therefore, this study aims to assess the biomass energy status so that the knowledge gap can be filled to some extent.

Despite the existence of some information on biomass gathered by relevant governmental agencies such as the Department of Forests, Department of Agriculture and Department of Livestock Production, the nature of the data does not allow assessment of the energy supply, as the purposes of the data collection by those institutions differ. Furthermore, the limited studies on biomass supply are based on confined areas, which relied on theoretical assumptions derived from international

[1] NEEP is jointly implemented by the Ministry of Energy with technical assistance of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). (First phase: 2010 – 2014 , Second phase: 2014 to 2017)

experiences. Apart from energy, biomass has other important uses that should also be critically analyzed in a local context in order to evaluate the supply-demand level of biomass energy.

Indeed, the foremost criteria for selection of a suitable BET for any targeted area should be linked with the biomass supply status. Besides supply level, the economic, social, technological and cultural factors also play a key role that directly relates to effective utilization of a BET. Despite the provision of impartial financial support in view of geographical and social considerations, however, there is still a lack of an approach on both policy and implementation level to prioritize and categorize the programs based on availability of biomass. The programs here refer not only to dissemination of a particular BET but also include delivering information on efficient utilization of biomass to users. As biomass varies both spatially and seasonally, in the absence of information on such variations prioritization and categorization of the energy programs is rather complex.

The current modality of promotion of the BETs is mostly based on the demand of the households, which is a result of awareness created by various local level governmental institutions, non-governmental agencies and private energy companies. However, a number of cases has been reported where participants in a BET either abandoned the program or were not convinced of the specific technologies. Among various other reasons, the availability of biomass is observed to be a crucial factor. In some areas, the lack of dung is the main hurdle in the regular operation of biogas plants, whereas in other areas, participants refuse to use improved cooking stoves because of fuelwood adequacy. Hence, the assessment of the potential biomass supply prior to implementation of the programs is necessary in order to develop the required strategy. The basic reality of the energy programs in Nepal is associated with financial constraints because of which the programs can only be implemented in selected areas. Hence, the information on biomass supply may be one of the milestones not only to prioritize the areas but also to design the programs accordingly so that the use of financial resources can be optimized.

Looking into the current pattern of biomass consumption in Nepal, three major types of biomass, namely fuelwood, dung and crop residues, are being used extensively for household cooking and heating energy needs. The utilization pattern of these resources is entirely dependent upon the availability of particular biomass. In general, fuelwood is considered superior, and every household tries to maximize its use, whereas the burning of crop residues and dung cakes is common in fuelwood-deficient areas. The use of biogas is limited to only few households. The households located in forest-rich areas only use fuelwood, whereas households in forest-deficient areas use a mixture of biomass. As the availability of both dung and crop residues is dependent on seasons, information on the variation of those resources plays a significant role in addressing demand-based site management. Furthermore, the use of biomass during the winter is noticeably higher than in the other seasons, which should also be evaluated in order to determine the supply-demand relationship.

Hence, based on the aforementioned factors, the study evaluates spatial variation of the supply and demand of biomass in addition to seasonal variation of fuelwood demand for energy generation by considering three districts among 75 to represent the country's three major topographic regions.

1.1.1 Biomass as energy resource

The term "biomass" refers to biological material from living or recently living organisms. The material may be in the form of forest residues, wood, crops with by-products, municipal solid waste, animal wastes, wastes from different biomass-based industries, aquatic plants, and algae (Ayhan 2001). As indicated by Pimentel (2001), the global production of biomass is 77 billion t yr^{-1}, which includes both marine and terrestrial ecosystems with a share of about 47% and 53%, respectively. Furthermore, human activities consume terrestrial biomass amounting to 20.25 billion t yr^{-1} ($81 * 10^5$ Kilo calorie yr^{-1}), which is 50% of the total available terrestrial biomass (Pimentel 2002).

Rosillo-Calle et al. (2007) classified biomass into eight major types by considering relevancy of approach of assessment and measurement into natural forests/woodlands, forest plantations, agro-industrial plantations, trees outside forests and woodlands, agricultural crops, crop residues, processed residues, and animal wastes. Chum et al. (2012) classified biomass resources into three groups of primary residues from conventional food and fiber production in agriculture and forestry, secondary and tertiary residues from food/forest-based industry and their by-products (wastes), and crops produced for energy production. Because of negligible utilization and uncertain availability, aquatic biomass (algae, seaweed, etc.) in general has been excluded when assessing the potential of biomass resources in most studies (BEE 2010).

Regarding fuel, the materials embedded in biomass can be classified into organic components, ash components and water content. The main organic components are cellulose, hemicelluloses, lignin, fat and waxes, whereas the ash components are nonorganic components which are either incorporated in the organic structure or dissolved in the water within this structure. Hence, the oxygen content in most of the biomass is normally 50 % in terms of weight whereas that of combustive materials is≤ 50 % (van Swaaij and Kersten 2015). In particular, the solar energy absorbed by photosynthesis is stored in the form of chemical bonds of the structural components in biomass (McKendry 2002). With efficient treatment of the biomass both chemically and biologically, the chemical bonds break down and discharge energy combined with oxygen, carbon dioxide and water. With a suitable technology, it is quite possible to capture and operate this energy, which is generally termed bio-energy (McKendry 2002).

Biomass, in principle, is considered as a carbon-neutral energy resource, since it releases the same amount of carbon dioxide during burning (conversion) that it consumed from atmosphere during the growth period. Hence, unlike fossil fuel, it does not add an extra amount of carbon dioxide to the atmosphere. Moreover, the regeneration period of biomass is much shorter than that of fossil fuel, which takes millions of years to form. Biomass is therefore categorized as a renewable energy resource (Twidell 1998; Omer 2011; van Swaaij and Kersten 2015).

In general, the uses of biomass are quite versatile in nature as compared to fossil fuel resources. The multiple uses of biomass in addition to energy provision such as food, fodder, fiber, building materials, medicines, fencing, etc., make it completely different to conventional energy resources (Koopmans and Koppejan 1997; Chum and Overend 2001; Odegard et al. 2012). In contrast to conventional energy resources, the by-product of biomass resources can also be modified for further purposes along with energy generation. Furthermore, after utilization of animal dung for biogas generation, the slurry obtained as a by-product from the biogas plant can be applied as fertilizer.

There are principally three ways for converting biomass into energy, i.e., thermo-chemical conversion, bio-chemical conversion and mechanical conversion (McKendry 2002). Thermo-chemical conversion consists of four processes: combustion (direct burning), pyrolysis (incomplete combustion), gasification (controlled burning), and liquefaction that requires external heat to harness energy from feedstock, where end products may be in the form of heat, electricity, producer gas or bio-oil (McKendry 2002). Bio-chemical conversion involves either digestion (production of biogas) or fermentation (ethanol production) (McKendry 2002). Mechanical conversion includes various processes required for biodiesel production such as crushing, densification, chipping and grinding, and drying of biomass seeds (McKendry 2002).

Of the total global primary energy supply in 2008, the share of biomass was 10.2 % (50.3 EJ yr^{-1}) in which the contribution from wood (trees, branches and residues) and shrubs was 80 % while the remaining fraction was contributed by the agriculture sector (agricultural residues, energy crops and by-products), various commercial sectors, and the organic fraction of different wastes and by-products (Chum et al. 2012). With rapid population growth and drastic development competition among the countries in the world, the energy consumption rate has been increasing at a tremendous speed. The total global energy consumption between 1973 and 2010 doubled, and for the year 2010 biomass represents the fourth largest energy source after coal, oil and natural gas (IEA 2012). The global use of biomass for energy production has also been increasing rapidly, and doubled between 1971 and 2005 (Ladanai and Vinterbäck 2009).

The biomass sector has considerable potential for growth over the coming years both in industrialized and developing countries mainly because of 1) depletion of easily accessible supplies of oil, 2) higher costs of oil extraction and processing, 3) climate change issues, 4) prerequisite to maintain energy security, and 5) context of rural development (IEA 2011). The global trade of biomass energy takes place in the form of biomass feedstock (wood chips, raw vegetable oils and agricultural residues) and modern energy carriers (ethanol, biodiesels and wood pellets). While the global trade in liquid biofuel and wood pellets in 2000 was practically zero, in 2009 in terms of energy equivalent values were 120-130 PJ and 75 PJ, respectively, which indicates the growth potential of the biomass business sector in recent years (Junginger et al. 2013). The implementation of improved technologies and efficient methods have led to a significant overall cost reduction for biomass energy production, which further enhances the promotion of the biomass energy market (IEA 2015). As reported by Scarlat et al. (2015), the share of biomass is expected to be 60 % of the EU Renewable Energy target in 2020, which will contribute to 12 % of the final energy use in the European Union. In Malawi, southeast Africa, the production of fuelwood is observed to have the largest share of trade in the energy sector (Openshaw 2010). In Japan, the production of wood pellets from 8.58 million t of unutilized woody biomass has a potential cash generation of USD 981 million annually with employment opportunities for 24,700 people (Nishiguchi and Tabata 2016).

In the context of developing countries, the supply of biomass energy contributes 35 % of the total energy in these countries, where the share of the rural areas is more than 90 % (Ayes and Imren 2007). However, inefficient or traditional technologies, in most cases direct burning of wood, livestock dung or other biomass, have led to serious problems with respect to the unsustainable supply of biomass as well as to indoor air pollution. Hence, modern biomass energy technologies in developing countries urgently need to be introduced, while at the same time the contribution of bio-energy has to be enhanced to substitute fossil fuel in developed countries to cope with the global climate change scenario.

1.1.2 Biomass and energy in Nepal

In the fiscal year 2011/12, the total energy consumption in Nepal was 10.5 million tons of oil equivalents (Mtoe) in which the share of biomass, commercial and renewable energy was 83.7 %, 15.6 % and 0.7 %, respectively. The contribution of firewood, agricultural residues and livestock residues was 74.9 %, 3.3% and 5.5 %, respectively (WECS 2014). When considering sector-wise utilization of biomass energy, it has been observed that more than 90 % of the energy is consumed for cooking and heating in the households (WECS 2010).

In the period 2000 to 2005, the national deforestation rate was 2.1 % where the estimated wood consumption in 2005 was 17 million t. Here, 60 % of the fuelwood supply was unsustainable as per the physical and socio-economical criteria set by the government (WECS 2010). Moreover, the direct burning of solid biomass in open or traditional stoves in most of the rural areas has been causing severe health problems to rural people in Nepal (Bates et al. 2013; Kurmi et al. 2013). It is assumed that more than 80 % of the population are exposed to dangerous levels of indoor air pollution causing around 7500 deaths every year (ENPHO 2008). A study in southern Nepal revealed that particulate matter (< 4 µm median aerodynamic diameter - PM_4) in the air over 24 hours average weighted over the whole year was 168 µg m^{-3} which is high compared to the recommendation by both the World Health Organization (WHO) and National Ambient Air Quality Standards for Nepal (Devakumar et al. 2014).

Considering the country's hydropower resources with an economical potential of 42,000 MW out of total exploitable 83,000 MW, the question may be raised why inefficient biomass energy in rural households cannot be substituted by electricity. However, the history of hydropower development and management in Nepal has not been positive because of technical, economic, social and cultural factors (Sovacool et al. 2011; Butler 2014; Shrestha 2015). About 30 % of all households in the country are still without electricity, with a share of 40 % in rural areas and 6 % in urban areas (CBS 2012). Looking into current scenario of electricity demand and supply where lack of about 410 MW exists during peak load times when demand reaches 1201 MW (NEA 2014), one can argue that bringing electricity to all rural households for cooking and heating purposes is unimaginable in the next decades.

The country's high dependency on imported petroleum products for energy purposes has had a serious impact on its economy, and the trend has been increasing drastically due to a long-standing power crisis because of the halt in the development of hydro projects. As indicated in a report published by the National Bank of Nepal in 2015, petroleum products were the largest import item for the fiscal year 2013/14, the worth of which had increased by 21.72% as compared with the previous year. About 38 % of the national revenue in that year was spent on imported petroleum products (NRB 2015).

Nevertheless, being endowed with various natural biomass resources, Nepal has a high potential to capture clean energy from those resources in a sustainable way. Around 40 % of the country is covered by forest in which more than 51 % is considered accessible. This can provide 12.5 million t of fuelwood with an energy value of 209 PJ in a sustainable manner (WECS 2010). However, the consumption of fuelwood in the year 2008/09 was around 311 PJ, which indicates overuse of forest wood. Similarly, the annual agricultural residues during 2008/09 were estimated to be 19.4 million t with an energy value of 243 PJ, which is about 61 % of the total energy consumption (400 PJ) in that year. Moreover, as per the findings of the research conducted by SWMTSC[2] in 51 different municipalities in Nepal, the annual weight of solid waste in these areas was 0.5 million t with a 61.5 % share of organic waste (AEPC 2010). However, due to the lack of comprehensive bio-energy resource assessments with analyses of the supply-demand scenario, the information on bio-resources has not been adequate for proper planning of the utilization of bio-energy resources.

[2] Solid Waste Management Technical Service Center, a government agency in Nepal.

After establishment of the Alternative Energy Promotion Center (AEPC) in 1996, the promotion of renewable energy technologies on the national level has taken place in a systematic way. With the aim of bringing clean energy solutions especially to rural areas, AEPC has been actively promoting biomass-based energy technologies along with others. As of end of July 2015, more than 0.85 million Improved Cook Stoves (ICS) and about 0.3 million household-level biogas plants had been installed in rural areas (AEPC 2015a). Similarly, pilot programs for the promotion of other technologies such as gasifiers, briquettes and biofuel are ongoing.

Analyzing the current practices and progress made by the country in the field of biomass for energy, it has been found that progress has been slow due to the fact that the focus has only been on the limited technologies of ICS and biogas at the household level without integrated and long-term planning and strategies especially in terms of resource utilization. Moreover, no concrete or effective work has taken place towards optimum utilization of biomass for energy generation mainly due to lack of scientific, updated information regarding different kinds of biomass. Kuisma et al. (2010) revealed the importance of precise statistics on the biomass available under local conditions on different spatial scales for planning in practice. Scientific and accurate biomass information not only provides decision support for decentralized planning but also supports carbon cycling computing and climate change analyses. Due to the lack of such information, serious problems due to possibly ill-matched financial resource mobilization may occur during decentralized energy planning (Joshi et al. 1991a; Ramchandra and Rao 2005; Schneider et al. 2007; Brandoni and Polonara 2012). Because of the versatile nature and integral part of biomass in an environment, the biomass-for-energy production has to be assessed in terms of optimum yields and maximum utilization of resources (Gerber 2008). As concluded by the International Energy Agency (IEA), the government will only be able to formulate a long-term national energy plan, policy and strategy by considering the population to be served, potential bio-energy resources, technology, infrastructure and potential providers with socio-economic consideration and based on an accurate national database of biomass resources (IEA 2006).

Considering the existing biomass information gap in the country, it is worthwhile to conduct research on the development of inventories of biomass for energy production by analyzing the demand-supply relationship. Biomass mapping is quite a cumbersome process due to the versatile nature and dynamic interactions in a natural environment. Moreover, the variation of availability of different biomass throughout a year is another important aspect that needs to be analyzed in order to achieve a continuous demand-supply balance. The application of the Geographic Information System (GIS) has been considered as a strong computer-based tool to assess total available biomass resources in a particular area/region, and would allow integration of comprehensive data/information and illustrate the spatial relationship of biomass (Iverson et al. 1994; ESRI 2007; Crocker 2008; Kindermann et al. 2008). Moreover, based on the information obtained through GIS, the net technical potential of bio-energy could be estimated by considering distance, means of transportation and relevant landscape details in view of the demand-side management (ESRI 2007; APEC 2008; Van Hoesen and Letendre 2010).

The findings of biomass mapping of the energy demand-supply would play an important role in long-term energy planning and the sustainable utilization of the resources, which is the most promising way to cope with the energy situation in Nepal.

1.2 Research objective

The overall aim of this study is to analyze spatial variation of the demand and supply of biomass, namely fuelwood, crop residues and livestock dung, for potential energy use at the household level in three different districts in Nepal. Specifically, the study has the following objectives:

1. To assess spatial distribution of biomass supply for household energy needs
2. To carry out a demand analysis for utilization of biomass for fulfilling household energy needs
3. GIS-based syntheses of the demand and supply pattern of biomass energy resources at the lower administrative level.

1.3 Thesis outline

The thesis is organized in nine interrelated chapters. Following an introduction (Chapter 1) with the research objectives, the study area and methodology are described in Chapter 2. Chapter 3 deals with the fuelwood consumption pattern of different households adopting multiple energy mix sources. The seasonal and altitudinal variation of fuelwood consumption are also assessed in this chapter. Chapter 4 presents a description of the production of crop residues and their different uses. The assessment of annual dung yield is done in Chapter 5, where the net potential of dung for biogas production is evaluated. The seasonal variation of dung is also assessed for three different seasons. Chapter 6 investigates the overall energy consumption pattern based on the findings presented in the previous chapters. The annual share of each type of energy source of the households with four different categories in terms of energy mix is also evaluated. The biomass supply and demand analysis based on a GIS is presented in Chapter 7, where evaluation of the net supply potential of fuelwood is done by analyzing the physical and legal accessibility of forest areas. The annual supply and demand of biomass at the lower administrative level is analyzed and presented in maps. The general discussion incorporating all findings and their interrelations is presented in Chapter 8, where the way forward to exploit biomass and its probable impact on different aspects in national level is discussed. The final Chapter 9 provides overall conclusions and recommendations.

2 STUDY AREAS AND METHODOLOGICAL APPROACH

2.1 Nepal – A country review

Nepal, a landlocked country, is located in southern Asia bordered by China in the north and India in the south, west and east, and covers an area of 147,181 km^2. It stretches 885 km from west to east and an average 200 km from north to south. The country has a population of 26.6 million, with an annual growth rate of 1.4 %. More than 80 % of the population live in rural areas (CBS 2012). The human development index was 0.54 in 2013 (UNDP 2014) with a per capita nominal gross domestic product of USD 717 for the fiscal year 2013/14 (MoF 2015).

The country is divided into 75 administrative districts. Each district is further divided into Village Development Committees (VDC) and municipalities. The municipality has the same function in urban areas as the VDC in rural areas. Wards are the smallest units in both the VDCs and municipalities; each VDC is divided into nine wards, whereas a municipality consists of at least nine wards but the numbers may exceed depending on the size/area and population (Prasad Timsina 2003).

Based on its topography, the government broadly classified Nepal in three categories, i.e., mountains, hills and lowland (terai), which extend from west to east with an irregular width from north to south. The altitude of the mountain region is over 2,000 m a.s.l., while the hills are between 300 m and 2,000 m. The lowland areas are below 300 m. However, in the mountain districts there are also areas that can be defined as hilly, in the hill districts areas that can be defined as mountains and lowland, and in the lowland area there are also hills. The number of districts comprising mountains, hills and lowland are 16, 39 and 20, respectively. Of the total population of the country 50 % lives in the lowland, followed by 43 % in the hill regions and 7 % in the mountainous areas (CBS 2012). Based on potential vegetation, the country is classified into seven different agro-physiological regions (Barnekow Lillesø et al. 2005) (Table 2.1).

Table 2. 1 Agro-physiological regions of Nepal

Agro-physiological region	Elevation range	Type of crop	Type of livestock
Tropical*	≤ 1000 m	Double paddy, winter, summer and spring corn, wheat, potato, mango, lichi, jack fruit, citrus, wild vegetables, off-season vegetables, tropical vegetable seed, cash crops (intensive crop production)	Terai cattle, Terai buffalo, Terai goats, Lampuchhre sheep, black pigs and chickens
Sub-tropical	1000 – 2000 m	Paddy, spring/summer, corn, millet, wheat, potatoes, stone fruits, citrus/peach, sub-tropical vegetables, summer/off-season vegetables, hill cash crops	Hill cattle, hill buffaloes, hill goats, Kage sheep, black pigs, chickens and angora rabbits
Temperate	2000 – 3000 m	Cold-tolerant paddy, summer corn, wheat, barley, potatoes, apples, walnuts, off-season vegetables, peaches, cole crops, amaranthus, bucketwheat	Chaiuri, Sinhal goats, Baruwal sheep, hill cattle, hill buffaloes, Chyangra and angora rabbits
Subalpine	3000 – 4000 m	Naked barley, potatoes, apples, cabbage, bucket wheat, wild vegetables, cauliflower (restricted crop production)	Bhyaglung sheep, Yak/Nak, Chyangra
Alpine	4000 – 5000	No crop production	Bhyaglung sheep, Yak/Nak, Chyangra
Nival	>5000m	No agricultural potential	

*includes both lower tropical (< 300 m) and upper tropical (300 – 1000 m) zones

Source: Barnekow Lillesø et al. 2005

In Nepal, the seasons are climatologically divided into four categories: pre-monsoon (March – May), summer monsoon (June – September), post-monsoon (October – November) and winter (December – February) (Kansakar et al. 2004). As the altitudes vary from 66 m to the highest peak in the world, Mt. Everest at 8,848 m a.s.l. within the relatively narrow strip of land of about 200 km, the country experiences various climatic regimes and precipitation patterns (Ichiyanagi et al. 2007). The annual mean precipitation is 1,858 mm with extreme ranges of 5,000 mm to less than 150 mm (Practical Action 2009). During the pre-monsoon, the weather is hot and dry with little rain, ending with high humidity and thunderstorms. The summer monsoon generally starts in mid June in the eastern part of the country and advances towards the west, covering the whole country within a week. Hence, the eastern region receives higher rainfall than the west. About 80 % of the rainfall occurs during the summer monsoon. The post monsoon is characterized by a drastic reduction in rainfall and is considered the driest season, whereas winter is dry and cold with snow in the northwestern areas (Kansakar et al. 2004; Shrestha and Kostaschuk 2005; Duncan and Biggs 2012) (Table 2.2 and 2.3).

Table 2. 2 Temperature and precipitation in the agro-physiological regions of Nepal

Agro-physiological region	Mean temp. (°C)	Precipitation range (mm)	Mean precipitation (mm)
Lower tropical	24.1	1,159 – 2,827	1,738
Upper tropical	22.0	947 – 3,867	1,904
Sub-tropical	17.6	591 – 5,284	1,875
Temperate	12.7	262 – 3,949	1,685
Sub-alpine	6.9	440 – 2,131	1,132

Source: Barnekow Lillesø et al. 2005

Table 2. 3 Temperature conditions in the agro-physiological regions of Nepal

Agro-physiological region	Days > 30 °C	Max temp. (°C)	Min temp. (°C)	Days < 0^0C
Lower tropical	199 – 246	41 – 46	0 – 5	0
Upper tropical	62 – 215	35 – 45	-2 – 7	0
Sub-tropical	0 – 173	29 – 40	-9 – 4	0 – 53
Temperate	0 – 47	23 – 42	-14 – 0	0 – 132
Sub-alpine	0	20 – 26	-18 – -13	145 – 229

Source: Barnekow Lillesø et al. 2005

2.2 Study area

Three different administrative districts were selected to represent the three main topographic regions of the country. The districts Bajhang, Lamjung and Morang represent mountains, hills and lowland, respectively (Figure 2.1).

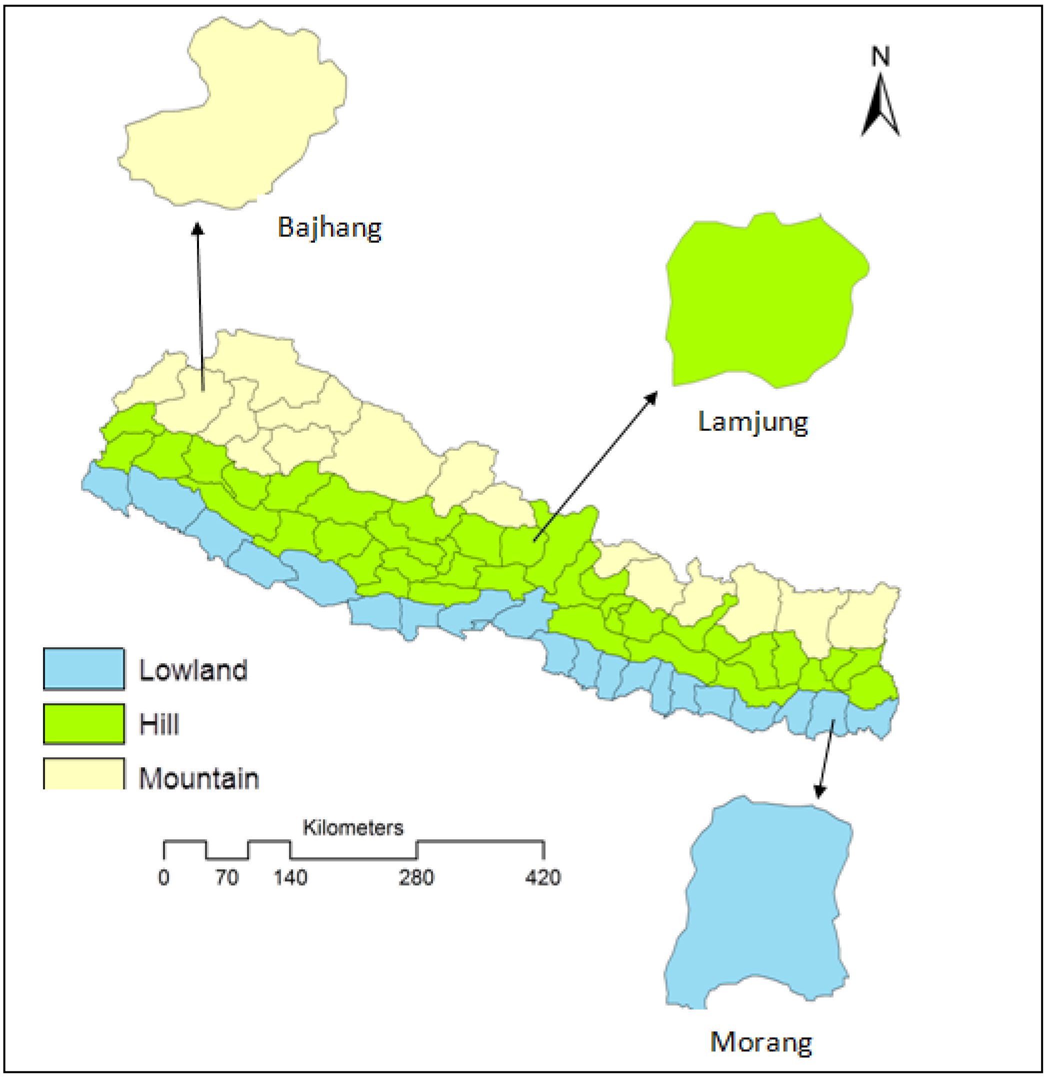

Figure 2.1 Map of Nepal showing study districts and topographic regions

Covering 3,422 km^2 and ranging from 900 to 7,077 m a.s.l., Bajhang is rich in biodiversity with valuable plants such as *Ophiocordyceps sinensis* (a medicinal mushroom), *Dactylorhiza maculata* (heath spotted-orchid), *Dioscorea villosa* (wild yam root), etc., and wildlife such as *Macaca mulatta* (Rhesus monkey), *Lutra lutra* (Common otter), *Hemitragus jemlahicus* (Himalayan thar) etc. (MoFSC 2009). Because of poor infrastructure and complex terrain, the district is one of the most isolated and economically deprived in Nepal. Hence, the district suffers from food insecurity, and the people have very limited economic opportunities (Beck and Schött 2013). Lamjung is officially categorized as a hilly district and covers 1,691 km^2. The district has great potential for hydropower development due to its extensive water resources (Mandal and Jha 2013). It is also a famous tourism sector as it is one of the four regions crossed by the Annapurna circuit, one of the world's most famous trekking routes (Subedi and Chapagain 2013). Morang covers an area of 1,855 km^2, which is categorized as a lowland district. It is one of the industrially most developed districts in Nepal. The good road infrastructure along with its location near the Indian border has contributed to the development of industries. Here the country's industrialization began in 1937 with the establishment of the Biratnagar Jute Mill (Rimal 2011). The area of the different agro-physiological regions within the study districts is presented in Table 2.4.

Table 2. 4 Agro-physiological regions in the study districts

Ecological zone	**Area (%)**		
	Lowland (Morang)	**Hills (Lamjung)**	**Mountains (Bajhang)**
Lower tropical	81	-	-
Upper-tropical	12	19	1
Sub-tropical	7	34	18
Temperate	-	20	26
Subalpine	-	14	17
Alpine	-	8	8
Nival	-	5	30

Source: Barnekow Lillesø et al. 2005

The land-use map showing the four different land-use classes in the study districts is presented in Figure 2.2.

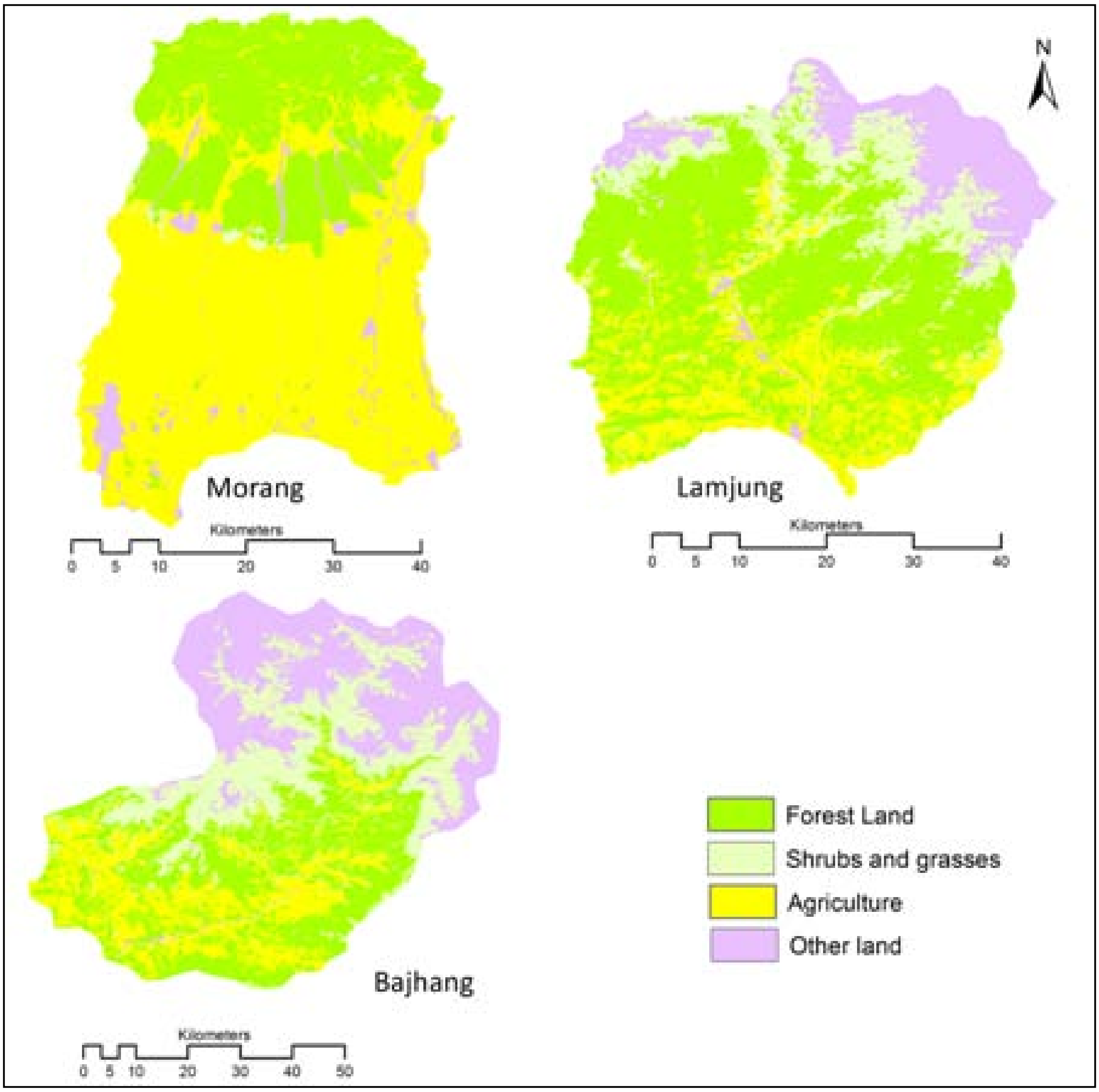

Figure 2.2 Land use in the study districts based on Uddin (2013)

The socio-economic indicators of the study districts are listed in Table 2.5.

Table 2. 5 Socio-economic indicators in the study districts

District	No. of households	Household size (number of persons)	Sex ratio(males per 100 females)	Population density (persons per km^2)	Income (USD per capita)	HDI[3]
Lowland	213,870	4.31	93.6	520	1,104	0.513
Hill	42,048	3.99	82.7	99	1,186	0.507
Mountain	33,773	5.78	90.7	57	487	0.365

Sources: CBS 2012 & UNDP 2014

About 17 % of the households in the lowland district and 15 % in the hill district have house roofs with reinforced concrete whereas this is limited to only 1 % in the mountain district. The literacy rates are 70, 72 and 55 % in the lowland, hill and mountain districts, respectively. Only 23 % of the population in the lowland district, 16 % in the hill district and 12 % in the mountain district completed school level education.

2.3 Household energy consumption pattern

Fuelwood is the main energy source for almost all households in the mountain district whereas this share is about 70 % in the hill district and 45 % in the lowland district (Table 2.6), where the households use other fuel types such as dung cake, LPG (liquefied petroleum gas), kerosene and biogas. About 25 % of these households burn dung cake in the lowland district whereas no such households exist in the other two districts (Table 2.6). Even though burning crop residues for cooking and heating by poor households especially in the lowland district was observed, this is not reflected in

[3] HDI (Human Development Index) is a composite index measuring average achievement in three dimensions of human development: a long and healthy life, knowledge and a decent standard of living, which was computed as the geometric mean of the normalized indexes measuring achievements in each of these three dimensions. (UNDP 2014)

national statistics. Various other sources such as electricity, waste, coal, briquettes, etc. are incorporated in 'Others'.

Table 2. 6 Relative distribution of households by main type of cooking and heating fuel

Districts	**Households (%)**					
	Fuelwood	**Kerosene**	**LPG (liquefied petroleum gas)**	**Dung**	**Biogas**	**Others**
Lowland	45.0	1.3	23.2	24.6	3.9	2.0
Hill	70.0	0.3	19.0	0.0	10.3	0.4
Mountain	99.0	0.0	0.0	0.0	0.0	1.0

Source: CBS 2012

More than 75 % of the households in both the lowland district and hill district are electrified via national and mini grids, whereas this only applies to 17 % of the households in the mountain district (Table 2.7). The share of households with solar systems is relatively high in the mountain as compared to that of the lowland district and the hill district. This might be because of government provision of a subsidy to the households not connected to the electrical grid system in the mountain district. The national survey report has not elaborated the term 'Others', however various earlier studies indicated that the use of biomass for lighting purposes especially in mountainous areas is quite common(Bhusal et al. 2007; McKay et al. 2007; Mann 2009; Chitrakar and Shrestha 2010) ; this was also observed during the household survey for this study. The local term for burning biomass for lighting is "Jharo" (a resin-rich wood).

Table 2.7 Relative distribution of households by main source of lighting

Districts	Households (%)				
	Electricity	Kerosene	Biogas	Solar	Others
Lowland	76	23	0	1	0
Hill	77	15	0	7	1
Mountain	17	13	1	40	29

Source: CBS 2012

2.4 Data source and methodology

The data used in the study was mainly acquired from a household survey, and complemented by secondary information from various past studies and GIS applications.

2.4.1 Sampling technique

First, the mountain and hill districts were stratified in three altitudinal zones, and the lowland district in urban and rural zones (Table 2.8). The wards in the municipality were treated as 'urban', and the remaining wards as 'rural'. The sample wards were then selected on the basis of probability proportional to size. Then lists of all households where the name of the household head was known were obtained from the respective ward offices. These lists were later revised with local-level participation and only the households with at least one mode of biomass energy consumption were considered. Accordingly, 80 households from the sample wards in each district were selected on a random basis.

Table 2. 8 Stratification of study districts

District	Basis for stratification fraction	Number of strata	Classification
Mountain	Altitude	3	- 900-1,500 m - >1,500-2,000 m - >2,000-7,077 m
Hill	Altitude	3	- 500-1,000 m - >1000-1,500 m - >1500-7,690 m
Lowland	Urban – rural	2	- Urban - Rural

2.4.2 Questionnaires and data collection

Two sets of questionnaires were developed for the household survey (Annexes 1 and 2) . The first questionnaire set (Q1) conducted in 80 households per district was structured and particularly focused on general household information about energy uses, fuelwood collection, crop residues and livestock management. The measurement of biomass supply and consumption was the main focus of the second questionnaire set (Q2) with 27 households (nine households in each district), where various factors affecting the net amount of biomass used were considered. The details of the survey for fuelwood, crop residues and dung are described in chapters 3, 4 and 5.

Table 2. 9 Household survey

Questionnaire	Number of respondents	Schedule
Q1	240 households	Aug.- Nov., 2013
Q2	27 households	Dec. 2013, Mar. 2014 & Aug. 2014

2.4.3 Selection of enumerators

Graduated students were selected and provided with guidance on both theoretical and field aspects of the survey. The total number of enumerators including the main researcher was six where one main enumerator and one assistant for each district were fixed. The main enumerators were from urban areas while the assistants were from the respective districts. The training was carried out in 20 households in a village in the hill district. The findings were presented by each enumerator in a group, and feedback was delivered to refine the survey process. Based on the results of the training survey, minor amendments in the questionnaires were made.

2.4.4 Problems encountered

Various problems were faced in different phases of the survey. The foremost problem was about the time of interview, as only the old persons and children were at home during the day time in most of the households. With these persons, interaction would not have been effective. Hence, most of the surveys took place before the morning meal by considering the time availability of the main respondents. Because of probable fatigue of the main respondents from the day's work, the surveys were not carried out during the evening. The persons who were actively and directly involved in biomass collection, agriculture and livestock management were considered as the main respondents. Depending upon physical presence and availability of time, the information was collected from both male and female respondents with respect to their work divisions. In almost all cases, activities in connection with biomass energy were observed to be conducted by the female respondents, whereas activities in connection with agriculture and livestock were conducted jointly by male and female respondents. The economic activities were mostly handled by the male respondents. The details of the difficulties faced during the survey for three different types of biomass are elaborated in the respective chapters.

2.5 Conceptual framework

The main theme of the study is based on the two aspects demand and supply analysis of the available biomass for energy utilization in the study areas (Figure 2.3).

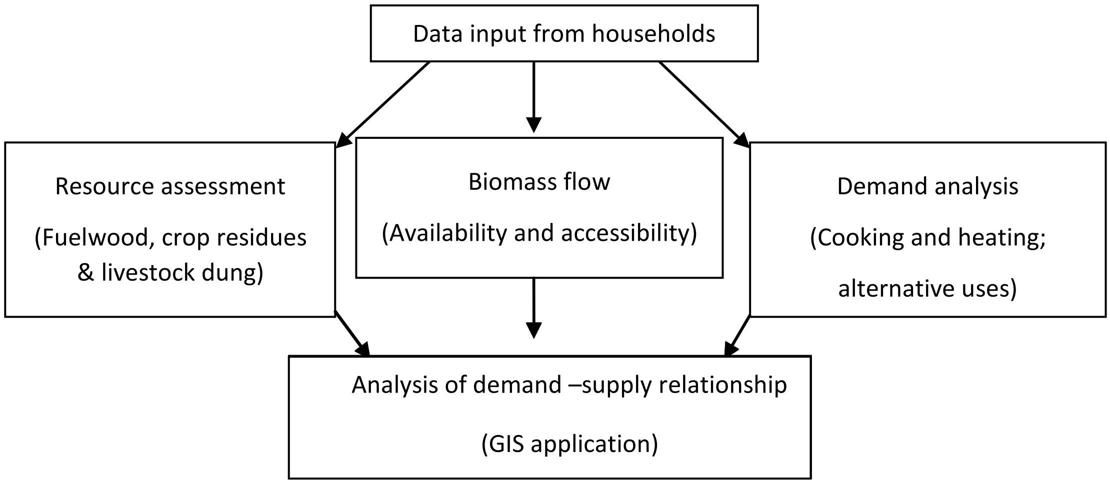

Figure 2.3 Scheme of methodology used to assess the biomass energy demand – supply scenario

The first step was to explore and collect information about available biomass from the sample households in each district. The biomass demand as well as supply potential of crop residues and livestock dung was directly evaluated based on household survey information while the supply potential of fuelwood was carried out based on mean annual increment for forest as obtained from past studies.

The area of forests, annual crop production and number of livestock were the basis for evaluating annual supply of fuelwood, crop residues and dung, respectively. The necessary basic information was obtained from the relevant government institutions. The accessibility of biomass for potential utilization was evaluated on the basis of the respondents' information in the surveys. Then the alternative uses of biomass (except energy use) were assessed based on which the net available quantity of biomass for energy generation was obtained. The conversion of weight of net available biomass to corresponding energy values was done by applying the moisture contents and calorific values as obtained from laboratory experiments. The explanation of the assessments for fuelwood, crop residues and dung are provided in chapters 3, 4 and 5. Based on the results of the supply and demand, an analysis was done to relate their status on the VDC level using GIS (Chapter 7).

3 FUELWOOD CONSUMPTION PATTERNS

3.1 Introduction

Being the oldest source of energy, fuelwood for cooking and heating at household level in developing countries remains a vital resource (FAO 2005). At the same time, there is an increasing trend for producing high-quality energy with fuelwood by adopting efficient and modern technologies such as energy-efficient stoves especially in OECD countries (Organization for Economic Cooperation and Development) (FAOstat 2009). Of the total global primary energy consumption of 500 EJ, the share of biomass energy is 10 %, where fuelwood for cooking and heating in developing countries alone contributes around 66 % (FAOstat 2009). The annual global supply of wood accounts for roughly 3.45 billion m^3 where the consumption share in the form of fuelwood for cooking and heating is 56 % (FAOstat 2009). About 2.6 billion people in developing countries fulfill their basic energy demand for cooking and heating by mostly using fuelwood in a very inefficient, unhealthy and unsustainable way (Fritsche et al. 2014), and the trend will persist in the foreseeable future especially in rural areas of those countries (Lefevre et al. 1998; Arnold and Persson 2003; Arnold et al. 2006).

Because of the easy availability of fuelwood in the local environment in most of the cases, the dependence on fuelwood is mostly to be observed in poor households, the majority of which are located in Africa and South Asia (Kamara 1986; Mercer and Soussan 1988; Rehfuess et al. 2006; Smith et al. 2014). Hence, the pattern of energy consumption by households can be considered as an indication of a country's well-being (Singh and Gundimeda 2014). The fuelwood consumption pattern within such regions varies considerably depending on availability and accessibility of commercial or other sources of energy (Alvarado and Mies 2011). Even the better-off households in these regions who had access to commercial sources of cooking energy such as LPG or electric stoves continued to use fuelwood, as they considered food to be tastier when cooked using fuelwood (Elkan 1988; Dunkerley et al. 1990; Joshi et al. 1991c). The higher population growth in these regions has led to an increase in the number of people dependent on fuelwood despite the decrease in its share of total global energy. When lacking fuelwood, the poorer households are forced to use agricultural residues, dung cake and shrubs, which are considered as inferior sources (Barnes et al. 1993; Holdern and Smith 2000). When even such inferior sources are lacking, households reduce the number of cooked meals from two to one, or prepare inadequately cooked food which has negative health impacts especially on children and women due to the low nutritional level (Adams et al. 1980; Cecelski 1984).

The existing practice of burning of fuelwood in the house in an inefficient way has caused severe problems in connection with indoor air pollution, which is a serious health concern especially for women and children. Furthermore, the massive and unsustainable harvesting of fuelwood has negative consequences not only for the environment but also for socio-economic conditions. As explained by Mercer and Soussan (1998), the nature of such consequences varies from place to place depending on the biophysical/environmental and socio-economic conditions of the particular area.

Various interventions have been made in order to reduce or replace the traditional way of fuelwood consumption at household level particularly in developing countries by introducing alternative energy technologies (Mendis and van Nes 1999; Kristoferson and Varis 2013; Singh 2014). As they are relatively cheap and user-friendly, improved cooking stoves have been the most widely disseminated technology in rural areas of developing countries (Barnes et al. 1993; Wallmo and Jacobson 1998; Adkins et al. 2010; Jeuland and Pattanayak 2012) . Depending upon availability of feedstock and affordability, the household level biogas technology has also been promoted to various areas (Islam et al. 2006; Wu et al. 2010; Hazra et al. 2014). As indicated by Masera et al. (2000), Heltberg (2004) and Heltberg (2005), the households adopt multiple sources of energy where the use of each source or technology is defined by different local variables such as economy, seasons, dietary variation, end-applications and cooking requirements.

Being a developing country, the trend of fuelwood consumption in the Nepal context is not different to that in other developing countries. Although the share of fuelwood in total primary energy consumption remained stagnant between 1992/93 and 2010/11 (70-72 %), the actual consumption of fuelwood increased by about 31 % in this period (WECS 2014). As estimated by Pokharel and Chandrashekhar (1994), the energy from the use of fuelwood in 1992/93 was 199 PJ whereas in 2010/11, it was 262 PJ (WECS 2014). In 2010/11, 95 % of the total annual fuelwood consumption was at household level for cooking and heating, which represents about 87 % of the total household energy consumption(WECS 2014).

About 40 % of the area of the country (5.8 million ha) is estimated to be covered by forest in which the share of forest land and shrubland is 29 % and 10.6 %, respectively (DFRS 1999). Within a period of 15 years (1979-94), the forest area decreased by 24 % at an annual rate of 1.6 % (Dhital 2009)**.** The recently conducted forest assessment in the lowland areas revealed that the annual decrease rate was 0.44 % and 0.40 % for the periods 2001-2010 and 1991-2010, respectively (FRA/DFRS 2014). Most of the forest areas have been cleared in the lowland for cultivation, and hence the forest resources are mostly concentrated in hilly and mountainous areas (Bluffstone 1998).

The fuelwood consumption rate in Nepal is higher than the carrying capacity, which is causing land degradation and forest encroachment (Metz 1990; Sharma 1991; WECS 2010). Based on a study on the hilly regions of the country, Bluffstone (1995) concluded that open access to the forests, rural poverty and excessive population growth were the fundamental causes of forest degradation. Salerno et al. (2010) found the average reduction of forest biomass from 1992 to 2008 in one of the remote mountain areas was 38 %, where massive consumption of fuelwood for energy due to tourism growth was identified as one of the major reasons.

The literature on Nepal also revealed that level of fuelwood consumption in any particular area is mainly governed by availability and accessibility of modern cooking and heating energy services (Rijal et al. 1990; Malla 2013; Parajuli et al. 2014). Because of the fuelwood deficit, the use of agricultural residues and dung cake is quite extensive especially among poor households in the lowland (WECS 2010; K.C. et al. 2011; Panta 2013). The growing trend of urbanization[4] as well as the expansion of roads to rural areas the country has led to exponential growth of imported LPG in the past 20 years (NOC 2015). At the same time, the consumption of kerosene in Nepal drastically dropped to 24,000 L in 2012/13 from 162,000 L in 1993/94 (NOC 2015) with the replacement of LPG, which reveals the popularity of LPG among Nepalese households.

Although 56 % of the households are connected to the national grid line, the use of electricity for cooking and heating is quite negligible, as the supply of electricity is low compared to the demand, and hence regular electric load-shedding takes place (NPC 2013). With the intervention of clean cooking energy programs, the major technologies biogas and improved cooking stoves (ICS) are disseminated to about 15 % of households in the country, which are mainly located in rural areas (AEPC 2015b). Households in developing countries generally adopt multiple energy sources (Barnes and Floor 1996; Masera et al. 2000; Heltberg 2005). The situation in Nepal follows the same trend, and thus the evaluation of fuelwood consumption at the household level is relatively complex. As the consumption pattern of different sources of energy varies not only with location but also with season as described by Bajracharya (1983), Singh et al. (2010), Marufu et al. (1999), Ramachandra et al. (2000) and Rijal et al. (1990), a study focusing only on a particular area and particular sources of energy does not provide a correct picture of the energy consumption situation.

Many studies evaluated fuelwood consumption at household level by focusing on particular geographical locations at a specific point of time. Some of the studies were intensively conducted to evaluate fuelwood consumption by measuring it on a daily basis for at least a week (Bajracharya 1983; Fox 1984; Mahat et al. 1986; Metz 1994) . A relatively larger number of studies was carried out on the basis of respondents' recall of the number of bundles of fuelwood they used (Shrestha 1985; Amacher et al. 1999; Adhikari et al. 2007; Webb and Dhakal 2011). As the main aim of

[4] Annual rate of urbanization in Nepal 2010-2015 is estimated at 2 % (UN 2014).

these studies was to evaluate fuelwood consumption, the studies ignored the use of alternative energy sources. As energy mix has been increasing throughout the country (WECS 2014), the effect of the use of different energy sources on fuelwood consumption is a vital aspect in the evaluation of the effectiveness of those sources. There are very few studies in the Nepalese context which deal with quantification of different energy sources on the household level. For instance, a study conducted by Rijal et al. (1990) in a lowland area in Nepal revealed that the total annual useful energy consumed by a household was about 100 GJ, where the share of livestock dung, agricultural residues, fuelwood and commercial energy (kerosene and electricity) in the total energy consumption was 63 %, 23 %, 9 % and 5 %, respectively. In one of the villages in the hills, the share of fuelwood, agricultural residues, kerosene and electricity was found to be 93 %, 4 %, 2% and 1 %, respectively (Pokharel 2000). Rijal (2000) conducted a study to assess variation of fuelwood consumption in five districts in different topographical regions in the country, where some households used mixed energy sources comprising fuelwood, LPG, kerosene and crop residues. However, the distribution (number) of households in that study was not clearly defined, which makes it difficult to interpret the results.

Studies also estimated the annual per capita fuelwood consumption assuming uniform consumption throughout the year. However, some studies revealed that additional fuelwood is consumed for space heating during the winter (Fox 1984; Shrestha 1985; Cooke 2000; Pokharel 2003). While examining the seasonal variation of fuelwood consumption in one of the villages in a hilly area, Fox (1984) found a significant variation of fuelwood consumption during different seasons with the highest consumption being in winter . Although slight variations among the other seasons were observed, he observed that these variations were related to the variation of the moisture content of the fuelwood. Metz (1994) evaluated fuelwood consumption in different seasons in one of the upper elevation villages where all households consumed fuelwood throughout the year. Furthermore, the annual fuelwood requirement for space heating is highly dependent on altitude (Rijal and Yoshida 2002; Bhatt 2004). The households in fuel-deficit areas extensively use agricultural residues and dung cake instead of fuelwood for space heating (Pokharel and Chandrashekhar 1994; Kanu 2014).

In this chapter, the prevailing pattern of fuelwood consumption at household level with different combinations of energy sources for the three main topographic regions in Nepal is evaluated. By analyzing the effective uses of alternative energy sources, the study further assesses the seasonal variation of fuelwood consumption between the winter and the rest of the year.

3.2 Methodology

The data used in the study is from household surveys using two questionnaires (Q1 and Q2). The major aspects covered in Q1 were estimation of annual fuelwood consumption, harvesting schedule, fetching time, status of additional fuelwood consumption for space heating during the winter, and the main fuelwood tree species. The number and weight of each bundle of fuelwood used in a year by the sample households was reported.

The purpose of Q2 was to assess the variation of fuelwood consumption between the winter and the rest of the year by measuring the actual consumption for fulfilling the daily energy needs over 24 h at household level for 7 days in each of the 27 sample households, and to estimate the 'fuelwood equivalent' of other energy sources. The households used a mix of different kinds of energy such as fuelwood, biogas, dung, saw dust, crop residues, kerosene, LPG, and electricity (rice-cooker). The households in the lowland had 15 different combinations of such sources whereas in the hills 8 were observed. All sample households in the mountains only used fuelwood. Based on aggregated information from Q1, the households in all study districts were categorized into three different groups by considering three modes of energy mixes, i.e., fuelwood only (F), fuelwood plus biogas (FB), and fuelwood, dung cake and crop residues (FDC). The households using only fuelwood are located in the mountain district, the households with fuelwood plus biogas in the hill district, and the households with fuelwood, dung cake and crop residues in the lowland district. In case of solid biomass (fuelwood, dung cake, crop residues), the daily consumption of each biomass type was weighed, while in the case of biogas, consumption was derived on the basis of time of biogas operation to cook food (see Chapter 6). Detailed information was noted for each application category such as type of cooked food/fodder, cooking time, number of food consumers, and type of stove vis-à-vis biomass energy sources used over 24 hours.

3.3 Results and discussion

3.3.1 Harvesting practices

The forests in Nepal are broadly classified into two categories, i.e., national forest and private forest. Based on the management system, national forest is further divided into five classes: government managed, protected, community, leasehold and religious (Amatya and Shrestha 2010b).

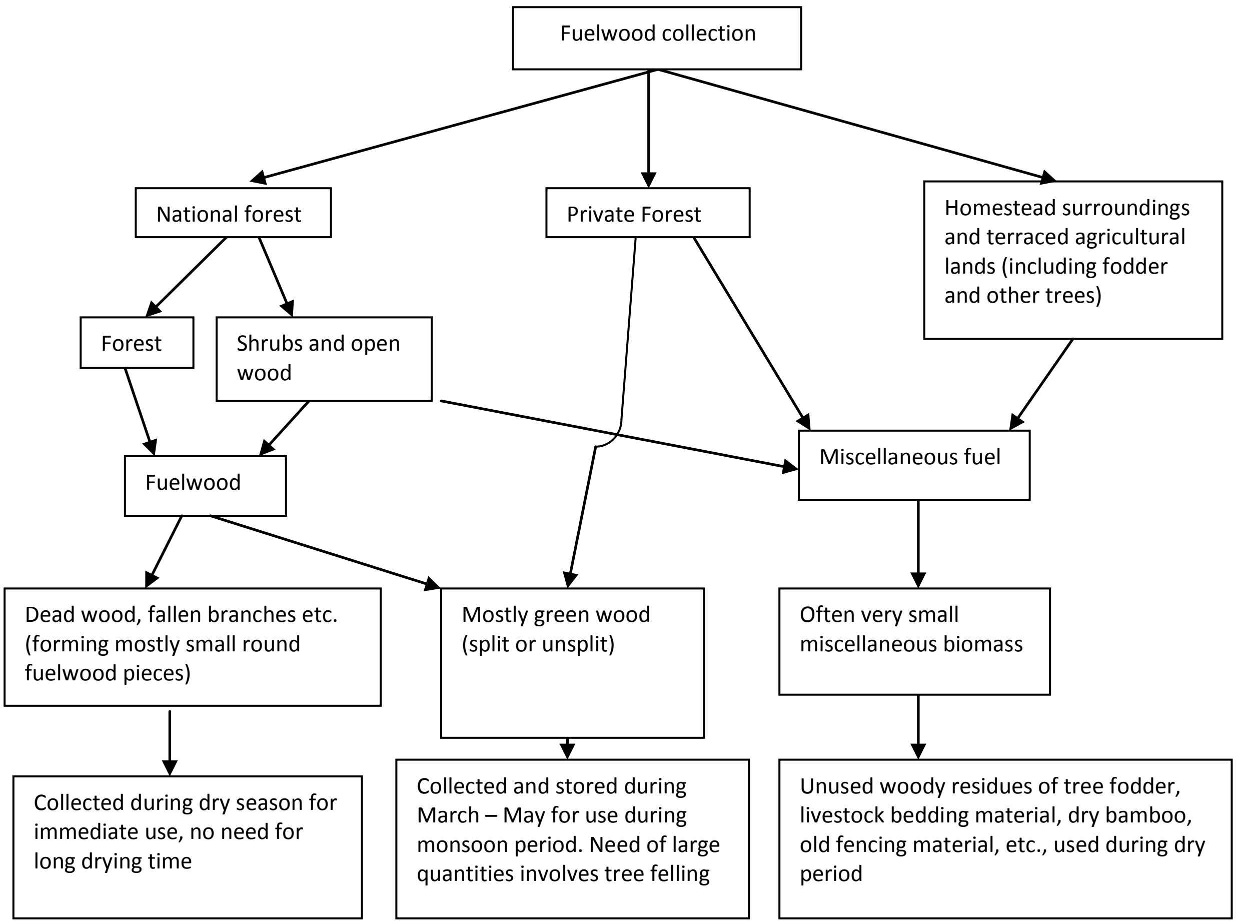

Figure 3.1 Fuelwood sources and harvesting methods in Nepal (adapted from Mahat, 1987)

In view of fuelwood supply, besides from these forests, the households were also observed to collect various forms of woody residues from the homestead surroundings (Bajracharya 1983; Mahat 1987).The contribution of each energy source greatly varied according to availability and accessibility (Figure 3.1). The national forest was highly prioritized for collecting fuelwood while the share of other sources varied. As the distance to the national forests from the households was in most cases higher than that of the other two sources, workload and availability of human resources also played a significant role with respect to the quantity of fuelwood collected from the national forest. In the lowland, because of the few forests there, fuelwood was complemented by crop residues and dung cake whereas the use of these two energy sources was negligible in the hills and mountains (Mahat 1987).

In the present study, all households in the mountain and hill districts had access to the national forest whereas this was limited to only 20 % of the lowland households. The common method of fuelwood harvesting was cutting off branches from the end of February to the end of April, and leaving them for one to two months for drying. Then, depending upon the available time, the fuelwood was transported to the house and stacked in a pile for further drying. This was also observed by Bajracharya (1983) and Mahat (1987) during surveys in the rural areas of Nepal. The harvesting period was based on time availability, as most of the households were fully occupied from May to August with cereal crop cultivation, and from September to November with harvesting. Hence, the households collected fuelwood that had to last till the end of December. The cropping pattern varied strongly in the study districts and consequently the growth and harvesting period. During the remaining months, the households collected dead wood, felled parts of trees, and collected fuelwood from around their homesteads. Fuelwood collection was frequently once a week, however no trend was observed. Frequency of collection also depended upon the weight of the bundles and fuelwood consumption by particular households. Some households collected fuelwood four times a week. It was also observed that fuelwood was collected from along the pathway by children on their way home from school or by herders.

3.3.2 Main fuelwood tree species

The ten main fuelwood tree species in the sampled households are listed in Table 3.1.

Table 3. 1 Main fuelwood tree species in the study districts

Lowland		Hill		Mountain	
Local name	**Botanical name**	**Local name**	**Botanical name**	**Local name**	**Botanical name**
Kadam	*Neolamarckia cadamba*	Chilaune	*Schima wallichi*	Banjh	*Quercus leucotricophora*
Bamboo	*Bambusa vulgaris*	Musuro katush	*Castanopsis tribuloides*	Khote sallo	*Pinus roxburghii*
Sishau	*Dalbergia sissoo*	Uttish	*Alnus nepalensis*	Uttish	*Alnus nepalensis*
Bakaino	*Melia azedarach*	Kafal	*Myrica esculenta*	Rato gurans	*Rhododendron arboretum*
Kalo sirish	*Albizzia lebbeck*	Saal	*Shorea robusta*	Aayar	*Lyonia ovalifolia*
Aap	*Mangifera indica*	Kutmiro	*Litsea polyantha*	Khasru	*Quercus semecarpifolia*
Kutmiro	*Litsea polyantha*	Pakhuri	*Ficus hispida*	Chiuri	*Aesandra butyraceae*
Ipil	*Leucaena leucocephala*	Ginderi	*Premna integrifolia*	Okhar	*Juglans regia*
Teak	*Tectona grandis*	Gogan	*Sauraria nepalensis*	Tooni	*Cedrela toona*
Sakhuwa	*Shorea robusta*	Khanayo	*Ficus cunia*	Tantari	*Dellenia pentagyna*

3.3.3 Pattern of fuelwood consumption

The average number of bundles of fuelwood collected by households in a year and the average weight of each bundle for three study districts is presented in Table 3.2. The households in the mountain district collected the highest number of bundles as compared to those in the hill and lowland districts.

Table 3. 2 Mean number of bundles of fuelwood in a year and weight of each bundle

District		Observations	Mean	SD	Min	Max
Lowland	No. of bundles	52	51	33	40	150
	Weight of each bundle (kg)		27	5	21	45
Hill	No. of bundles	80	71	37	17	180
	Weight of each bundle (kg)		37	9	21	68
Mountain	No. of bundles	80	132	55	38	300
	Weight of each bundle (kg)		36	9	23	61

Based on the results of Q1, the average annual fuelwood consumption was estimated (Table 3.3). The rate of fuelwood consumption is influenced by the use of other energy sources. Hence, for a sound comparison of fuelwood consumption, the households need to have a similar combination of energy sources. In the households in the lowland and hills, this varied strongly. The distribution of these households with a particular combination within the three altitudinal zones in the hill district and in the rural and urban zones in the lowland district was however uneven, and in some cases not one representative household was present in the respective zone, which made it difficult to evaluate the variation of each combination of energy sources. Hence, by considering only the households using only fuelwood, the variation of fuelwood consumption was evaluated both within these zones in each district and among the districts. However, in the case of the lowland district, the number of such households was limited to only seven (three in urban and four in the rural zone), and hence a single district level value of fuelwood consumption was considered.

Table 3. 3 Mean annual per capita fuelwood consumption (kg $capita^{-1}$ yr^{-1}, air-dried)

District	Zone	Observations	Mean	SD	Min	Max
Lowland	Rural & Urban	7	467	183	386	685
Hill	< 1000 m	7	633	275	365	1310
	1000 – 1500 m	9	812	240	429	1095
	> 1500 m	12	892	370	425	1500
Mountain	< 1500 m	32	682	421	328	2310
	1500 – 2000 m	28	715	367	263	2100
	> 2000 m	20	742	313	364	1500

The annual average per capita fuelwood consumption ranged from the lowest value of 467 kg in the lowland to the highest of 892 kg in the hill zones (Table 3.3). In order to test the variations of mean fuelwood consumption among the respective altitudinal zones in the hill and lowland districts, a one-way ANOVA test based on the Bonferroni model was applied (Milliken and Johnson 2009) (Table 3.4).

Table 3. 4 Mean differences in fuelwood consumption

	Difference (kg)	Significance level
District		
Hill vs. lowland	346	0.000
Hill vs. mountain	84	0.663
Mountain vs. lowland	278	0.000
Zone		
H2 vs H1	179	0.653
H3 vs H2	79	1.000
H3 vs H1	258	0.191
M2 vs M1	34	1.000
M3 vs M2	27	1.000
M3 vs M1	61	1.000

H1 = less than 1000 m, H2 = 1000 to 1500 m, H3 = above 1500 m for the hill district

M1 = less than 1500 m, M2 = 1500 to 2000 m, M3 = above 2000 m for the mountain district

As expected, the district-wise variation in fuelwood consumption clearly reveals that fuelwood consumption was significantly lower in the lowland district as compared to the hill and mountain districts. However, no significant variation was observed between the hill and mountain districts. The results from the hill and mountain districts are unexpected. It was expected that the households at higher altitudes consume more fuelwood than those from the lower because of the likely higher need of fuelwood during the cold periods (Bhatt 2004). A positive relation between fuelwood consumption and altitude was also observed in different parts of the world (Türker and Kaygusuz 2001; Dhanai et al. 2014; Mislimshoeva et al. 2014; Kumar and Kumar 2015). Because of the lack of comparable studies on the variation of fuelwood consumption at different altitudes in Nepal, the consistency of the results in this study could not be investigated. The other crucial aspect is that almost all sample households above 1500 m were in an indigenous community in the hill district where the tradition of brewing local beer exists. The annual per capita consumption of fuelwood for brewing beer was observed to be 183 kg (±80 kg). The evaluation was done on the basis of information obtained from 12 households. The average annual per capita beer consumption was 76 l with relatively higher consumption during the winter and festivals. The fuelwood needed to produce one liter of beer was 2.4 kg, whereas Rajbanshi (2005) observed 1.9 kg in an area closer to the capital city (Kathmandu). Higher fuelwood consumption in the zone where households brewed beer was also observed by Amacher et al. (1993, 1999), Bajracharya (1983) and Pokharel (1991). These studies did not clearly show the level of significance of variation in fuelwood consumption between brewing and non-brewing households while Fox (1984), however, did observe significant differences.

Taking into consideration the insignificant variation in fuelwood consumption, it might be assumed that fuelwood harvesting and consumption methods were similar both within and among the hill and mountain districts. Because of good access to the forest, the quantity of fuelwood collected was independent of the actual demand, which entirely depended upon the traditional practices, and there was the tendency of relatively higher consumption than demand. Various studies in Nepal (Arnold and Jongma 1977; Bajracharya 1983; Varughese 2000; Sah and Heinen 2002) also revealed that the households with good forest access usually consumed more fuelwood than actually required.

Fuelwood consumption in Nepal on an annual per-capita basis from selected literature was reviewed to determine the range (Table 3.5). As no significant variation in fuelwood consumption between the hill and mountain districts was observed in this study, a single average value was estimated: 735 kg in the mountain and hill districts and 467 kg in the lowland. Both values lie within the range documented in the literature (Table 3.5).

Table 3. 5 Fuelwood consumption in lowland, hill and mountain areas in Nepal

Regions	Source	kg capita^{-1} yr^{-1} (air-dried)	Altitude of households
Mountains/ Hills	Fox (1984)	570	1200 m
	Bajracharaya (1983)	940	600 – 2000 m
	Webb and Dhakal (2011)	683	400 – 1650 m
	Mahat et al. (1986)	408	600 – 2360 m
	This study	746	450 – 2350 m
Lowland	WECS (1987)	315	Below 250 m
	Soussan et al. (1991)	400	
	Thapa and Chapman (2010)	483	
	Shrestha (2007)	247	
	Subedi et al. (1993)	479	
	This study	467	

3.3.4 Drivers of fuelwood consumption

Several studies analyzed the effect of various socio-economic, cultural and environmental factors on fuelwood consumption at household level (Amacher et al. 1999; Malla et al. 2003; Baland et al. 2005; Lamichhane 2009). However, the findings are inconsistent. Hence, in order to identify and understand these factors, a regression analysis was performed. The variation of annual per capita fuelwood consumption was analyzed based on seven explanatory variables (Table 3.6).

Table 3. 6 Explanatory variables for regression analysis

Income	Annual per capita income in Nepali rupees (NPR)
Land	Area of cultivated land (ha)
Household size	Number of persons living and cooking together in a house
Fetching time	Time to fetch fuelwood (h)
Livestock	Number of livestock owned by a household
Caste	Categorization of households; brewing or not brewing beer (if yes 1; otherwise, 0)
Energy sources	Based on availability of various energy sources, the households were classified into F, FB, FL, FD and FDC by defining levels of 1, 2, 3, 4 and 5, correspondingly (F =1 as a base level)

F = fuelwood only, FB = fuelwood and biogas, FL = fuelwood and LPG, FD = fuelwood and dung, FDC = fuelwood, dung and crop residues

Based on the energy sources, 15 different combinations were determined. However, because of the lack of a sufficient number of households for all combinations, only the households as categorized by energy sources (Table 3.6) were considered for the analysis as these existed in more than 8 households (Table 3.7). Eleven (11) households were not considered in the regression analysis that had combinations of energy sources different to those listed in Table 3.7.

Table 3. 7 Distribution of households in terms of energy source combinations in the study districts

Energy source combination	**Number of households**
Fuelwood only (F)	115
Fuelwood and biogas (FB)	33
Fuelwood and LPG (FL)	29
Fuelwood and dung (FD)	11
Fuelwood, dung cake and crop residues (FDC)	31

Since the test on homoscedasticity (equal variances) for fuelwood consumption with the explanatory variables was significantly rejected (p = 0.0000; Breusch-Pagan test), robust ANOVA via robust regression was used (Milliken and Johnson 2009). The results of the regression show that only household size and energy sources significantly defined the annual fuelwood consumption, whereas other factors had no influence (Table 3.8).

Table 3. 8 Factors affecting fuelwood consumption (regression analysis

Variable	**Coefficient**	**SE**	**T**	**Significance level**
Income	0.0046	0.002	0.35	0.728
Household size	-51.503	9.240	-5.57	0.000
Cultivated land	24.591	23.959	1.03	0.306
Livestock	-6.224	9.850	-0.63	0.528
Time to fetch	10.926	12.134	0.90	0.369
Caste	-19.560	47.040	-0.42	0.678
Energy types				
FB	-327.218	59.556	-7.17	0.000
FL	-382.814	73.971	-5.18	0.000
FD	-323.036	73.008	-6.75	0.000
FDC	-313.167	36.008	-7.65	0.000

n = 219. F (10, 208) = 12.73; probability > F = 0.000; R^2 = 0.439; root mean squared error = 268.76

The presence of livestock was also observed to have no effect on fuelwood consumption. In a study Lamichhane (2009) also observed no correlation between number of livestock and fuelwood consumption. In fact, not all livestock were provided with cooked fodder on a regular basis. It is common to only prepare cooked fodder for lactating livestock and in some cases for all livestock during extremely cold days in winter. In the hill and mountain districts, livestock fodder was also prepared in stoves which in some cases were outside the house where fuelwood was complemented by corn residues, small twigs and other biomass generated from kitchen garden waste. As such biomass produced a relatively high amount of smoke, the households preferred to cook outside. In the lowland district, households extensively used crop residues and dung cake for cooking and heating due to the lack of fuelwood.

No correlation between fuelwood fetching time and consumption was observed. This was the case in most of the households in the hill and mountain districts, as they had good forest access. In addition, in connection with livestock herding in the forest areas the herders could collect fuelwood daily. It was not important for those households to be near a forest area because rearing livestock was an integral part of their livelihood. Bajracharya (1983) and Amacher et al. (1993) observed that fuelwood collection in rural Nepalese households also offered opportunities for child care and socialization. However, because of the relatively low forest in the lowland, most of the households limited their fuelwood collection to the supply from nearby sources such as homestead surroundings and private wood lots.

Household income was not observed to influence fuelwood consumption in any of the three study districts. Some earlier studies found relatively higher fuelwood consumption by wealthier households than by poor households(Malla et al. 2003; Adhikari et al. 2004; Baland et al. 2005). Their arguments were related to availability of private fuelwood sources and higher potential of mobilizing labors to collect fuelwood of the wealthier households. In contrast, Sapkota and Odén (2008), and Fox (1984) argued that poor households were unlikely to switch to alternative energy technologies such as biogas, LPG, electricity and kerosene as compared to wealthier households because of the costs associated with these technologies. Hence their fuelwood consumption should have been higher than that of wealthier households.

The analysis of the prevailing contribution of clean cooking sources such as biogas and LPG to curtail fuelwood consumption is of great importance especially for energy policy makers. The variations of energy consumption between households only using fuelwood and the households using two different combinations of energy sources (fuelwood and biogas, and fuelwood and LPG) in the hill and lowland districts are analyzed in Chapter 6.

3.3.5 Seasonal variation

Additional fuelwood was used by the households in the mountain (41 %), hill (33 %) and lowland (12 %) districts during the winter for heating, whereas there was no difference in the other seasons. As crop residues and dung were extensively utilized for heating in the lowland district, the seasonal variation of fuelwood consumption there was analyzed by applying the fuelwood equivalent of crop residues and dung. Thus, the seasonal variation is described in terms of biomass consumption to incorporate fuelwood, dung and crop residues.

Because of the highly diversified settlements along different altitudinal ranges within each district, it was difficult to define the duration of winter for a district. The households' responses in the questionnaires were classified into three groups of above 1500 m, 1000-1500 m and below 500 m in order to represent the unique characteristics of mountains, hills and lowland, respectively, based on which the average duration of the winter period was estimated. The average monthly temperatures were obtained from the Department of Hydrology and Meteorology in Kathmandu where the data for the hill and lowland districts were from the respective study districts, whereas due to the lack of information from the mountain district, the data of another similar mountainous district was used. As the lowest temperature was in January in all districts, the average maximum and minimum temperatures of the years 2001 to 2010 were calculated (Table 3.9).

Table 3. 9 Duration of winter season with average monthly temperatures (2001 – 2010) for the study districts

District	Duration of winter	Average monthly temp. in January[a] (⁰C)	
		T_{max}	T_{min}
Mountain	4.5 months (mid Oct. to end of Feb.)	11	0
Hill	3.5 months (Nov. to mid Feb.)	16	3
Lowland	3 months (Nov. to end of Jan.)	22	8

Source: DHM 2014(a)

The biomass consumption per capita per day during the winter and the other seasons was used to analyze the seasonal variation (Table 3.10).

Table 3. 10 Daily biomass consumption in winter and other seasons (kg capita-1day-1, air-dried)

District	Observations	Winter	Other seasons
Mountain	9	2.20 (0.84)	1.38 (0.39)
Hill	9	2.37 (0.54)	1.80 (0.99)
Lowland	9	1.52 (0.67)	0.99 (0.42)

Values in parentheses represent standard deviations

A further analysis was carried out in those households who did not consume extra biomass energy during the winter. Based on the responses of the households, the reasons for not utilizing additional biomass during the winter were categorized into three main groups: 'supply constraints', 'not necessary' and 'television impact', where television influenced the households' use of extra biomass, as the people watched TV in a room without heating and, therefore, fuelwood was saved in the evening (Table 3.11).

Table 3. 11 Percentage distribution of households with and without extra heating in the study districts

District	**With extra heating (%)**	**Without heating**		
		Supply constraints (%)	**Not necessary (%)**	**Television impact (%)**
Mountain	41	18	30	11
Hill	33	11	34	22
Lowland	12	50	10	28

Those households that needed but did not use extra fuelwood because of the scarcity of fuelwood were categorized under 'supply constraints', whereas 'not necessary' represented the households that did not require extra fuelwood regardless of the supply situation. The 'supply constraints' households fulfilled their heating needs while cooking. The family gathered around the stove while the cooking was done to keep warm and after the evening meal they immediately went to bed. This revealed that the higher the scarcity of fuelwood, the less extra fuelwood was used as also indicated by Meyers and Leach (1989), and that the households tended to optimize the energy use by the use of the same energy source for cooking and heating. The majority of the 'not necessary' households were south facing and located at altitudes of less than 1000 m, and are unlikely to use extra fuelwood because there is more sunshine and it is less cold so that the house is relatively warmer. Regarding the television impact, as television was watched in a room without heating, one might argue that this led to a reduction in fuelwood consumption.

3.3.6 Fuelwood fetching time

The task of fetching fuelwood is both labor intensive and time consuming. The fuelwood fetching time was dependent not only on distance between forest and household but also on the terrain to be crossed. The time required to fetch a unit bundle of fuelwood was analyzed for all zones within each study district (Table 3.12). A unit bundle is the bundle of fuelwood that a single person can carry from the forest to the house. The weight of the bundle varied not only from district to district but also from place to place within a single district (Table 3.2). Even the weight of a bundle collected by the same person varied throughout the year. The fuelwood species, fuelwood moisture content, distance and trail accessibility between forest and house, and the typical physical characteristics (age, gender, height and weight) of the respective fuelwood collector were observed as major determinants of the weight of the bundle.

The average fuelwood fetching time was observed to be relatively higher in the mountainous as compared to the hill and lowland districts (Table 3.12). However, the time required in the hill district was less than that in the lowland district. The higher fetching time in the mountain district is likely due to the relatively higher altitudes, which reduce the walking speed. However, the fetching time above 2000 m is lower than that of the range of 1500 – 2000 m in the mountain district, which indicates that forest accessibility there might be poorer at that altitude, i.e., the forest areas there are more widely distributed.

Table 3. 12 Fuelwood fetching time in study districts (hrs)

District	Zone	Observations	Mean	SD
Lowland	Rural	42	2.80	1.46
	Urban	14	2.75	1.46
Hill	< 1000 m	29	1.87	0.37
	1000 – 1500 m	24	1.92	0.67
	> 1500 m	17	2.02	0.81
Mountain	< 1500 m	21	4.08	2.97
	1500 – 2000 m	30	6.68	3.21
	> 2000 m	18	4.43	3.08

Because of the smaller area of national forests in the lowland district, the majority of the households relied on fuelwood obtained from private forests and homestead surroundings. In a study in one of the lowland regions (Soussan et al. 1991), it was observed that because very little fuelwood was available, some villagers travelled more than a day to fetch fuelwood. However, this was not observed in this study. The fuelwood fetching time for the different altitudinal zones in the study districts (Table 3.13) indicates that the households at 1500 – 2000 m spend the most time whereas the lowest fetching time is for the households at 500 – 1000 m.

Table 3. 13 Fuelwood fetching time at different altitudes (hrs)

Altitudinal zone	Observations	Mean	SD
< 500 m	53	2.78	1.44
500 – 1000 m	38	2.29	1.15
1000 – 1500 m	44	3.15	2.71
1500 – 2000 m	35	6.02	3.45
> 2000 m	25	4.20	2.99

3.3.7 Fuelwood price

In the hill and mountain districts, none of the households purchased fuelwood for cooking or heating. In the lowland district, 13 households bought fuelwood at the market. These households tended to limit their fuelwood consumption by using biogas, dung and crop residues depending on availability. The price they paid for the fuelwood was considered in the analysis. In order to estimate the monetary value of fuelwood in the hill and mountain districts, the respondents were asked the price of fuelwood in case they sold to the nearby market or district centers. A fuelwood market in these districts existed only at the district centers and in their vicinity where the customers were small hotels and restaurants. Thus, the price in these districts was taken from these customers. In the price comparison, the statistical parameters are based on cost (Euro[5]) of hundred kg of fuelwood (Table 3.14).

Table 3. 14 Fuelwood prices in the study districts (Euro per 100 kg)

District	Observations	Mean	SD	Min	Max
Lowland	13	7.33	0.96	3.31	10.76
Hill	40	3.52	2.44	2.07	5.17
Mountain	68	4.29	2.26	1.03	10.35

The lowest price for 100 kg of fuelwood was Euro 1.03 in the mountain district and the highest in the lowland district with Euro 10.76.

3.4 Conclusions and recommendations

There is no significant variation in annual per capita fuelwood consumption for the households with only one source of fuelwood between the three different altitudinal ranges within a district and also between the hill and mountain districts. However, the

[5] 1 Euro = 120.73 NPR (13 September, 2015)

households in the lowland district use a significantly lower amount of fuelwood than in the aforementioned districts. The relatively lower forest resource in the lowland is the main reason. Given the insignificant variation of fuelwood consumption in the hills and mountains, it can be concluded that the fuelwood consumption trend is similar in those households regardless of the actual demand. For all districts, fuelwood consumption is independent of income, area of cultivated land, fetching time, number of livestock, and caste whereas it depends on family size and energy source.

The implementation of clean cooking energy programs in the mountains where all households only use fuelwood is negligible. Because of the difficult transportation situation due to the mountainous terrain, even the better-off households cannot adopt LPG. In the hill and lowland districts, a positive impact in households with biogas and LPG was observed, as those households used significantly lower amounts of fuelwood than the households using only fuelwood. The variation in fuelwood consumption among the former households is non-significant in both the hill and lowland districts. Despite the relatively better accessibility of clean energy sources because of good transport and market facilities, most of the households in the lowland district compensate the fuelwood deficit by using crop residues and dung cake; this is not only related to economic but also to cultural aspects.

Policies to motivate households to not harvest more fuelwood than they need could reduce over-utilization of fuelwood in households in forest-rich areas in the hills and mountains. There is an urgent need to amend prevailing energy policies so that the households in fuelwood-deficit areas, especially in the lowland, replace crop residues and dung cake with clean cooking sources. For instance, amendment of the policies to this end should include introduction of special financial offers to adopt biogas by prioritizing fuelwood-deficit areas, and enhanced information to farmers about the detrimental effects of dung burning.

As this study only covers households with four different energy combinations, it is recommended to analyze the fuelwood consumption pattern in households with other combinations. Personal communication in this study revealed that out-migration and TV in the villages have different impacts on fuelwood consumption, and it can be assumed that other socio-economic factors need to be studied to gain sound information on fuelwood consumption in Nepal.

4 POTENTIAL OF CROP RESIDUES FOR ENERGY GENERATION

4.1 Introduction

In general, crop residues are all non-edible parts of a crop remaining aboveground in different stages from harvesting until final processing, i.e., residues in the field and processed parts (Koopmans and Koppejan 1997; Lal 2005). For instance paddy straw is an example of field residues whereas paddy husks are the residues obtained after processing. Depending on the harvesting method, there are different forms of field and processed-based residues.

Around 2.6 billion people in developing countries rely on various forms of biomass (fuelwood, charcoal, animal dung and agricultural residues) for cooking energy requirements (IEA 2013). The share of crop residues in terms of dry matter is more than 50 % of the global agricultural phytomass (Smil 1999) . With a share of 75 %, cereals were the largest category of crop residues with a global production of 2.8 billion t in 2001 (Lal 2008). About 60 % (0.3 billion t) of China's annual production of crop residues was consumed for cooking and heating in rural households in China (Jinming and Overend 1998). Many studies suggest that poor households in developing countries usually tend to switch to inferior energy sources, mainly agricultural and livestock residues, when fuelwood becomes deficient (Meyers and Leach 1989; Arnold et al. 2006; Joon et al. 2009; Kristoferson and Varis 2013).

Of various energy conversion technologies, direct combustion of crop residues is the most common. This is the most inefficient way of energy generation with severe impacts on the environment in conjunction with indoor air pollution (Leach and Gowen 1987). Different modern technologies for converting the energy from crop residues exist such as anaerobic digestion, gasification, briquetting, liquefaction, carbonization, bio-coal, etc. (McKendry 2002; Demirbas 2004; Sims et al. 2006; Zeng et al. 2007).

Presently, particularly in developing countries, a large part of the crop residues are either left in the field, which leads to methane and carbon dioxide emissions during decomposition, or burnt in open areas with the release of gaseous emissions and black carbon. Thus, both activities result in greenhouse gas (GHG) emissions (UNEP 2009). From the perspective of soil nutrients and crop production, the decomposition of crop residues in the field has both positive and negative effects (Kumar and Goh 1999). The positive effects are on soil function are by protection from erosive forces, increasing or maintaining soil organic matter, improving water conservation and storage, adding to the available pool of soil nutrients, and improving soil structure and crop yields (Power et al. 1998; Andrews 2006). Some researchers reported that residues may have negative effects on crop production by increasing crop diseases (Sumner et al. 1981; Govaerts et al. 2007) and the subsequent need for extra nitrogen fertilizers (Green and Lackmer 1995).

To combat the overriding challenges of climate change and energy security, crop residues, being a carbon-neutral source, are considered as one of the potential alternative sources to reduce the increasing demand of fossil fuel (UNEP 2009). Many developed and industrialized nations initiated the energy use of crop residues in modern applications, the rate of which is increasing (Callé and Rosillo-Calle 2007). Looking into the uses of crop residues in developing countries, the effective utilization of crop residues for energy generation can ameliorate the energy security by reducing GHG emissions. A systematic study should be conducted to obtain production details of specific crop residues along with their various alternative uses in order to address the sustainability of the energy uses of the residues.

Apart from occasional estimations as part of studies assessing the potential for maintaining better agro-ecosystems or the scope for biomass energy production, no nation has statistics of the production of crop residues (Smil 1999). This may be because of their versatile and random uses (Lal 2005). Different literature is available on the estimation of the gross and technical potential of crop residues for energy uses (Milhau and Fallot 2013). These estimates are based on the data of crop production, which uses the Residue to Product ratio (RPR) (Callé and Rosillo-Calle 2007). The ratio refers to the weight of the air-dried residues available after processing a harvested crop to the weight of grain obtained from the same process (FAO 2014). Koopmans and Koppejan (1997) reviewed the literature on RPR values for various crops. Based on different studies in various geographical regions of the world, the RPR values are recommended. However, the estimated value cannot be converted fully to energy generation, as these residues are utilized for different purposes such as livestock feeding, building material, mulching, etc. depending upon type of crop residues and geographical region. The study highlighted the multiple uses of crop residues with '**6 F**'s as fuel, fodder, fertilizer, fiber, feedstock and further uses.

Many studies have evaluated the potential of the crop residues for energy generation on different levels ranging from local to global. Most of these studies are based on the assumptions of certain fraction to be utilized for energy generation considering their competitive uses. Because of the variation in the quantity of crop residues as livestock fodder, in their evaluation of biomass potential in Serbia, Ilić et al. (2004) estimated a potential 50 % of total crop residues for energy generation in large farming systems, but only 20 % in small farming systems. Wang & Mendelsohn (2003) assumed that 15 % of the crop residues need to be left in the field for maintaining soil nutrients in their study in China. Depending on soil texture, the minimum quantity of straw recommended for covering the soil ranges from 1-2 t ha^{-1} to protect it from wind and water erosion in Canada (Sokhansanj et al. 2006). Ramachandra (2007) also considered 50 % of crop residues to be available for energy generation when assessing the energy potential in Karnataka, India. The variation of uses of crop residues depends upon type along with the socio-economical, ecological and topographical characteristics of the particular area.

Nepal is a nation dependent on agriculture, where more than 66 % of the population are engaged in the agriculture sector, which contributes 33 % of the gross domestic product (MoAD 2012). The total arable area is 3.1 million ha (about 20 % of total land area) with a cropping intensity[6] of 183 % (Pariyar 2005). Agricultural practices are based on mixed crop-livestock production systems where livestock

[6] Cropping intensity refers to the proportion of cultivated land that is harvested. With more than one crop cycle in a year on the same area, crop intensity may exceed 100 %. (FAO 1997b)

provides manure, draught power, milk and meat whereas crops are the sources for food and fodder (Tulachan and Neupane 1999). These systems provide a considerable source of energy through direct burning of dung and crop residues in the fuelwood-deficient lowland, whereas this is negligible in the hill and mountain districts due to the relatively higher abundance of fuelwood (WECS 2010). The on-going energy crisis in the country has raised serious concerns on finding alternative energy resources, and crop residues are being considered as one of the potential options. The annual production of cereal crop residues in Nepal for the period 2011/12 was estimated to be 24.21 million t (AEPC 2014). WECS (2010) estimated the theoretical national energy potential of crop residues to be about 234 million GJ, which was around 61 % of the total energy consumption of the country in 2008/09.

No experimental studies exist on the potential uses of crop residues for energy generation in Nepal. It was estimated that one third (3.2 million t) of the major crop residues was used as fuel in the country (CSMT 1996). Furthermore, the data base on the availability of crop residues is highly inadequate in the country (Shakya and Shakya 2002).

Against this background, this chapter presents the analysis of the production and prevailing uses of crop residues to assess their potential for energy production. The five major cereal staple crops paddy, corn, wheat, millet and barley are considered. The information on the household use of crop residues was gained in surveys, while field studies were conducted to quantify these residues in different stages.

4.2 Methodology

4.2.1 Cropping pattern in Nepal

Based on three main ranges of altitude and two types of cultivated land within each range, the cropping pattern of major cereal crops in Nepal is shown in Table 4.1. As indicated in Chapter 2, three different ranges represent the three topographic areas of the country: mountains, hills and lowland. However, none of the study districts is entirely covered by a single altitude range; for example, some areas of both the lowland and mountain districts are in the range 500-2500 m (typical hill landscape).

Table 4. 1 Major cropping pattern of cereal crops in Nepal

Altitude range	Type of land	Cropping pattern	Jan. – Apr.	May – Aug.	Sept.- Dec.
2500 to 3000 m	Bariland	Corn-wheat-millet (2 years)	Wheat	Early corn from June to Sept and millet from May to Oct	Wheat
		Corn+potato+ wheat+millet	Wheat	Corn+ potato from April to Oct or finger millet June to Oct	Wheat
	Khetland	Paddy-barley	Barley	Paddy (fallow from Sept- Nov)	Barley from Dec
		Wheat-barley	Barley	Wheat (fallow from Sept – Nov)	Barley from Dec
500 to 2500 m	Bariland	Millet – wheat	Wheat	Wheat or millet	Wheat from Oct
		Corn+upland paddy –	Fallow	Corn or upland paddy	Fallow
		Corn+paddy-wheat	Wheat	Corn or paddy	Wheat
		Corn + barley	Barley	Corn	Barley from Nov
	Khetland	Paddy-wheat	Wheat (fallow April and	Paddy	Wheat from Dec
		Paddy-paddy-wheat	Wheat	Paddy	Paddy
		Paddy-wheat-corn	Wheat	Corn (April – June) or paddy (Jun-Nov)	Wheat from Dec
Up to 500 m	Bariland	Corn-mustard-fallow	Mustard, fallow March and April	Corn , fallow August	Mustard
		Paddy-wheat-fallow	Wheat, fallow (Feb- May)	Paddy from June to Nov	Wheat from Dec
	Khetland	Paddy-paddy-wheat	Wheat, fallow April	Early paddy, late paddy July – Nov	Wheat from Dec
		Paddy-wheat-dhaincha	Wheat	Dhaincha and paddy	Wheat

Bariland = rain-fed upland, Khetland = irrigated lowland paddy fields, Source: Pariyar 2005

The agricultural lands in Nepal are generally characterized as 'Bariland' and 'Khetland', where Bariland refers to non-irrigated rainfed terraces, and 'Khetland' to irrigated terraces '(Sherchan et al. 1999; Gerrard and Gardner 2002). In general, corn, millet, dry paddy, wheat and barley are grown in Bariland, whereas wet paddy is mainly produced in Khetland. Furthermore, based on irrigation facility, Khetland may be either double or single irrigated. In double-irrigated Khetland, paddy is grown twice a year, one in the pre-monsoon and the other in main monsoon season (Regmi and Zoebisch 2004; Khanal and Watanabe 2006).

Not only crop yield but also the size of average cultivated land per holding is the highest in the lowland and the lowest in the mountain (Table 4.2). The share of paddy is the highest in the lowland and hill districts and wheat in the mountain district. As barley production in the lowland and hill districts are negligible, crop residues for barley are not considered in these districts. The evaluation of crop residues in this study is based on production details of Table 4.2.

Table 4. 2 Cereal crop cultivation in the study districts (number of holdings, area and yield)

Crop	Lowland district			Hill District			Mountain District		
	No. of holdings	**Area (ha)**	**Yield(kg ha^{-1})**	**No. of holdings**	**Area (ha)**	**Yield(kg ha^{-1})**	**No. of holdings**	**Area (ha)**	**Yield(kg ha^{-1})**
Paddy	126,891	100,911	3,550	31,143	10,150	2,356	31,550	5,890	1,959
Corn	43,659	12,895	3,000	31,385	7,854	2,316	18,696	1,778	1,555
Wheat	48,467	37,346	2,396	2,541	197	1,970	31,902	7,412	1,462
Millet	3,300	881	1,200	23,145	3,393	1,037	12,908	891	951
Barley	-	-	-	-	-	-	12,772	1,019	899

Source: CBS 2014

4.2.2 Data collection

Prior to the Q2 survey, 9 households from each district were informed about the survey to be conducted during the time of crop harvesting for quantifying each cereal crop and their residues. Based on information about the crop harvesting schedule of the respective households, surveys were carried out in three different crop cycles in each district (Table 4.1). The households were requested to separate all crop residues collected from a predefined land area and to process them as usual. The area was different in every household as it was defined based on recommendations by the respective households. The sample area varied from 50-100 m^2. After crop processing, the grains and residues were weighed on an air-dry basis 25 to 30 days after harvesting based on which corresponding RPR values were calculated.

4.2.3 Basis of weight measurement

The net potential of crop residues for energy production was evaluated by considering the quantity of crop residues used for burning in the field and prevailing uses of energy in the households. The unburned crop residues remaining in the field were not considered because of their essential role in maintaining soil nutrients (mulching) (FAO 2010).

The quantity of crop residues for building material was evaluated on the basis of total quantity of material that was produced by crop residues in a year vis-à-vis requirement of crop residues for the uses (mat, cushion etc.) Because of the different energy-mix patterns in a household; it was difficult to quantify the amount of crop residues used for energy generation. Therefore, a bottom-up approach for analyzing the annual energy consumption was applied where the basis was the average daily weight of residues required for energy use. The quantity of livestock fodder was calculated by deducting the quantities used for building material and energy production from the total production. The production of crop residues for livestock fodder was also examined on the basis of daily fodder consumption by 72 livestock in each district in order to analyze the possibility for energy production. The information on the different uses of crop residues as obtained from the sample households was extrapolated to evaluate each use of each crop residues at the district level.

When applying the corresponding RPR in order to evaluate the quantity of crop residues, the weight measurement was associated with the corresponding values of moisture content taken on a dry basis mode after oven-drying in the laboratory in the digital muffle furnace (model DMF 05). The average moisture content in three samples for each type of crop residue was considered as the basis for the analysis. A single representative RPR value (sample average) for a particular crop residue for all districts was used. The net heating values for the oven-dried crop residues were also evaluated.

4.3 Results and discussion

4.3.1 Crop harvesting methods

Most households in all districts adopted traditional, manual planting and harvesting of the crops, where livestock was an integral part for ploughing (tillage). In the lowland, the use of tractors for ploughing and mechanical threshers was used by some households (6 %).

Paddy

Paddy harvesting generally included cutting straw using a sickle leaving 5-10 cm straw and, depending upon weather conditions, transporting this straw after three to seven days to a processing location for threshing. The people mostly transport the straw on their back in the hill and mountain districts, while bicycles, tractors and bullock carts are frequently observed in the lowland district. Depending upon the topography of the field and distance from the settlement, threshing is carried out either in the field or at the homestead. In most of the households in the lowland district, threshing is done in the field either manually or using livestock, whereas most of the households in the hill and mountain districts do the threshing at their homestead.

Milling of the paddy kernel is done to separate the outer part (husk and bran) from the grain. Different ways of milling are practiced in the study districts such as manual grinding (leg and hand pounder), water mill, Engelberg steel huller, and modern sheller. The huller and sheller are most common in the lowland and in some accessible areas in the hills, whereas water mill and manual grinding are the most common milling methods in the mountain and inaccessible areas of the hill districts.

Corn

The harvesting procedure for corn is similar in all districts, where the corn cobs are removed after maturity and tied in bunches (six to eight) and allowed to dry in the sun for four to five days. The top leaves of the corn stalk (one third of the stalk) are removed for fodder for livestock, leaving the remaining part in the field usually for mulching purposes. In some cases, these are removed and left in a corner of the farmland and later either burnt in the field or at the homestead for energy production. The corn husks are used as livestock fodder while the corn cobs without kernels are utilized for energy production.

Wheat

The harvesting procedure for wheat follows the same method as paddy except for the height of the stalks left in the field, which differs district-wise. In the lowland district, the height is the same as that of paddy (5 - 10 cm), whereas in the mountain and hill districts about two-thirds of the stalks (average 30 cm) remain on the land, which later either will be burnt or mulched.

Millet

Harvesting of millet includes collection of panicles after maturity by cutting the plants with a sickle, transporting these to the homestead and letting them dry in the sun for one to three weeks. Hand pounding with a stick is the common threshing method, and done on a sunny day in the home yard. The grain is manually separated from the husks (winnowing) on windy days for additional cleaning. The millet husks thus obtained as a by-product of these processes is used for livestock fodder.

Barley

Barley was observed to be cultivated entirely for livestock fodder in 60 % of the households in the mountain district, where both panicles and straw are fed to livestock. Only 40 % of the households use barley for making bread. The barley is harvested manually by pulling out the plants leaving no straw residues on the farmland.

4.3.2 Different uses of crop residues

The main use of crop residues is as livestock fodder, where all households tend to maximize the utilization of available crop residues because a fodder deficit generally exists in all regions of the country (Upreti and Shrestha 2006).

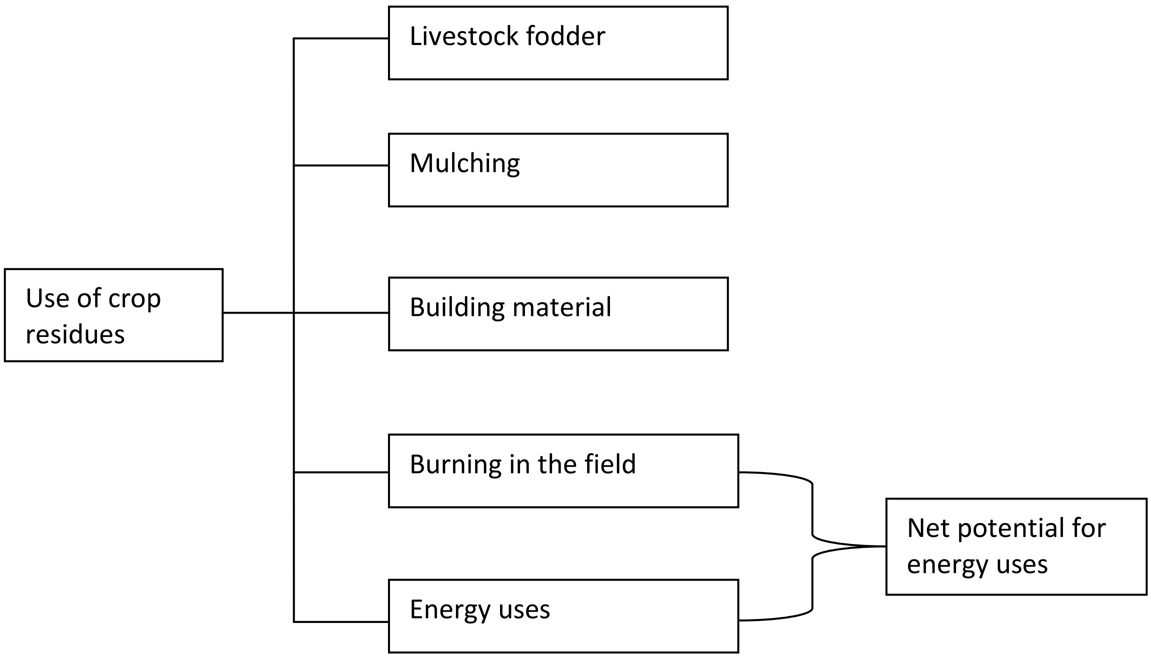

Figure 4.1 Net potential of crop residues for energy production at household level

The residues from the five cereal crops consist of dedicated fodder and non-dedicated fodder residues, and except for corn stalks and corn cobs, all crop residues are dedicated fodder residues. The crop residues utilized for livestock fodder represent dedicated fodder whereas those residues not applicable for livestock fodder are non-dedicated fodder residues. Corn cobs without kernels were used by all households entirely for energy production, whereas apart from energy production, corn stalks were also burned in the field. The use of crop residues for building material was mainly for roofing of houses or livestock stalls or for cushions of different sizes. The use of dedicated residues for energy production was only in the lowland district and then by most of the households there.

4.3.3 Residue-to-product ratio and moisture content

The residue-to-product ratio (RPR) values obtained from the Q2 survey are presented in Table 4.3.

Table 4. 3 Residue-to-product ratios (RPR) of different crop residues

Crop residues	N	Mean	SD	Min	Max
Paddy husks	18	0.36	0.14	0.08	0.79
Paddy straw	18	1.97	0.57	1.08	3.33
Wheat husks	11	0.82	0.17	0.55	1.21
Wheat straw	11	1.46	0.39	0.98	2.12
Corn stalks	11	2.12	0.45	1.63	3.11
Corn cobs	11	0.28	0.05	0.18	0.37
Corn ears	11	0.29	0.06	0.22	0.38
Millet husks	11	0.14	0.04	0.06	0.23
Millet straw	11	1.89	0.53	1.22	3.20
Barley straw	9	1.52	0.43	1.01	2.11

The following assumptions were made for the RPR analysis:

1. Wheat husks refer to the mixture with the top parts of the straw, as this was the common method to provide fodder.
2. Corn stalks did not include the top leaves, as these were immediately fed to the livestock as a green fodder during harvesting.

The moisture content of the residues was determined in the laboratory by oven drying at 105° C.

4.3.4 Crop residues as building material and energy uses

Among various dedicated fodder residues, the paddy straw, wheat straw and barley straw were utilized for building material at household level. The quantity of crop residues for building material and energy production at a household depends on the household size and area of cultivated land. As the weights of crop residues for building material and energy uses were obtained from different households with varying household size and area of cultivated land, the average weight of these residues for particular uses may lead to higher inconsistency at the district level. In order to reduce such inconsistency, the weight of residues was expressed in percentage of total production (Tables 4.4 and 4.6) by assuming that the households with higher production of crop residues utilize more residues for respective uses and vice-versa. This aspect is later applied to evaluate crop residues at the district level.

Table 4. 4 Straw used for building material at household level (hh) in the study districts

Type of straw	Lowland		Hill		Mountain	
	Weight (kg DM $hh^{-1}yr^{-1}$)	Share (% of total production)	Weight (kg DM $hh^{-1}yr^{-1}$)	Share (% of total production)	Weight (kg DM $hh^{-1}yr^{-1}$)	Share (% of total production)
Paddy	115 (29)	21(6)	118 (43)	13 (7)	69 (23)	3 (2)
Wheat	127 (33)	32 (8)	85 (33)	15 (8)	20 (6)	4 (2)
Barley	5.5 (2.4)	15 (6)	-	-	-	-

n = 9, the values in parentheses are standard deviations.

In the hill and mountain districts, the households use a larger amount of straw as building material compared to the lowland (Table 4.4). The percentage of households using crop residues as building material is the highest in the mountain district (Table 4.5). The relatively lower dependence on commercial structures because of poor infrastructure is a reason why the households in the mountain district rely more on crop residues as building material.

Table 4. 5 Percentage of households using crop residues as building material in the study districts

Type of residue	Lowland	Hill	Mountain
Paddy straw	30	45	76
Wheat straw	25	12	45
Barley straw	-	-	10

As mentioned above (section 4.3.2), the use of dedicated fodder residues for energy production only takes place in the lowland. Because millet is only cultivated in the northern (hilly) part of the lowland district where there is a relatively better source of fuelwood, energy production from millet residues does not take place. Paddy and wheat residues are extensively used by a large number of households in the southern part of the lowland district. As obtained from the Q1 survey, the percentage of households using paddy husks, paddy straw, wheat husks and wheat straw for energy production was 20 %, 30 %, 24 % and 27 %, respectively.

Table 4. 6 Use of residues for energy production at household level in the lowland district

Residue type	Energy production		
	N	Weight ($kg\ DM\ hh^{-1}\ yr^{-1}$)	Share of total production (%)
Paddy straw	9	232 (119)	10 (5)
Paddy husks	9	9 (4)	11 (6)
Wheat straw	9	55 (20)	11 (5)
Wheat husks	9	33 (15)	10 (4)

Values in parentheses are standard deviations

4.3.5 Crop residues as livestock fodder

Numerous studies (Hopkins 1983; Thakur 1983; Sharma and Pradhan 1985; Ghimire 1992; Joshi 1992; Paudel and Tiwari 1992; Thorne et al. 1998; Maharjan 2003; Barsila 2008) revealed that fodder deficit is common in all regions of the country, which indicates the importance of crop residues for fodder use. In order to evaluate the annual amount of crop residues needed for fodder, data on crop residue consumption per day for cattle and buffaloes for the three districts were collected. The cattle and buffaloes were categorized into four groups calves (under 1 year), young (1 to 3 yrs), mature (> 3 yrs) and lactating. The measurement of crop residues as fodder was done for 9 animals of each category at different households. As the production of paddy straw is relatively high and it is quite a common fodder in all districts, this was taken as a reference.

The data were collected during the winter as the demand for crop residues is high in all districts in that period. The respective households were requested to provide only paddy straw for the whole day, and were not allowed to use additional fodder. However, the lactating buffaloes and cattle were provided with extra nutrients in a concentrated form. As expected, buffaloes had a higher fodder consumption than cattle, and the consumption of lactating livestock was higher than that of non-lactating. Consumption was relatively lower for all livestock categories in the mountain district than in the hill and lowland districts (Table 4.7). As the sample livestock within a category in each region has large variation in terms of age and species, the question may be raised about the significance of average consumption. It should be noted that the evaluation of fodder for this research is only quantitative and does not indicate qualitative aspects of total digestible nutrients and digestible crude protein.

Table 4. 7 Average daily consumption of paddy straw by unit livestock in the study districts (n=9 in each category)

Livestock type	Category	Average weight of paddy straw consumed (kg DM livestock^{-1} day^{-1})		
		Lowland	**Hill**	**Mountain**
Cattle	Calves (under 1 year)	1.1 (0.7)	1.0 (0.5)	0.8 (0.5)
	Young (1 to 3 yr)	4.6 (2.4)	4.4 (2.5)	2.9 (2.0)
	Mature (> 3 yr)	7.3 (3.3)	7.1 (3.3)	5.9 (2.9)
	Lactating	12.2 (3.4)	11.5 (2.9)	9.6 (2.6)
Buffaloes	Calves (under 1 year)	1.6 (0.7)	1.7 (0.7)	1.1 (0.6)
	Young (1 to 3 yr)	7.0 (3.2)	6.5 (2.4)	5.3 (2.4)
	Mature (> 3 yr)	13.7 (3.3)	14.1 (3.2)	11.2 (3.0)
	Lactating	17.6 (5.7)	18.3 (4.9)	15.9 (3.2)

Values in parentheses are standard deviations

On the basis of livestock distribution (CBS, 2014) and the corresponding average daily consumption of crop residues (Table 4.7) vis-à-vis annual production of crop residues (Table 4.9) for the study districts, the amount of time that crop residues can sustain livestock is estimated by assuming that the daily fodder consumption of other residues by the respective livestock is same as that of paddy straw (Table 4.8).

Table 4.8 Crop residues for fodder in the study districts

District	Crop residue consumption(kg DM day^{-1} district^{-1})	Annual production (kg DM yr^{-1} district^{-1})	Annual sustained period (months)
Lowland	1,986	735,760	12.5 months
Hill	703	56,870	3 months
Mountain	965	46,450	1.5 months

In view of annual production and consumption basis, only in the lowland district is there a surplus of crop residues for livestock fodder for more than a year. Crop residues for fodder are only available for around 3 months and 1.5 months in the hill and mountain districts, respectively. Hence, the estimation clearly shows that the use of fodder crop residues for energy generation is unimaginable in the hill and mountain districts, as the fodder only lasts for three months at the most there. Most importantly, the assessment was done for only large ruminants, whereas in practice there are large numbers of small ruminants (goat, sheep, pigs, etc.), poultry, and fisheries, etc., where the use of crop residues as fodder is equally crucial. Bearing this fact in mind, other uses of fodder crop residues in the lowland are questionable and a detailed analysis of the production potential of alternative fodder is needed. Hence, it is not recommended to use the surplus fodder crop residues in the lowland for energy generation.

4.3.6 Quantification of crop residues for various uses

The annual availability of different crop residues for various uses was evaluated (Table 4.10). The available amount of five major cereal crop residues in the lowland, hill and mountain districts was 877,820 t, 92,030 t and 51,810 t, respectively, of which the corresponding share of dedicated fodder crop residues was 84 %, 62 % and 90 %, respectively (Table 4.9). The annual availability of crop residues for each household in the lowland, hill and mountain districts was turned 4,104 kg, 2,189 kg and 1,534 kg, respectively (based on number of households in the districts as indicated on Table 2.5, Chapter 2). On a per capita basis, the average annual availability of crop residues in the lowland, hill and mountain districts was 954 kg, 547 kg and 263 kg, respectively. Of the total production, the percentages of crop residues for energy generation were 16 %, 38 % and 10 % in the lowland, hill and mountain districts, respectively (Table 4.9). Hence, despite the higher crop residues production in the lowland than in the hill district, the net usable amount of crop residues for energy generation is observed to be higher in the hill (207 kg capita^{-1} yr^{-1}) than in the lowland (152 kg capita^{-1} yr^{-1}) district.

Table 4. 9 Weight of available crop residues (t DM district^{-1} yr^{-1}) in the study districts

Residue type	Total production	Energy potential	Building material	Livestock fodder
Lowland				
Paddy husks	107,910	11,730	0	96,180
Paddy straw	528,230	49,560	15,847	462,823
Corn stalks	53,010	53,010	0	0
Corn husks	8,300	0	0	8,300
Corn cobs	8,100	8,100	0	0
Wheat husks	63,320	6,880	0	56,440
Wheat straw	107,200	11,570	4,288	91,342
Millet husks	120	0	0	120
Millet straw	1,630	0	0	1,630
Total	877,820	140,850	20,135	716,835
Hill				
Paddy husks	7,960	0	0	7,960
Paddy straw	37,770	0	4,910	32,860
Corn stalks	30,100	30,100	0	0
Corn husks	4,870	0	0	4,870
Corn cobs	4,750	4,750	0	0
Wheat husks	280	0	0	280
Wheat straw	470	0	71	399
Millet husks	430	0	0	430
Millet straw	5,400	0	0	5,400
Total	92,030	34,850	4,981	52,199
Mountain				
Paddy husks	3,830	0	0	3,830
Paddy straw	18,220	0	3,827	14,393
Corn stalks	4,570	4,570	0	0
Corn husks	730	0	0	730
Corn cobs	720	720	0	0
Wheat husks	8,040	0	0	8,040
Wheat straw	13,190	0	4,221	8,969
Millet husks	90	0	0	90
Millet straw	1,290	0	0	1,290
Barely straw	1,130	0	170	960
Total	51,810	5,290	8,218	38,302

The use of both non-dedicated and dedicated fodder crop residues for energy generation in the lowland district clearly reveals the scarcity of fuelwood in most of the areas there. Non-dedicated fodder residues in the hill and mountain districts are not used for cooking regular meals, rather the households use them for fodder, which generally is prepared outside the house. Based on the laboratory results, the net energy potential of all crop residues for the three districts was estimated (Table 4.10). The annual per capita energy potential of crop residues in the lowland, hill and mountain districts were calculated (Table 4.11).

Table 4.10 Annual energy production potential of crop residues (TJ yr^{-1}) in the study districts

Crop residue	Net calorific value (MJ kg^{-1})	Lowland	Hill	Mountain
Paddy husks	16.57	195	0.00	0.00
Paddy straw	15.80	783	0.00	0.00
Corn stalks	15.44	818	465	71
Corn cobs	15.57	126	74	11
Wheat husks	17.46	120	0	0
Wheat straw	17.46	202	0	0
Annual potential		2,244	539	82

The hill district shows the highest potential of crop residues for energy production due to the higher per capita production of corn. As the corn stalks and cobs are non-dedicated fodder residues, they can be fully utilized for energy production. In the present context, although all corn cobs were utilized for energy production at the household level, this was not the case for corn stalks. Even the full utilization of crop residues in the region with the highest production of crop residues (hill district) contributes to only 31 % of the total energy consumption (Table 4.11), and the contribution is negligible in the mountain district.

Table 4.11 Annual per capita energy supply potential of crop residues in the study districts

District	Population	Energy consumption (GJ $capita^{-1}$ yr^{-1})	Crop residue supply	
			Energy potential (GJ $capita^{-1}$ yr^{-1})	% share potential of total energy consumption
Lowland	964,553	8.21	2.32	28
Hill	167,771	10.34	3.21	31
Mountain	195,207	11.78	0.41	3

4.4 Conclusions and recommendations

The investigation of crop residues for energy production is critical to reduce the prevailing overexploitation especially of fuelwood in the hills and mountains where the use of crop residues is negligible. As the households in the lowland already consume all types of crop residues for energy production because of the fuelwood deficit there, the assessment of the use of crop residues for energy production is extremely important in order to examine the possible consequences of other uses mainly for fodder. As this study evaluates the potential of crop residues for energy production by considering their different other uses under pragmatic conditions, the results are pertinent for further considerations. Crop residues in the hills have a potential to contribute significantly to total energy consumption whereas the contribution in the mountains is negligible. The prevailing use of residues for energy production does not affect the fodder supply in the lowland district.

As even full utilization of the net available residues can only provide around 28 % of the total annual household energy requirement in the lowland (high fuelwood scarcity), exploration of other potential sources such as livestock dung and household wastes to address the fuel crisis situation there is called for. It is also highly recommended to conduct further studies to evaluate the potential of non-fodder agricultural residues especially in the fuelwood deficient zones.

The current trend of inefficient utilization of crop residues by direct burning for energy production needs to be modified by the introduction of modern and efficient technologies. Of various technologies, briquetting might be a promising energy technology for households. Given the significant potential energy contribution of crop residues in the hills, the local-level awareness and incentives programs for energy use of crop residues could reduce overexploitation of fuelwood. In the mountains, herbaceous materials and dung for energy production should be investigated to compensate the lower production of crop residues there.

5 DUNG AVAILABILITY FOR BIOGAS PRODUCTION

5.1 Introduction

Biogas is produced through biological decomposition of organic material in the absence of oxygen. Biogas is a mixture of methane (40 – 75 %) and carbon dioxide (15 – 60 %) with small amounts of different gases and by-components i.e. nitrogen (0 – 2 %), carbon monoxide (<0.6%), hydrogen sulfide (0.005 – 2 %), oxygen (0 – 1%) and alkaline gases (<1 %). Apart from these, trace amounts of halogenated hydrocarbons (< 0.65%), siloxanes (0 – 0.02%), and other non-methane organic compounds such as aromatic hydrocarbons, alkanes, alkenes, etc., are sporadically exhibited (Ryckebosch et al. 2011).

Biogas produced from livestock waste is widely used as a clean bio-fuel source, which in general is used for generating energy on a large scale in developed countries while extensive use on the household level exists in many developing countries (Thien Thu et al. 2012). Because of its potential reduction of greenhouse gas (GHG) emissions from manure storage and the production of renewable energy, the promotion of biogas technologies has been supported by many developing governments and agencies (Møller et al. 2004; Baxter 2015). Moreover, because of multiple benefits of biogas to the rural population in developing countries in terms of coping with problems resulting from the use of low-quality fuels, such as indoor air pollution, extra burden of fetching fuelwood, and reduction of livestock fodder and manure (by direct burning of dung cake and crop residues), the promotion of biogas is considered as one of the key steps for sustainable energy use (Hjortsø et al. 2006; Gosens et al. 2013).

More than 30 million households in China (8.1 %) have installed biogas plants followed by India with 3.8 million households (1.9 %) but only about 60,000 households (0.3 %) in Bangladesh (Rajendran et al. 2012). The installation of biogas plants at the household level has been increasing in many African nations (Amigun and von Blottnitz 2010). Depending on the availability of livestock, there are differences in terms of dung utilization for biogas production. For instance, pig manure is quite commonly used in China for biogas production (Chen et al. 2010), while dung from cattle and buffalo is used in almost all biogas plants in India (Rao et al. 2010). Hence, based on the respective numbers of livestock available within a region, the potential of biogas was analyzed in different studies (Batzias et al. 2005; Rao et al. 2010; Gosens et al. 2013). These studies considered the average dung production per day by each category of livestock as a basis for assessment of the potential for biogas. Albeit such assessments offer general ideas for the promotion of biogas in macro-perspectives within the specified area, further analyses on the variation of dung yield from livestock with different ages and species along with the livestock and dung management practices are important in order to gain more reliable information on the net production potential of biogas throughout a year.

Because of different practices of livestock management and variation of alternative uses of dung in different locations, there may be significant variations in the net amount of dung for biogas production (Batzias et al. 2005). As reported by Dikshit and Birthal (2010) for India, more than 33 % of the total dung production was directly burnt for energy production and the rest used for manure, while 3 % was used for coating the mud houses in rural areas. Recently, the FAO (2010) in its implementation guideline of the Bio Energy and Food Security approach (BEFS) also included the livestock category (type and age) and their overall management for assessing the net potential of biogas production. Indeed, such a micro-level analysis helps not only decision makers but also biogas users in their selection of the suitable size of biogas digesters at the upfront stage and in managing other potential feedstock for regular operation of biogas plants. The seasonal variation of dung yield due to differences in availability of fodder is a crucial aspect which has to be considered in the evaluation of the biogas production potential (Hoffmann et al. 2001; Gupta et al. 2007; Kakkar and Gupta 2010; Zake et al. 2010). As indicated by Joshi (1992), the dung yield in Nepal is the highest in the wet period (June - August) because of higher availability of forage feed. Therefore, the estimation of dung based on only one particular season especially during the wet period may be misguiding when assessing the actual annual biogas production potential. There are no systematic studies available which quantify the variation of dung yield in different seasons in Nepal, which hinders obtaining meaningful information on the actual potential of biogas production. The variation of livestock management in different topographical regions may also mean significant variation of dung yield.

The impact of biogas plants is only positive when users operate these plants effectively on a regular basis, which ultimately depends upon the availability of dung (feedstock) on a daily basis. This also makes it easier for users to manage alternative of energy sources such as fuelwood, liquefied petroleum gas (LPG), kerosene, etc., in case the biogas does not fulfill all cooking needs throughout a year.

In this chapter, the assessment of the net potential of livestock dung for biogas production at household level in three districts is presented. The analysis considers seasonal variation of dung yield, livestock management practices, livestock species and age, and pragmatic limitations of use of dung for biogas production. Apart from the amount of dung as a feedstock, the production of biogas strongly depends upon various factors such as pH, temperature, hydraulic retention time (HRT), C/N ratio, etc. (Hill 1983; Yadvika et al. 2004; Alvarez et al. 2006; Ferrer et al. 2011), which are however not considered in this study.

5.2 Biogas development in Nepal

A coordinated attempt to promote biogas technologies in Nepal was started in 1974 by installing demonstration plants. Throughout 1974–1975, about 200 biogas plants were introduced by the Department of Agriculture. In 1977, a biogas organization was formed under the Agricultural Development Bank Limited (ADBL) with the objective of promoting biogas technologies in the country with a dissemination rate of 100 to 300 biogas plants per year until 1985 and around 800 biogas plants per year between 1985 and 1990. The pace of biogas development rapidly increased after the establishment of the Biogas Support Program (BSP) in 1992 with the financial and technical aid from Netherlands Development Organization (SNV/Nepal). In order to streamline the function of BSP along with promotion of other renewable energy technologies, the Nepalese government established the Alternative Energy Promotion Centre (AEPC) in 1996 under the then Ministry of Science and Technology. The BSP has been developed as the pioneer clean development mechanism (CDM) project with the registration of two projects in 2005 with the World Bank, which generated an annual revenue of about USD 607,000 from 2005 (AEPC 2011) and is still ongoing. The cumulative number of households with biogas plants in the country until 2014 was about 290,000 (AEPC 2015b). It has been affirmed that 95 % of the biogas plants are in operation and that each plant has been reducing 7.4 t GHG a year saving the users three hours a day for fuelwood collection (AEPC 2014).

In the Nepalese context, livestock dung is almost the only feedstock used for production of biogas at the household level. The kind of biogas plant in Nepal is based on the Chinese fixed-dome model, which includes an underground digestion chamber to store the biogas. The feedstock is made by mixing equal amounts of dung and water. This mixture remains in the digester for a certain time period before production of gas takes place. This critical time period is called hydraulic retention time (HRT) and is highly influenced by ambient temperature. The common sizes of the biogas plants (sum of digester volume and gas storage) in Nepal are 4 m^3, 6 m^3, 8 m^3 and 10 m^3, and based on the topography, the HRT varies from 55 to 90 days (Karki et al. 2005). Based on HRT, the daily amount of input feedstock (dung and water) required can be estimated for a particular digester volume to operate biogas regularly (Equation 5.1) (Karki et al. 2005).

$$\textit{Daily amount of feedstock } (m^3\ d^{-1}) = \textit{digester volume } (m^3) / \textit{HRT } (d) \qquad (5.1)$$

where d = number of days

CES (2001) recommended a HRT of 70 days for both hills and mountains and 55 days for lowland, and accordingly 6 kg fresh dung m^{-3} for biogas plants in the mountain and hill districts and 7.5 kg m^{-3} in the lowland are recommended. The higher HRT in the hills and mountains require a relatively larger digester volume as compared to the lowland to maintain an equal gas supply on a daily basis (Table 5.1). This leads to relatively higher upfront costs.

Table 5. 1: Biogas plant size versus daily loading rate in Nepal

Plant size (m^3)	Daily loading rate (kg)	
	Lowland	Mountains and hills
4	30	24
6	45	36
8	60	48
10	75	60
15	110	90
20	150	120

Source: CES 2001

As the design of all biogas plants in Nepal is based on dung only from cattle and buffalo as a primary feedstock, these play a significant role in promoting the country's biogas sector based on which the government has been implementing various plans and programs. By considering national census data of households, livestock and socio-economic indicators for the year of 2001 , the number of potential households for installation of biogas was estimated to be 1.9 million, which represents about 42 % of the total households of the country (BSP/N 2008).

5.3 Methodology

5.3.1 Data collection

The fresh dung yield by livestock for 24 hours was measured, and flow analysis of dung from stall to end use was conducted. The dung of 210 livestock from the sample households was measured. In this study, the livestock samples were divided based on four categories: mature cattle (> 3 yrs), young cattle (≤ 3 yrs), mature buffalo (> 3 yrs) and young buffalo (≤ 3 yrs). The households with grazing practices were requested to keep their livestock in the stall for the entire 24 hour period.

The quantity of dung yield from a particular livestock is directly correlated to the amount of fodder supplied to it (Odend'hal 1972; Schlecht et al. 2006; Bationo et al. 2007; Dikshit and Birthal 2010). The milking and draught livestock are provided with relatively higher amounts of fodder (Hayashi et al. 2006; Matthews et al. 2006), which may ultimately misguide the prediction of daily dung yield, hence the survey excluded such livestock to avoid misinterpretation. Because of the seasonal variation of available quantity of livestock fodder (Upreti and Shrestha 2006), the yield of dung fluctuates accordingly throughout a year. The seasonal variation of dung yield was evaluated (Q2 survey) for three different seasons (winter, pre-monsoon and monsoon) (Table 5.2). The conversion of fresh to oven-dried weight was done by evaluating the moisture content of dung in two phases. In the first phase, the moisture content of the dung was determined in the field where the samples were sun-dried until constant weight; this took about 47 to 55 days. A digital muffle furnace (model DMF 05) was used for the test with sun-dried samples, while the net heating values of the samples were evaluated using a digital bomb calorimeter (model CC01/M2).

Table 5.2 Schedules for daily dung measurement (Q2 survey)

Season	**Survey time**
Winter	December 2013 – January 2014
Pre-monsoon	April – May 2014
Monsoon	August -September 2014

5.3.2 Livestock management

In general, two broad types of livestock management were practiced in all three districts. One with only stall-fed livestock where the livestock was not taken to graze outside and the other with semi-stall-fed livestock with grazing. The time period for grazing was entirely dependent on the decision of household, which was based on nature of grazing area, distance from the house, seasonal factors and time availability of the herder. Since the common livestock management followed by 80 % of the households was semi-stall feedstock management, the households with only stall-fed livestock were not considered in the analysis, as the findings of this study can also be safely applied to those households.

Especially in high hill and mountainous areas, the livestock moves long distances over the year especially at the highest altitudes. This is commonly termed as 'full transhumance' (Rayamajhi 2000). The short up-down movement of livestock maintaining a base camp at or near the homesteads for certain months of a year is especially observed in high-hill areas, and is referred to as 'semi transhumance' (Rayamajhi 2000).

Full-transhumance livestock management was not considered for the analysis as the purpose of this management did not coincide with the key aspect of this study, because the dung was not accessible for household needs. As dung was available for household use in the semi-transhumance system, this livestock management was incorporated in the analysis.

5.3.3 Evaluation of net potential of dung

A number of factors associated with livestock dung management prevented the full utilization of the total dung yield for biogas production. These factors were related with livestock management, dung collection method, and alternative uses of dung. Based on these factors, a relationship was developed for estimation of the net annual potential for biogas production at household level (Figure 5.1).

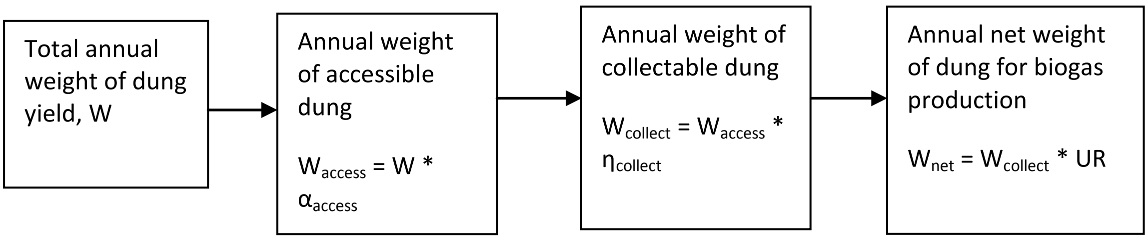

Figure 5.1 Steps to estimate net annual potential of dung for biogas production at household level

Accessibility factor (α_{access})

The accessibility factor is the fraction of the total number of hours in a year that a particular livestock has been kept in the stall. The ultimate aim of this factor is to exclude the quantity of dung available at the time of grazing, as almost all households with livestock herding leave the dung in the grazing area. For example, if a household grazes cattle for 8 hours a day for 5 months in a year, then the dung accessibility factor can be obtained as defined in Equation 5.2.

$$Accessibility\ factor = 1 - (total\ number\ of\ grazing\ hours\ per\ year / total\ no.\ of\ hours\ per\ year) \quad (5.2)$$

$$= 1 - (8 * 5 * 30)/(365 * 24)$$

$$= 0.86$$

Hence, the accessibility factor for the specified household is 0.86, which implies that the dung can be accessed in 86 % of in a year. The information received during the Q1 survey is taken as a basis for evaluating the accessibility factor.

Collection efficiency ($\eta_{collect}$)

The collection efficiency measures the efficiency of collection of accessible dung and is defined as the ratio of weight of actually collected dung to the total weight of accessible dung. Because of practical limitations such as stall structure and haphazard management of dung collection, the total dung yield could not be collected. In general, some of the dung is mixed with fodder and most of it is left in the stall. In some cases, dung blends with urine and this is also not collected. In order to evaluate the collection efficiency, the respective household users were requested to collect samples of available fresh dung, and the remaining part of the dung usually left in the stall was added to the samples for the weight measurement.

Utilization ratio (UR)

The alternative use of dung is mostly for coating of the kitchen, and is common practice in most of the households in the rural areas. This quantity has to be deducted from the collected dung to determine the actual weight of the dung that can be used for biogas production. For the analysis, the alternative uses of dung are expressed as 'utilization ratio' (UR). The UR for a household is defined as the ratio of total weight of dung used for alternative tasks in a year to the total weight of collectable dung. The potential use of dung as fertilizers was not evaluated, as dung slurry, which is a by-product of the energy generation in the biogas plant, can be used as fertilizers.

Hence, by considering the three aforementioned factors, the net weight of fresh dung *(W_{net})* available for energy generation in a year per household is obtained using the relation as shown in Equation 5.3.

$$W_{net} = \left[\sum_{k=1}^{4} n_k * W_{0,k} \right] * \alpha_{access} * \eta_{coll} * (1 - UR) * 365 \tag{5.3}$$

where

W_{net}	= net available dung for potential biogas production in a year (kg household^{-1} yr^{-1})
n	= total number of respective livestock category in a household
k	= livestock category (four types; see above)
W_0	= weight of fresh dung yield per day (24 hours) by unit livestock (kg livestock^{-1} day^{-1})
α_{access}	= accessibility factor (dimensionless)
$\eta_{collect}$	= collection efficiency (dimensionless)
UR	= Utilization Ratio (dimensionless)

5.4 Results and discussion

5.4.1 Moisture content and net calorific value

The average moisture content of fresh dung was observed to be 82 % (n = 9, SD = 5.1 %). A moisture content of 4.7 % (n = 3) was determined in the oven-dry test (at 105° C) of the sun-dried samples and thus, the overall moisture content of the fresh dung was found to be 86.7%. The net calorific value of oven-dry dung from the laboratory experiment was 14.92 MJ kg^{-1} (n =3).

5.4.2 Variation of daily dung yield

As expected, the dung yield by mature livestock was higher than that of young, while that of buffalo was higher than that of cattle in all districts (Table 5.3). Furthermore, livestock in the lowland district produced the highest daily dung yield, whereas the yield in the mountain district was lower than that in the hill district.

Table 5.3 Mean values of weight of dung yield (kg DM $livestock^{-1}$ day^{-1})

Age/species	District	N	Pre-monsoon	Monsoon	Winter
Young cattle	Lowland	20	1.26 (0.59)	1.52 (0.63)	1.01 (0.47)
	Hill	11	0.67 (0.23)	0.97 (0.27)	0.51 (0.26)
	Mountain	21	0.30 (0.06)	0.38 (0.09)	0.18 (0.06)
Mature cattle	Lowland	31	1.98 (0.93)	2.24 (0.93)	2.10 (0.94)
	Hill	20	1.22 (0.26)	1.52 (0.33)	1.33 (0.26)
	Mountain	32	0.51 (0.22)	0.73 (0.25)	0.49 (0.21)
Young buffalo	Lowland	7	1.52 (0.42)	1.75 (0.50)	1.23 (0.33)
	Hill	14	1.40 (0.70)	1.52 (0.33)	1.18 (0.65)
	Mountain	8	0.75 (0.17)	1.01 (0.21)	0.73 (0.25)
Mature buffalo	Lowland	12	2.66 (0.90)	3.51 (1.05)	2.80 (0.85)
	Hill	25	3.23 (1.01)	3.45 (0.87)	3.01 (0.83)
	Mountain	9	2.11 (0.42)	2.54 (0.49)	2.10 (0.30)

Values in parentheses are standard deviation

The daily dung yield is observed to be the highest in the monsoon and the lowest in winter, which can be explained on the basis of availability of fodder.The seasonal variation of daily dung yield at household level was obtained (Table 5.5) by considering the livestock distribution (Table 5.4) and their corresponding dung yield (Table 5.3).

Table 5.4 Number of average livestock per household in the study districts

Livestock type	**No. of livestock type per household**		
	Lowland	**Hill**	**Mountain**
Young cattle	0.8	0.2	1.5
Mature cattle	1.3	1.1	2.8
Young buffalo	0.2	0.7	0.3
Mature buffalo	0.3	0.8	0.6
Average livestock per household	2.6	2.8	5.2

Source: CBS, 2014

Some studies based on the comparison of fodder supply potential from different land types and livestock densities in Nepal found supply deficiencies in all regions (Rajbhandari and Shah 1981; Rajbhandari 1981; Fonzen and Oberholzer 1984; Lane 1990; Fox 1993; Amatya and Shivakoti 1996; Raut 2000; Yadav 2005; Upreti and Shrestha 2006). Because of the relatively lower crop productivity in the mountains, the production of crop residues is limited compared to that of the hills and mountains (Thapa and Paudel 2000; Upreti and Shrestha 2006). Paddy, wheat, millet, barley and corn are the main cereal crops in Nepal, and the residues are extensively used as livestock fodder. According to CBS (2014), the ratios of cropland (cereals) to livestock (total number of cattle and buffalo) are 0.103 ha, 0.265 ha and 0.493 ha livestock^{-1} in the mountain, hill and lowland districts, respectively. The corresponding periods where crop residues for livestock fodder are available are 1.5 months, 3 months, and 12.5 months (Chapter 4).

Hence, only considering the number of livestock for assessing dung potential is misguiding in biogas projects, and detailed assessment of livestock categories with their fodder consumption behavior is necessary.

5.4.3 Net availability of dung per household

Based on average daily yield of dung of different categories of livestock (Tables 5.3 and 5.4), the net availability of dung for biogas production per household was assessed by considering the relationship of accessibility, collection efficiency and utilization ratio as per equation 5.3 (Table 5.5).

Table 5.5 Assessment of net annual dung yield at household level (hh) in the study districts

Parameter	Lowland	Hill	Mountain
Average daily hours of herding (hr day^{-1})	7.1	8	9.3
Average number of months of herding in a year (months)	5	7	9
Average annual hours of herding (hr yr^{-1})	1068	1680	2521
Annual dung yield (kg DM hh^{-1} yr^{-1})	1610	1739	894
Accessibility factor	0.8	0.8	0.7
Collection efficiency	0.7	0.6	0.6
Utilization factor	0.1	0.2	0.2
Annual net available dung for energy(kg DM hh^{-1} yr^{-1})	1127	1113	536

On a per capita basis, the average annual net available dung production in the mountain, hill and lowland districts was 262 kg, 278 kg and 93 kg, respectively, based on the average household size (Table 2.5).

5.4.4 Biogas production potential

The field experiment (Chapter 6) on 'fuelwood equivalent' of biogas revealed an annual per capita savings of fuelwood with biogas from dung in the mountain, hill and lowland districts of 114 kg DM, 344 kg DM and 324 kg DM, respectively (Table 5.6). Despite the relatively higher annual biogas production potential at household level in the lowland district as compared to the hill district, because of the relatively higher average household size in the lowland, the annual potential of biogas production per capita is slightly lower than that of the hill district (Table 5.6).

The study conducted by AEPC in 2008 in 461 households in 15 districts revealed an annual per capita saving of 600 kg after the introduction of biogas (Katuwal and Bohara 2009) whereas Somanathan et al. (2014) observed savings of 250 – 300 kg. Hence, the potential savings of 114 – 344 kg determined in this research are within the range of the latter study. However, as observed (Chapter 6), the prevailing use of dung for biogas production in the hill and lowland districts is only about half of the net available.

Table 5.6 Biogas production and fuelwood saving potential in the study districts

Particulars	Lowland	Hill	Mountain
Annual net weight of available dung (kg DM hh^{-1} yr^{-1})	1127	1113	536
Average household size	4.3	4.0	5.8
Annual potential of biogas production (m^3 $capita^{-1}$ yr^{-1})*	71	75	25
Annual potential per capita saved fuelwood (kg DM $capita^{-1}$ yr^{-1})**	324	344	114

** 1 kg DM dung produces 0.28 m^3 of biogas (BSP/N, 2011)*

*** Based on 1 m^3 biogas = 4.57 kg of fuelwood*

In the present Nepalese context, the exploitation of dung for biogas production cannot completely replace fuelwood at household level in any of the districts. However, some measures to increase biogas production per unit of dung could increase the fuelwood substitution rate. Various successful experiments have been conducted, and some of the techniques are based on using additives, varying operational parameters, fixed bio-filters, recirculation of digested slurry on a daily basis, or stirring of the feedstock (Laura and Idnani 1971; Malik 1995; Yadvika et al. 2004; Haque and Haque 2006). Because of its simplicity and cost effectiveness, recirculation of digested slurry on a daily basis may be a viable option. Depending upon availability, mixing of crop residues or other suitable green biomass to feedstock can be an alternative solution (Laura and Idnani 1971; Hills and Roberts 1981; El-Shinnawi et al. 1989; Plöchl and Heiermann 2006; Lehtomäki et al. 2007).

The prevailing rate of distribution of biogas plants is another critical issue that needs to be addressed by utilizing available dung effectively in order to resolve household energy issues. As of end of 2014, 23 % of the households in the hill district had biogas plants, whereas this share was only 5 % in the lowland and less than 1 % in the mountain district (AEPC 2015b). The presence of cattle and/or buffalo at the household level is mandatory to obtain government support under the current framework. Hence, because of the lack of exact information about the distribution of households according to fuel sources and presence of cattle and buffalo makes it difficult to reliably estimate the number of potential households for the adoption of biogas plants.

5.5 Conclusions and recommendations

The net annual per capita biogas production potential in the mountain district is only about 33% (25 m^3) of that of the hill and lowland districts. The use of dung for energy production is only in the hill and lowland districts. In the hill district, dung is only used for biogas production, while dung is frequently burnt in the lowland district.

When considering the existing practice of direct burning of dung cake by a large number of households because of the fuelwood deficit in the lowland, high priority should be given to these areas. The implementation of biogas technologies in the present scenario is observed to be only a partial substitution of other traditional biomass types, especially fuelwood, at the household level. Because of the lack of slurry management for fertilizer use, the households are reluctant to utilize all dung for biogas production. Therefore, policy intervention is required to promote slurry management so that the biogas production can be doubled. Further suitable measures should be implemented to utilize the dung efficiently for biogas production. Among various measures, recirculation of digested slurry and mixing of livestock urine in feedstock may be viable options in Nepal. At the same time, based on availability, it is worthwhile to promote other designs of biogas plants based on alternative feedstock such as dung from other small livestock (goats, sheep, pigs, chickens), organic wastes, and herbaceous materials.

6 COOKING AND HEATING ENERGY CONSUMPTION PATTERN

6.1 Introduction

The burning of traditional biomass such as fuelwood, agricultural residues and dung is the only source of cooking and heating energy for 2.7 billion people worldwide. This not only has negative consequences for the global environment, it also leads to over 2 million deaths a year from indoor air pollution (WHO 2011). Almost all households that traditionally use biomass as a source of energy are in developing countries (Leach 1992; Martinot et al. 2002; MacCarty and Bryden 2015). For various reasons such as fuel supply situation, income status, culture and traditions, the rural households in developing countries usually adopt a multi-fuel approach (Hosier and Dowd 1987; Masera and Navia 1997; Guta 2012; Mirzabaev et al. 2014; Behera et al. 2015; Ahmad and Puppim de Oliveira 2015; Treiber et al. 2015).

Most of the rural households in Nepal also use different sources of fuel, which entirely depends on the geographical location of a particular household. As shown in studies in different parts of the world, fuelwood scarcity largely determines the intensity of switching of energy sources in any particular area. Better-off households are likely to adopt relatively efficient energy technologies, whereas poor households turn to inferior energy sources such as agricultural residues and livestock dung (Koopmans and Koppejan 1997; Heltberg et al. 2000; Mahiri 2003; Saud et al. 2011). Similar findings were reported by Amacher et al. (1993), Pokharel and Chandrashekhar (1994), Amacher et al. (1999), Panta (2013), and (Bhattarai 2014) in their analyses of household energy behavior in rural areas of Nepal. Link et al. (2012) analyzed the pattern of household energy consumption with reference to fuelwood transition in between 1996 and 2001 in one of the lowland areas of the country focusing on household behavior with respect to the adoption of alternative fuels. The results of the study reveal that when increasing time was spent in activities outside the family, the chances of adopting alternative fuels by the households was higher. This was also reported by Bluffstone (1995) who examined the household energy consumption of small farmers. The essence of these studies is that households adopt multiple fuel sources, where the availability of fuelwood along with the specific socio-economic and cultural aspects of the households decides on the type and level of consumption of other energy sources.

As the Nepalese national statistics (CBS 2012) classify households in six different classes (fuelwood, LPG, kerosene, biogas, dung and others) based on only the most dominant source, it is not possible to determine the number of households with a particular energy-mix pattern. Such information is crucial for energy policy makers and planners for appraising the prevailing energy programs. Some studies assessed the annual share of individual energy sources. For instance, Joshi et al. (1991) evaluated the annual household energy consumption in three different villages in three different topographical regions of Nepal. Fuelwood was found to be the only source of energy in households in the mountains, and in the hills 97 % was complemented by 3 % agricultural residues. Fuelwood contributed to only 9 % in the lowland but dung 63 % and agricultural residues 28 %. Pokharel and Chandrashekhar (1994) found an average per capita use of dung as fuel in the lowland of 5.1 GJ and of 0.7 GJ in hilly areas. Pokharel (2000) during a study in a village in the west of Nepal found a mix of energy sources, i.e., fuelwood (93 %), agricultural residues (4%), kerosene (2%) and electricity (1%). The studies are based on information obtained from household surveys where the quantification of each energy source was done according to the respondents' feedback. While the estimation of fuelwood consumption can be easily made based on the number of bundles that a particular household collects, this is not the case with crop residues and dung cake as these energy sources are not used consistently. Hence, such energy sources should be evaluated by considering both supply potential and level of fuelwood scarcity in order to obtain reasonable results. The monetization of energy sources such as LPG, kerosene and electricity made it simpler to evaluate their annual shares.

Against this background, in this chapter the analysis of the annual share of the four main energy combinations (fuelwood and biogas, fuelwood and LPG, fuelwood and dung, and fuelwood, dung and crop residues) is presented.

6.2 Fuel equivalent

As already discussed, fuelwood availability largely determines the amount of dung and crop residues used, while the use of biogas is limited because of the lack of dung and the low agricultural production during the winter. Among households using LPG, only few uses LPG to cope with fuelwood deficit, and despite sufficient fuelwood, most use LPG just for quick preparation of light snacks. Therefore, it was not possible to obtain information on the actual annual consumption of each of these energy types from the household surveys for all households. Hence, a bottom up approach was applied to evaluate the net annual energy consumption for cooking and heating and based upon fuelwood availability; the annual consumption of different energy sources was estimated.

Although the theoretical interchangeability factor of all energy sources can be estimated by applying their corresponding calorific value, this does not reflect a pragmatic basis for substitution of different energy sources at household level because of their unique conversion and combustion efficiency (Leach and Gowen 1987). To cope with this, the concept of the end-use task as suggested by Leach and Gowen (1987) for estimating the actual quantity of energy sources was applied. Here, the quantity of certain energy sources to complete particular end-use tasks was compared with the amount of other sources to fulfill same tasks in similar real life conditions. As fuelwood is common in all districts, was considered as a benchmark for assessing the substitutable factor 'fuelwood equivalent' among the different energy sources.

The 'fuelwood equivalent' refers to the conversion of energy sources such as dung, crop residues, biogas and LPG into the equivalent of the weight of fuelwood by considering fulfillment of particular energy needs. This weight was compared with other energy sources to fulfill the same needs. For instance, in one of the surveyed households, the daily requirement of fuelwood for cooking for a family of five was 6 kg, while 39 kg of paddy straw was needed on the same cooking stove. Therefore, the fuelwood equivalent for one kilogram of paddy straw is 0.15, i.e., 1 kg of paddy straw can cook the same amount of food as 0.15 kg of fuelwood on the same stove.

6.3 Methodology

The cooking experiment to evaluate the fuelwood equivalent was conducted three times each for fuelwood, crop residues, dung cake, biogas and LPG. Based on availability of the energy sources, the experiment was conducted in different households. As rice is a very common food throughout the country, this was considered for the experiment. In order to convert biogas and LPG into the fuelwood equivalent, the time needed to cook rice was taken as a basis based on which the consumption was estimated on the basis of the flow rate. The average flow rate of biogas per burner of 250 l hr^{-1} as reported during auditing of Nepalese biogas programs (Zifu et al. 2009) was applied, and for LPG the flow rate 0.036 kg hr^{-1} as determined by Pokharel (2004) in Nepalese urban areas. He used two burner stoves on the standard LPG cylinder with 14.2 kg of net gas, which was also done in this study. In the case of crop residues, based on availability during the experiment, paddy husks, paddy straw, corn stalk and corn cobs were used. The households used the same stove to burn crop residues and dung cake as for fuelwood. Only households in the lowland district used crop residues (paddy, millet and corn) for regular cooking (Chapter 4). Considering uniformity in pattern, the fuelwood equivalents of paddy husks and straw were applied to wheat husks and straw. The single fuelwood equivalent of the crop residues was estimated by averaging the respective values of fuelwood equivalent of the paddy husk, paddy straw, corn stalk and corn cob. Because of the extensive use of crop residues for energy generation, the weighted average of the fuelwood equivalent was done with reference to the lowland district. Since the cooking experiments were carried out in the local context, the moisture content of fuelwood, crop residues and dung was assumed to be insignificant when estimating the fuelwood equivalent.

6.4 Results and discussion

6.4.1 Fuelwood equivalent

The fuelwood equivalent of biogas, LPG, dung cake, paddy straw, paddy husks, corn stalks and corn cobs was obtained from the rice-cooking experiment in the households (Table 6.1).

Table 6.1 Results of rice-cooking experiment

HH code	Fuel type	Net consumed (kg, air-dried, for biogas m^3)	Fuelwood equivalent (kg)
A	Fuelwood	0.47	1.00
A	Biogas	0.10	4.70
A	LPG	0.02	26.11
B	Biogas	0.11	5.24
B	Fuelwood	0.59	1.00
B	LPG	0.02	27.31
C	Biogas	0.09	4.47
C	Fuelwood	0.41	1.00
C	LPG	0.02	22.78
D	Dung cake	1.73	0.91
D	Fuelwood	1.58	1.00
E	Dung cake	0.70	0.94
E	Fuelwood	0.66	1.00
F	Dung cake	0.61	0.95
F	Fuelwood	0.58	0.96
G	Fuelwood	0.61	1.00
G	Paddy straw	4.54	0.13
G	Paddy husk	0.82	0.74
G	Corn stalk	2.72	0.22
G	Corn cob	1.22	0.50
H	Fuelwood	0.42	1.00
H	Paddy straw	2.89	0.15
H	Paddy husk	0.57	0.74
H	Corn stalk	1.75	0.24
H	Corn cob	0.80	0.53
I	Fuelwood	0.69	1.00
I	Paddy straw	4.10	0.17
I	Paddy husk	0.92	0.75
I	Corn stalk	2.90	0.24
I	Corn cob	1.56	0.44

In each household, rice was cooked using different fuel sources

The fuelwood equivalent of each fuel type was calculated by relating the specific fuel consumption with that of fuelwood consumption for cooking rice in the respective household. Based on this, the average fuelwood equivalent was derived for biogas, dung cake, LPG, paddy straw, paddy husks, corn stalks and corn cobs (Table 6.2). For the crop residues, a single fuelwood equivalent was calculated by averaging the fuelwood equivalent of paddy straw, paddy husks, corn stalks and corn cobs.

Although the range of calorific values (15 – 17 MJ kg^{-1}) of fuelwood and crop residues was similar, the fuelwood equivalent of crop residues was relatively lower for the same cooking stoves (Table 6.1) because of relatively higher heat losses due to the higher burning rate. The burning rate is the rate of combustion of the biomass.

Table 6.2 Fuelwood equivalent of fuel sources

Source	**Fuelwood equivalent**
Dung (air-dried, 1 kg)	0.93 kg
Crop residues (air-dried, 1 kg)	0.40 kg
Biogas (1 m^3)	4.57 kg
LPG (1 kg)	23 kg

This was especially true for straw, where the share of total crop residues in the lowland district was more than 66 %. There are only few other studies that deal with the fuelwood equivalent as applied in this study. In a study in two villages in the lowlands in Nepal, Subedi et al. (1993) evaluated a fuelwood equivalent of agricultural residues of 0.71 kg and 0.97 kg of dung. As it was not clearly defined whether particular residues were estimated based on the average of available residues, it is difficult to compare these values with those in this study. However, the fuelwood equivalent of dung is comparable. In an experiment in India, Ravindranath and Ramkrishna (1997) observed a fuelwood equivalent of 0.89 kg, 5.15 kg and 14 kg for dung, biogas and LPG, respectively. As reported by GIZ (2014), 1 kg of LPG could replace 22 kg of fuelwood for cooking, which corresponds with the findings in this study.

6.4.2 Consumption analysis

The information acquired during the Q1 and Q2 surveys was applied to evaluate the energy consumption of each source for the households with four different energy mixes (Table 6.2). As obtained from the Q1 survey, the households in the hill district on average only used half a gas cylinder per year, while in the lowland district a whole cylinder was used. In the lowland district, some households used 5-kg gas cylinders. However, the estimation of LPG consumption was done on the basis of a standard cylinder with 14.2 kg gas. For the energy utilization of dung, the assumption was made on the basis of anecdotal evidence gained during the Q1 survey showing that only about 50 % of the annual available dung was utilized for energy generation in the form of biogas and dung cake. The annual available dung for the households was evaluated based on the findings presented in Chapter 5 (Tables 5.3 and 5.6).

For households using fuelwood, dung cake and crop residues in the lowland district, the assumption was made that the net available crop residues (152 kg $capita^{-1}$ yr^{-1}; see Chapter 4) were fully utilized for energy generation. By applying the fuelwood equivalent of different energy sources (Table 6.2), the annual energy consumption for different energy mixes was calculated in terms of “fuelwood equivalent” on a per capita basis (Table 6.3).

None of the households in the mountain district had such energy mixes. No estimations for other combinations of energy sources in the hill and lowland districts were made because of the negligible number of relevant households (Chapter 3). There is a high variation of energy consumption within the households having the same energy mix inside a district, and this is entirely based upon individual characteristics of the households.

Table 6.3 Average annual per capita energy consumption in terms of fuelwood equivalent for cooking and heating in the study districts

Household energy mix	Energy source	Fuelwood equivalent (kg $capita^{-1}$ yr^{-1})		
		Lowland district	**Hill district**	**Mountain district**
Fuelwood only ($n_L = 11$, $n_H = 22$ & $n_M = 80$)	Fuelwood	467(183)	779(295)	713(367)
Fuelwood & biogas ($n_L = 11$, $n_H = 22$ & $n_M = 0$)	Fuelwood	314 (195)	430 (235)	-
	Biogas	130 (53)	216 (78)	-
Fuelwood & LPG ($n_L = 8$, $n_H = 21$ & $n_M = 0$)	Fuelwood	405 (155)	533 (249)	-
	LPG	70	38	-
Fuelwood & dung cake ($n_L = 11$, $n_H = 0$ & $n_M = 0$)	Fuelwood	331 (172)	-	-
	Dung cake	145 (116)	-	-
Fuelwood, dung cake & crop residues ($n_L = 31$, $n_H = 0$ & $n_M = 0$)	Fuelwood	235 (128)	-	-
	Dung cake	161 (91)	-	-
	Crop	61	-	-

- *Figures in parentheses are standard deviations*
- *n_L, n_H & n_M are number of households in the lowland, hill and mountain districts, respectively*

Inefficient devices lead to relatively higher energy consumption, which is the reason for the higher consumption in those households that only use fuelwood in the hill and mountain districts. For the same reason, in the lowland district, households using a mix of fuelwood, dung cake and crop residues have higher energy consumption, as direct burning of crop residues is the most inefficient way to generate energy. About 66 % of households in the lowland district utilize crop residues and dung for energy generation (Table 6.3). Even though LPG devices are more efficient than others, the low rate of utilization in both lowland and hill districts has hindered the reduction of fuelwood consumption as compared to the households using other energy mixes.

The LPG here represents the only commercial source of energy. In general, it is considered to be a back-up energy source in both the hill and lowland districts. It is also typically used to save time when there is an overload of household activities especially during cropping and harvesting. The double amount of LPG used in the lowland district compared to the hill district can be explained by the poorer availability of fuelwood there. Furthermore, due to the complex terrain in some of the hilly areas transportation of LPG cylinders is difficult, which hinders the use of LPG even by better-off households there. A similar case was found by Mirza and René (2011) in Punjab, Pakistan, where because of remoteness, villagers were not able to adopt LPG.

The households in the lowland and hill districts using fuelwood and LPG show a similar tendency to use LPG only for cooking rice, tea and snacks. Evidently, the rate of utilization of LPG is directly associated with the economic status where every household was observed to reduce consumption of commercial energy sources by the maximum use of available biomass. Literature also revealed a low utilization of LPG in rural households in Nepal (Barnes and Floor 1996; Pokharel 2004; Cabraal et al. 2005; Bhattarai 2014) and in other countries such as Bangladesh (Miah et al. 2010), India (Ekholm et al. 2010), China (Xiaohua and Zhenmin 2001), South Africa(Howells et al. 2005) and Ethiopia (Gebreegziabher et al. 2012).

Thus, it can be concluded that both ease of transportation and affordability play a role in the adoption of LPG in the hill district, whereas only affordability is observed as a key parameter in the lowland district. The share of fuelwood in the hill and lowland districts was remarkably reduced in the households with biogas, where the introduction of biogas seemed to be quite promising in view of saving of fuelwood. Unlike the lower utilization rate of LPG, biogas has a relatively higher rate, which in most cases only depends upon availability of dung and surrounding air temperatures.

Despite the availability of dung, some households do not feed their biogas plants regularly mainly because of the lack of effective slurry management for further use as fertilizer. Therefore, in some cases households persuade to allocate large amounts of dung as fertilizer; this was also observed by Cheng et al. (2014) in most of the biogas plants in Nepal. Some households have no regular routine for feeding dung into their biogas plant, as also reported by Sigdel (2007) through carelessness, and they often overlook the possibility especially during peak working seasons. In the mountain district, no households have biogas plants, although the annual per capita supply potential is observed to be 25 m^3.

Hence, given the energy consumption pattern of rural Nepalese households, fuelwood still plays a predominant role. Its availability determines the use of crop residues and dung. The use of biogas is observed more effective in terms of fuelwood replacement than that of LPG.

6.5 Conclusions and recommendations

The household energy consumption pattern varies considerably, not only among the study districts but also within the districts. Regardless of the share in total energy consumption, fuelwood is used in almost all households. All households in the mountain district use only fuelwood, whereas the share of biogas, LPG, crop residues and dung differs in the households in the hill and lowland districts.

In terms of clean energy technology, biogas plays a significant role in reducing fuelwood consumption in both lowland and hill districts. However, various factors such as dung deficit, lower ambient temperature, absence of slurry management, and household behavior hinder its effective utilization. The economic factor largely determines the consumption level of LPG although in some cases, due to inaccessibility, even better-off households in isolated locations cannot use LPG despite their willingness to do so. Households especially in the hill district use LPG not to address fuelwood deficit but just for cooking quick meals and snacks. However, ten percent of the households in the lowland district resort to LPG to cope with fuelwood deficit.

As this study only covers four different household energy mix patterns, further research on other patterns is highly recommended in order to place household energy dynamics in a wider framework. The government's current practice of assessing households by only considering a single main energy source should be updated by indicating all sources of energy. The definition of 'main energy source' of a household is extremely vague, for example, it does not reflect the number of households that adopt particular energy mixes. Once such assessments focusing on households with particular combinations of energy sources have been made, the scale and type of energy solutions for policy makers will become clearer. Energy programs should be planned by targeting the prevailing energy-mix pattern and the biogas dissemination program should prioritized the needs in mountains, as almost all households there depend entirely upon fuelwood. Biogas users in the lowland and hill districts should be provided with training programs on slurry disposal and awareness of the importance of regular feeding of dung for optimum biogas production. In lowland, dung is mostly burnt. Here urgent focus should be put on the use of dung for biogas production. In order to address the clean energy demand of better-off households in isolated areas especially in hills and mountains, in addition to biogas, relatively smaller LPG cylinders (5 kg) as used in the lowland are recommended.

7 SPATIAL ANALYSIS OF BIOMASS SUPPLY AND DEMAND

7.1 Introduction

Availability and accessibility are the key aspects of energy resources that determine the actual potential of energy generation. These aspects are relative, and rely entirely on a particular location and need to be analyzed accordingly (Dresselhaus and Thomas 2001; Hedegaard et al. 2008; Angelis-Dimakis et al. 2011). With the introduction of the geographic information system (GIS), such evaluations have become very straightforward. In the real world, the collectable biomass is influenced by many factors such as distance between source and end-use locations, extent of protected areas, transportability and corresponding economic aspects for which the application of GIS is convenient (Fernandes and Costa 2010; Viana et al. 2010; Long et al. 2013). By applying various tools in GIS, the optimal location with a capacity of bio-energy production facilities can be recommended under various scenarios, which ultimately can support the decision-making process (Ayoub et al. 2007; Haddad and Anderson 2008; Iakovou et al. 2010). Hence, the use of GIS for biomass energy related studies has increased.

Depending upon the scope of the research, various studies applying GIS have been conducted on local, regional, national, continental and global levels. Considering the parameters influencing bio-energy production, Beccali et al. (2009)conducted a study to evaluate the technical and economical potential of biomass energy from agricultural and forestry sectors in Sicily. Shi et al. (2008) conducted a feasibility study for the establishment of biomass power plants in Guangdong province, China, based on spatial analysis of the supply of biomass and its transportation distance to candidate locations. Using crop statistics data and spatial data on transport, settlements and land use, Wekesa (2013) evaluated the potential of residues from four main crops for energy generation in Kenya. Milbrandt (2005) developed maps covering various biomass feedstocks such as crop residues, forest residues, mill residues, urban wood waste, and methane production potential from different categories of wastes in the USA. Based on maps of different inventories of population density, climate, vegetation, ecofloristic zones, soils and topography, the FAO (1997) presented a modeling approach to estimate biomass density. On the basis of suitability of climatic conditions and elevation, Tuck et al. (2006) carried out a study on the spatial distribution of 26 major bio-energy crops in Europe. Ramchandra (2007) conducted geospatial mapping of the supply-demand relationship of bio-energy at a lower administrative level in Karnataka, India, by considering agricultural, forest, and horticulture residues and livestock dung.

As in many developing countries, Nepal also lacks up-to-date spatial information on the availability of biomass and its use, which greatly hinders the formulation of effective policies and programs for sustainable resource management (APCTT-UNESCAP 2010; GIZ 2013; NPC 2013; AEPC 2014). In the Nepalese context, a limited number of studies based on GIS application to analyze biomass energy is available. For instance, Schreier et al. (1991) evaluated the fuelwood sufficiency in all districts of the country by a land evaluation model using the land-use map developed by the Land Resource Mapping Project (LRMP). Pokharel (2000) conducted a spatial analysis of the energy supply and demand in a village in western part of the country. Recently, Marzoli and Drigo (2014) evaluated the fuelwood supply and demand status for the whole country using a land-use map of 2010. However, no study has been done incorporating the supply and demand of three major biomass types fuelwood, dung and crop residues in an integrated way. This hinders energy policy makers in formulating or amending spatially differentiated policies and programs for establishing sustainable energy management. Based on the outcomes presented in chapters 3, 4, 5 and 6, this chapter provides the evaluation of the spatial variation of fuelwood, crop residues and dung in the study districts.

Of the three major types of biomass, the supply potential of crop residues and dung is analyzed in chapters 4 and 5, respectively and the results are applied to evaluate the corresponding potential at the Village Development Committee (VDC) level in the study districts. The evaluation of the fuelwood supply is carried out in this chapter which is primarily based on a GIS analysis of the land-use map of the study districts. The total biomass supply is evaluated by adding the supply potential of each biomass type at the VDC level in terms of “fuelwood equivalent”. For biomass demand, the energy consumption pattern (Chapter 6) is taken as a basis where demand is assumed to be equal to consumption.

The three analyses presented in this chapter are:

1. Annual supply potential of biomass (fuelwood, crop residues and dung) for household energy uses at VDC level
2. Annual demand of biomass (fuelwood, crop residues and dung) for household energy uses at VDC level
3. Evaluation of annual biomass surplus/deficit for household energy uses at VDC level

7.2 Annual biomass supply

7.2.1 Fuelwood supply

Fuelwood sources

There are diversified sources of fuelwood in terms of land types, which entirely depend upon both availability and accessibility for the specific users. The FAO (2015) classified these sources into three main categories:

1. Forest: An area of land at least 0.5 hectares (ha) with tree crown cover (or equivalent stocking level) of more than 10 %
2. Other wooded land: An area of land with either a crown cover of 5% - 10 % of trees able to reach a height of 5 m at maturity in situ, or a crown cover of more than 10 % of trees not able to reach a height of 5 m at maturity in situ, or with shrub or bush cover of more than 10 %.
3. Other land: This includes agricultural land, meadows and pastures, built-up areas, barren land, etc.

The annual production of fuelwood from any of the three sources is generally evaluated in terms of mean annual increment (MAI), which is the total biomass produced for a particular area divided by the number of years required to produce it. However, all biomass cannot be considered as fuelwood, as no belowground biomass along with some parts of aboveground biomass (AGB) such as leaves, twigs and stump are actually utilized in the form of fuelwood. Hence, such parts should be deducted to obtain the actual MAI of fuelwood as indicated in equation 7.1 (Amatya and Shrestha 2010a):

$$MAI\ (fuelwood,\ t\ ha^{-1}) = (AGB,\ t\ ha^{-1} * (1 - a - b) \qquad (7.1)$$

where a = biomass fraction of leaves and twigs ha^{-1}
b = biomass fraction of stumps ha^{-1}

Even though weighing tree biomass in the field is the most accurate way to estimate aboveground biomass, this procedure is almost impossible in large forests as it is both tedious and destructive in nature (Ketterings et al. 2001; Houghton 2005)**.** Hence, allometric equations are the preferred approach to evaluate forest biomass (St Clair 1993), as the principle of allometry refers to the fact that the proportions between height and diameter, between crown height and diameter, and between biomass and diameter of the tree follow a rule that is equally valid for all trees growing under the same conditions (Picard et al. 2012; Poudel et al. 2013). Based on this principle, various allometric equations have been developed to evaluate volume and biomass of forest under different ecological conditions (Nelson et al. 1999; Chave et al. 2001; Keller et al. 2001; Basuki et al. 2009; Singh et al. 2011; Mandal et al. 2013). Most of the studies on aboveground biomass in Nepalese forests are based on allometric equations developed by Sharma and Pukkla (1990). The utilization of remote sensing techniques such as long-wave-length radar, LiDAR and radar interferometer is increasingly used to evaluate forest biomass (Das and Ravindranath 2007). However, as different techniques, models and sample plots are applied, the estimation of aboveground biomass even from the same forest area may differ considerably. Hence, it is challenging to generalize the average value of aboveground biomass based on forest classification. Among the three different topographical regions of the Nepal, forests located in the lowland region have the highest aboveground biomass per hectare (Baral et al. 2009). For the age variation of 18-75 years, the variation of aboveground biomass was estimated to range from 76 ton ha^{-1} to 217 ton ha^{-1} (Baral et al. 2009).

Forest inventory in Nepal

The first systematic National Forest Inventory (NFI) in Nepal was initiated in 1963 by the Forest Resources Survey Office, Government of Nepal based on visual interpretation of aerial photographs. After the establishment of the Land Resource Mapping Project (LRMP) in Nepal with the joint effort of the Canadian International Development Agency and Government of Nepal, a reliable and uniform database of the land resources in the country was developed based on the study from 1980 – 1985, which estimated a share of forest and shrubland of about 42 % of the total area of the country (Amatya and Shrestha 2010a).

In the early 1990s, District Forest Inventories (DFI) were carried out in some districts by the Forest Survey Division with the support of the Forest Resource Information System Project (FRISP). From 1990 onwards, with the technical collaboration of the Government of Finland and FRISP, the second NFI was started, which was conducted in different phases between 1990 and 1998 in different areas of the country. The findings revealed that the coverage of forest and shrubland was 29 % and 10.6 %, respectively. Moreover, further classification of forest in accessible and inaccessible forest was done. Areas with slopes of more than 45° or surrounded by steep slopes, landslides or other physical obstacles, or located inside protected areas were considered as inaccessible. Based on these criteria, about 51.5 % of the total forest of Nepal was observed as accessible (DFRS 1999). With the bilateral cooperation between the governments of Nepal and Finland, a NFI has been recently done within the framework of the Forest Resource Assessment (FRA) project (2010-2014). It was done on the basis of RapidEye satellite images with a spatial resolution of 6.5 m and a field inventory conducted in 2010 and 2011 (FRA/DFRS 2014a).

Spatial variation of fuelwood supply

The supply module of the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) model was applied to evaluate spatial variation of the fuelwood supply. The concept of WISDOM was introduced by joint collaboration of FAO with the Institute of Ecology of the National University of Mexico (UNAM) (Ghilardi et al. 2007). WISDOM is based on GIS technology which allows multiple opportunities for combining or integrating, statistical and spatial information about the supply and demand side of wood fuels (Masera et al. 2006).

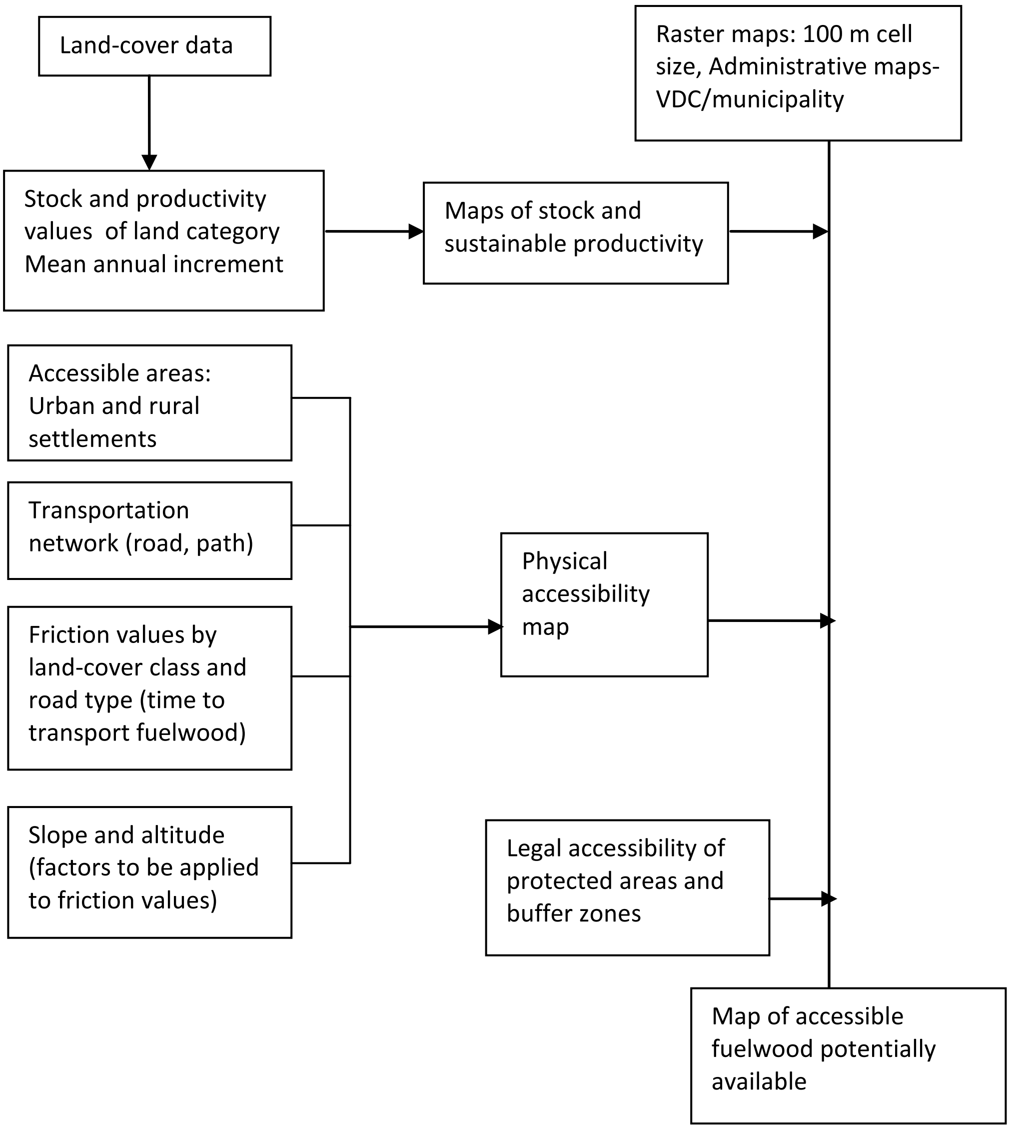

Figure 7.1 Process for fuelwood supply analysis (adapted from Marzoli and Drigo (2014))

So far, WISDOM has been applied to more than 26 regions on various levels including the national level in different countries such as Nepal (Marzoli and Drigo 2014), Slovenia (Drigo 2011) , Mexico (Ghilardi et al. 2007), Italy (Drigo et al. 2007), and Croatia (Segon et al. 2009). The recent WISDOM study in Nepal conducted by Marzoli and Drigo (2014) was carried out throughout the country by considering national level data sets, and was taken as a reference for this study (Figure 7.1).

The main steps adopted for the development of a GIS map for fuelwood supply are as follows:

1. The GIS maps of the study districts with layers of topography, land cover, VDC boundary, and road networks were collected from the Department of Survey, Government of Nepal.
2. The land-cover raster maps of the districts prepared from 30 m Landsat TM data for 2010 were obtained by free downloading from the International Centre for Integrated Mountain Development (ICIMOD), Nepal.
3. The digital elevation map (DEM) of Nepal of 30 m spatial resolution was obtained by free downloading from the ASTER Global DEM data product, which is a joint product of the Ministry of Economy, Trade, and Industry of Japan, and the US National Aeronautics and Space Administration (NASA).
4. The annual supply potential of fuelwood was estimated based on mean annual increment of different land-cover types derived from past studies. Based on the results of available studies, five different altitudinal ranges were considered for assigning respective values of productivity (Table 7.1).

Table 7.1 Annual fuelwood increment for different land covers at different altitudes

Land cover	Fuelwood increment (kg DM ha^{-1} yr^{-1})				
	Up to 500 m	**500 – 1200m**	**1200–2200m**	**2200–3500m**	**>3500m**
Coniferous open forest	1429	1429	1753	2457	2509
Coniferous closed forest	3039	2541	2612	3889	3889
Broadleaved open forest	2535	2535	2191	3451	2502
Broadleaved closed forest	3242	3242	3089	2883	2783
Grassland	549	426	385	289	212
Agriculture	612	612	612	612	NA*
Built up area	550	550	550	NA	NA

**NA = Not applicable*

Sources: DFRS 1999; FRA/DFRS 2014a; Marzoli and Drigo 2014; Neupane and Sharma 2014; FRA/DFRS 2014b

5. The GIS settlement map prepared by the Department of Survey, Government of Nepal, based on information of the national population census 2011 was used.
6. A fuelwood transport time map for the study districts was developed in order to analyze the physical accessibility of fuelwood supply (Nelson 2008). Accessibility was computed by applying a cost – distance algorithm. The 'cost' of travelling between two locations on a regular raster grid is measured in units of time. The raster grid defining the cost of movement is termed as a 'friction-surface' (Nelson 2008). The 'friction-surface' was generated by considering the friction cost of one round trip of fuelwood collection from the settlement to the fuelwood supply area and back to the start with the load of fuelwood. For the development of friction cost, district-level datasets of roads, land cover and terrain features (slope, altitude) were considered. As the upper limit of the time spent for a round trip to collect fuelwood in the lowland, hill and mountain districts was observed to be 7, 6 and 10 hours, respectively (Table 3.12, Chapter 3), the fuelwood supply was assumed to be completely inaccessible beyond these values (Table 7.2). For other time zones (number of hours), the references for fuelwood accessibility were taken from Marzoli and Drigo (2014). For fuelwood collection in the forest, where 3 hours

for a round trip from the settlement were necessary, accessibility is 88 %, 75 % and 94 % for the lowland, hill and mountain districts, respectively (Table 7.2).

Table 7.2 Defining fuelwood accessibility in reference to round trip hours

Number of Hours	Percentage of accessibility		
	Lowland	**Hill**	**Mountain**
1	100	100	100
2	94	98	98
3	88	75	94
4	75	65	88
5	60	50	70
6	30	30	58
7	20	0	44
8	0	0	28
9	0	0	15
10	0	0	10
>10	0	0	0

7. Despite the legal provision of fuelwood extraction in limited quantities near buffer zones around protected areas, no fuelwood extraction from these regions was considered for the analysis because of lack of actual information.

Following the aforementioned steps, a map of annual accessible fuelwood supply potential was developed (Figure 7.2). Besides energy use, the wider use of forest resources for construction material and cremations was deducted to obtain the net supply potential of fuelwood. More than 80 % of the country's population is Hindu. Here cremation of the dead body is quite common, and this requires a considerable amount of fuelwood. Hence, the estimation was made on the basis of district population data and death rate[7] considering 300 kg of air-dried fuelwood for cremation of one dead body (FAO 1991).

[7] Number of deaths per one thousand people per year. The national average death rate of Nepal is 6.67 (MoHP 2011) . Because of lack of districtwise statistics of death rates, the national average value is used for all VDCs in the three study districts.

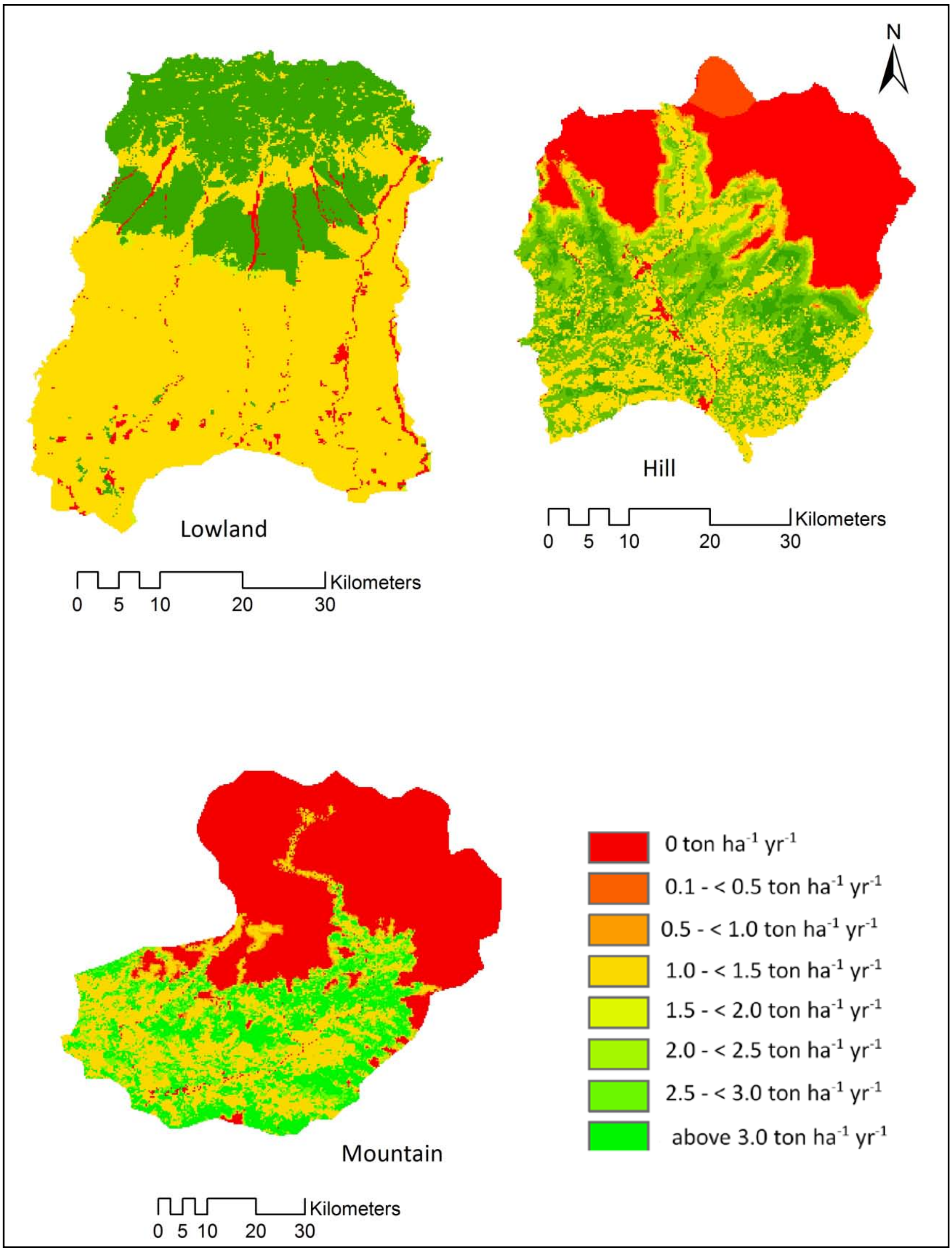

Figure 7.2 Annual accessible fuelwood supply in the study districts (t DM ha^{-1} yr^{-1})

Because of lack of exact statistics of fuelwood consumption for construction material, the assumptions made by Marzoli and Drigo (2014) of annual per capita requirement of 12.2 kg for rural areas and 4.1 kg for urban areas was applied.

The net annual per capita supply potential of fuelwood thus obtained at the VDC level was mapped (Figure 7.3). There is the high variation of fuelwood supply potential (100 - >800 kg $capita^{-1}$ yr^{-1}) among VDCs in each of the study districts. The numbers of VDCs that have annual per capita fuelwood supply lowest than 100 kg are four (out of 66), six (out of 61) and ten (out of 47) in lowland, hill and mountain respectively. In hill and mountain, the supply of fuelwood is primarily dependent on both availability and accessibility of fuelwood sources whereas the only issue of availability in case of lowland.

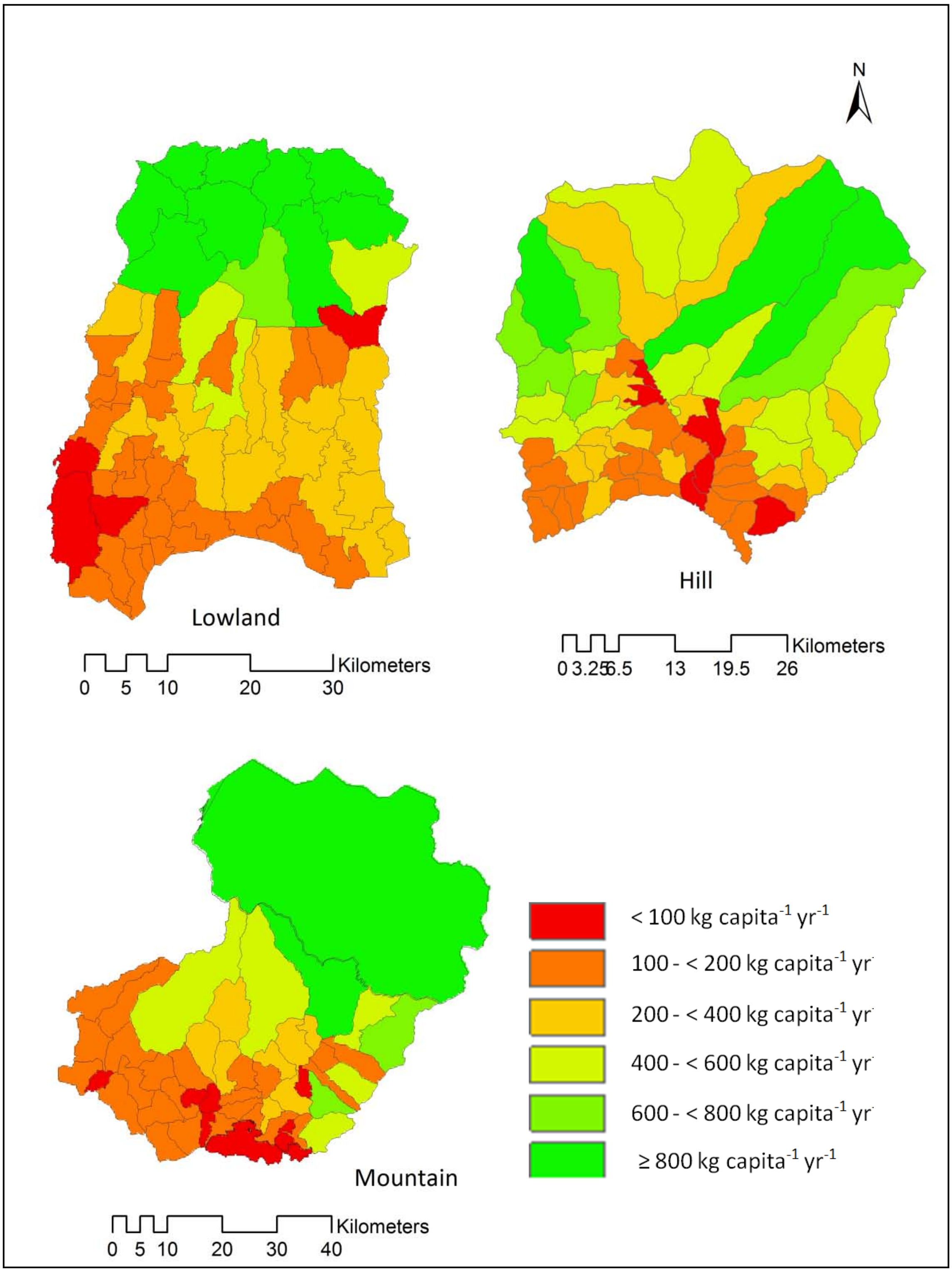

Figure 7.3 Annual per capita fuelwood supply potential at VDC level (kg DM capita^{-1} yr^{-1})

At the district level, the net annual supply of accessible fuelwood is estimated to be 232,950 metric tons, 43,025 metric tons and 44,534 metric tons in the lowland, hill and mountain districts, respectively. On a per capita basis, the hill district has the highest fuelwood supply with 257 kg, and the lowland and mountain districts 240 kg and 228 kg, respectively. In the lowland district, the VDCs with an annual per capita fuelwood supply higher than 800 kg are located in the northern part where only about 5 % of the district's population lives. Hence, the distribution of population and forest in the lowland district is comparably higher disproportionate as compared to that of the hill and mountain districts. This is the reason for the extensive utilization of crop residues and dung for energy generation in the lowland district.

7.2.2 Spatial variation of crop residues supply

As the cropping pattern varies highly with topography, the evaluation of arable land to assess suitable crop is necessary. A spatial analysis was carried out by classifying arable land into four sea-level altitudinal ranges of up to 500 m, 500 – 1200 m, 1200 – 1800 m and above 1800 m. The classification is based on information obtained during the household Q1 survey.

The limitations of the analysis were as follows:

1. The cropping pattern might have differed within each classified topography and accordingly the availability of crop residues
2. The spatial distribution of 'Khetland' and 'Bariland' along with cropping pattern could not be made via GIS analysis, which might have affected the crop yield assessment. Hence the information obtained during the household survey along with anecdotal evidence was taken as a basis for classifying the land and cropping pattern on the VDC level (Table 7.3). Moreover, the total area of respective cultivated land in a district was cross-verified with the corresponding district agricultural census report.
3. The status of irrigation and fertilizer input was not considered, which might have a significant impact on yield.

Table 7.3 Percentage of arable land for different crops for different altitudes

District	Crop	Up to 500 m (% land)	500-1200 m (% land)	1200-1800 m (% land)	>1800 m (% land)
Lowland	Paddy	45*	13	5	-
	Wheat	33	23	8	-
	Corn	11	10	51	-
	Millet	-	35	38	-
	Barley	-	-	-	-
Hill	Paddy	70 *	30	15	15
	Wheat	9	0.15	0.18	1
	Corn	10	20	41	20
	Millet	1	7	14	60
	Barley	-	-	-	-
Mountain	Paddy	-	30	15	5
	Wheat	-	31	32	23
	Corn	-	30	8	5
	Millet	-	1	2	3
	Barley	-	1	5	3

*Cultivated twice a year

Based on the findings and evaluation of potential crop residues for energy generation (Chapter 4), the variations in annual per capita potential at VDC level were mapped (Figure 7.4). All of the VDCs in the mountain district show annual per capita crop residues for energy production < 50 kg, whereas there were two such VDCs in the hill district and one in the lowland district.

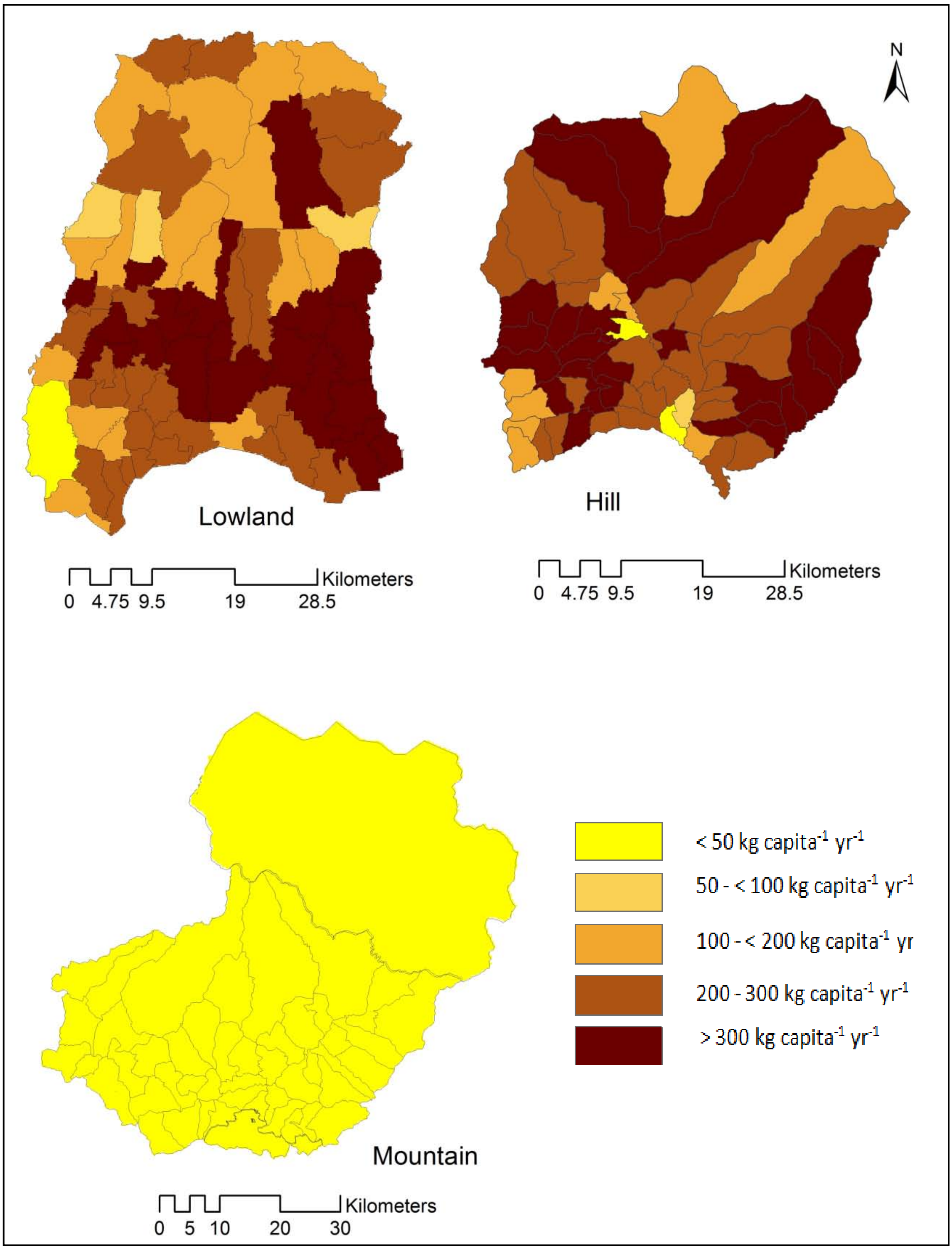

Figure 7.4 Annual per capita supply potential of crop residues for energy production at VDC level (kg DM capita^{-1} yr^{-1})

7.2.3 Spatial variation of dung supply

The average daily dung yield by four different classes of livestock (mature cattle, young cattle, mature buffalo and young buffalo) and the parameters (accessibility, collection efficiency, and utilization) (Chapter 5) were taken as a basis to analyze the spatial variation of dung for energy production at VDC level (Figure 7.5). The livestock inventory was obtained from CBS (2014).

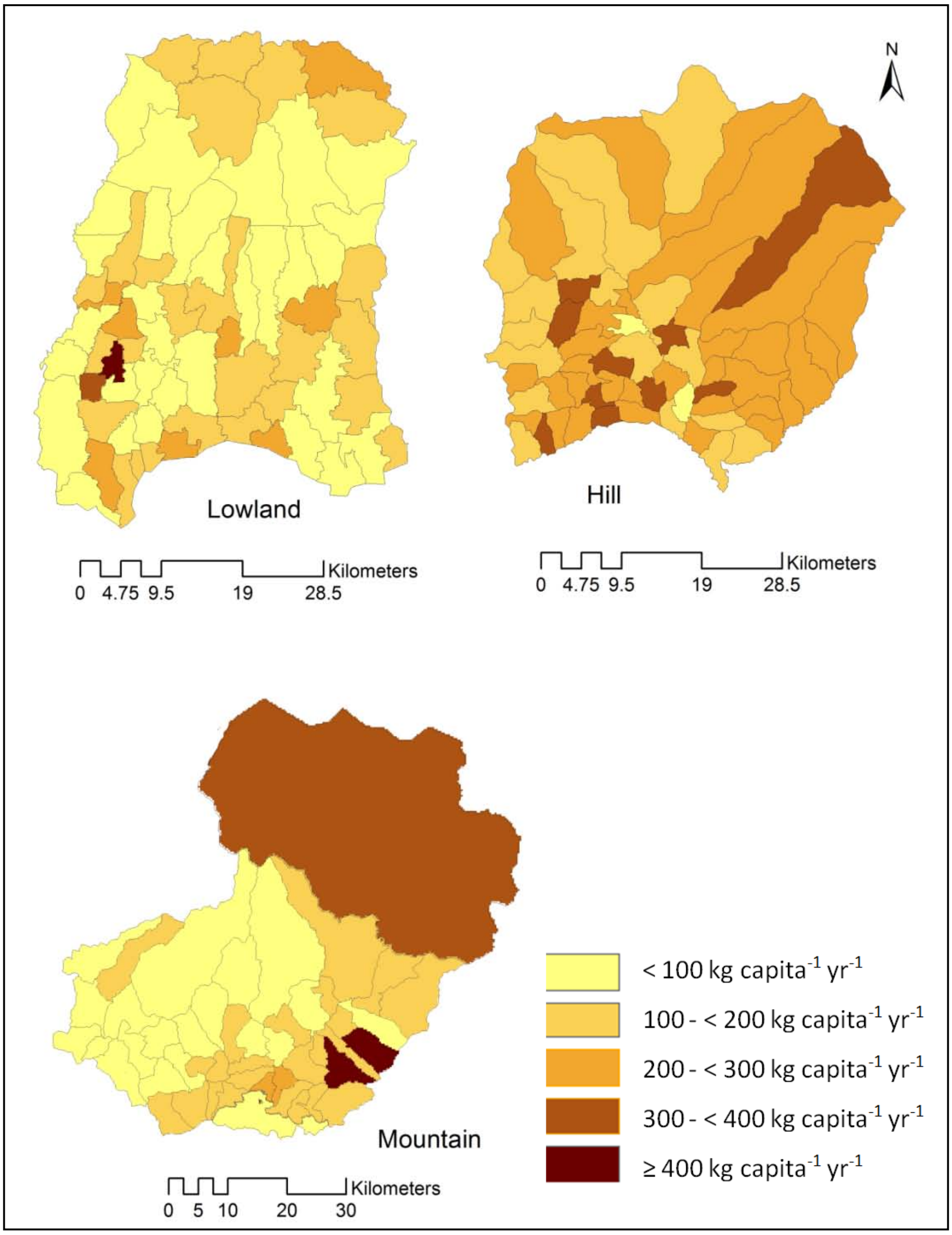

Figure 7.5 Annual per capita supply potential of dung for energy production at VDC level (kg DM $capita^{-1}$ yr^{-1})

7.3 Annual biomass demand

In order to align with VDC energy statistics, the four categories 'fuelwood only', 'fuelwood, dung and crop residues', 'fuelwood and biogas' and 'fuelwood and LPG ' applied in the demand analysis.

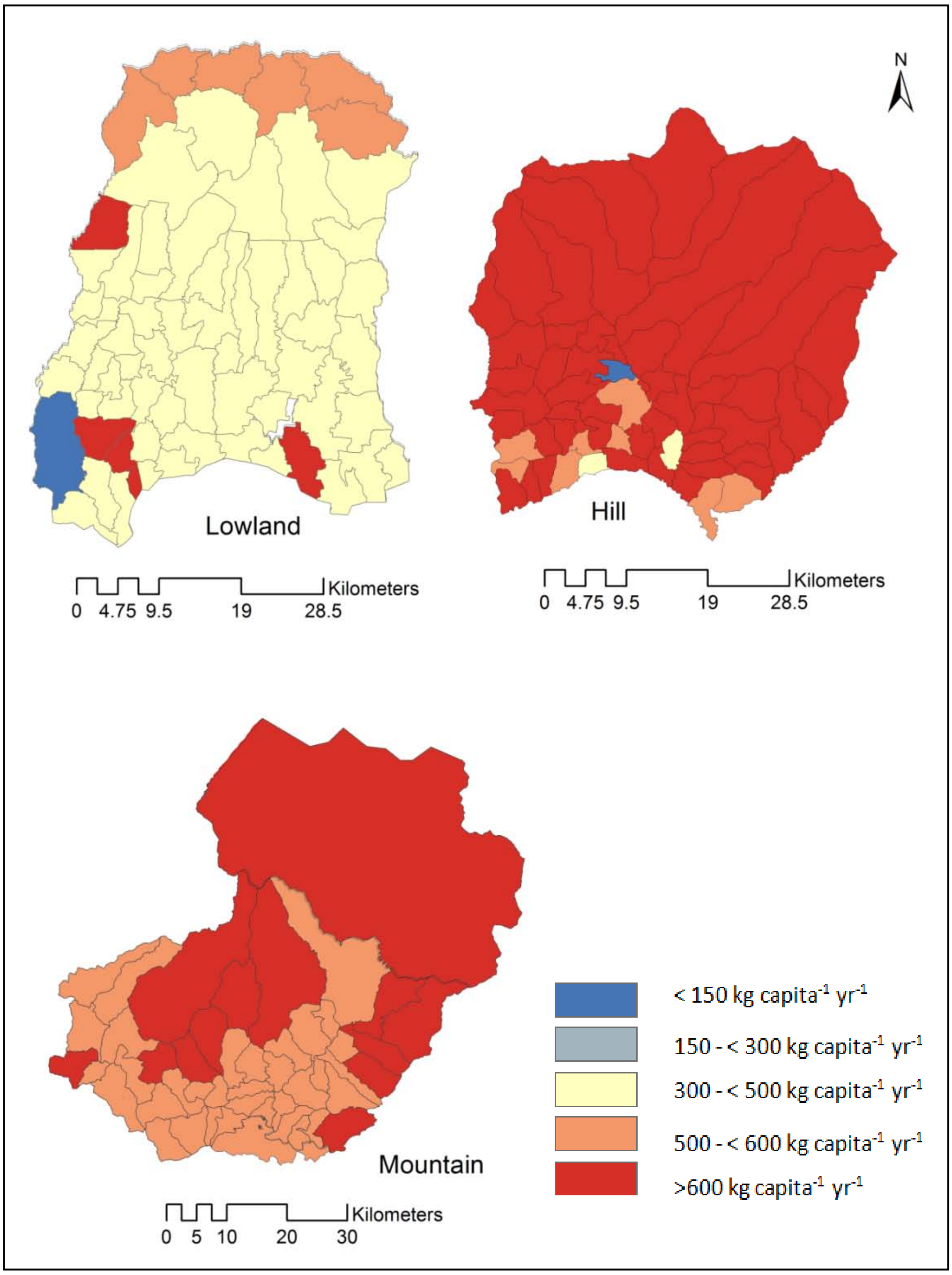

Figure 7.6 Annual per capita total biomass demand for energy production at VDC level (kg DM $capita^{-1}$ yr^{-1})

Based on the distribution of households in these four categories within a VDC (CBS 2012), the biomass demand in a particular VDC was determined using a weighted average value. For this, the biomass demand in terms of 'fuelwood equivalent' for a particular energy source applied (Chapter 6). Accordingly, the biomass demand was mapped for the VDC level (Figure 7.6). Only one VDC in the hill and the lowland districts have an annual per capita biomass demand lower than 150 kg, because these VDCs being the headquarters of the respective districts, most of the households use only LPG and electricity. Most of the VDCs (54 out of 61) in the hill and 13 VDCs in the mountain districts have a demand higher than 600 kg, whereas none of the VDCs in the lowland district have a biomass demand in this range. In the lowland district, most of the VDCs (58 out of 66) have a biomass demand lower than 500 kg. The VDCs with biomass demand higher than 500 kg are located in the northern part of the lowland district.

7.4 Biomass supply-demand analysis

The annual per capita supply of each of the three biomass types and biomass demands for all VDCs in the study districts are presented in Tables 7.4, 7.5 and 7.6.

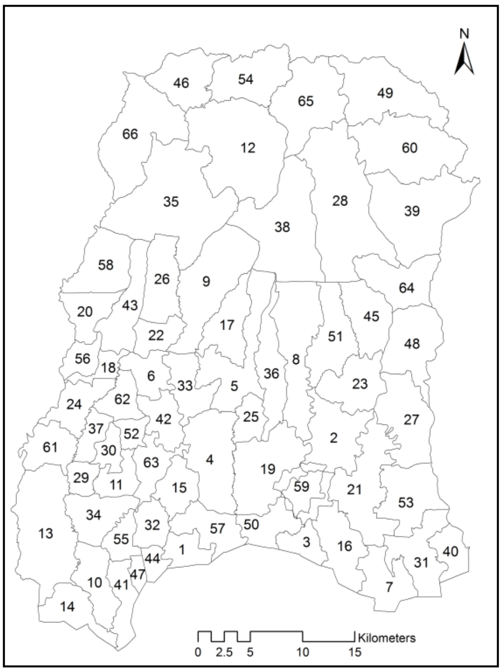

Figure 7.7 Distribution of VDCs with code numbers in the lowland district

Table 7.4 Annual per capita biomass supply and demand in terms of the 'fuelwood equivalent' in VDCs of the lowland district(kg DM $capita^{-1}$ yr^{-1})

Code no.	VDC	Supply				Demand	Surplus/ Deficit
		Fuelwood	Crop res.	Dung	Total		
1	Amahibariyati	188	83	221	492	370	122
2	Amardaha	220	97	194	511	404	107
3	Amgachhi	188	83	327	598	328	270
4	Babiyabirta	260	113	119	492	384	108
5	Bahuni	404	100	126	630	472	158
6	Banigama	217	112	169	498	430	68
7	Baradanga	281	80	96	457	352	105
8	Bayarban	359	59	178	596	479	117
9	Belbari	452	78	95	625	482	143
10	Bhathigachh	175	56	236	467	375	92
11	Bhaudaha	169	74	192	435	342	93
12	Bhogateni	3,981	54	133	4,168	500	3,668
13	Biratnagar	24	7	41	72	148	-76
14	Buddha Nagar	226	55	97	378	340	38
15	Dadarbairiya	261	75	93	429	341	88
16	Dainiya	168	74	243	485	371	114
17	Dangihat	151	30	43	224	487	-263
18	Dangraha	198	81	234	513	406	107
19	Darbesha	251	109	155	515	402	113
20	Dulari	97	71	187	355	415	-60

21	Gobindapur	238	105	155	498	384	114
22	Haraicha	215	85	279	579	463	116
23	Hasandaha	227	94	247	568	448	120
24	Hattimudha	207	77	221	505	392	113
25	Hoklabari	224	99	242	565	428	137
26	Indrapur	162	18	63	243	474	-231
27	Itahara	354	94	139	587	465	122
28	Jante	2,481	93	56	2,630	498	2,132
29	Baijanathpur	142	83	397	622	392	230
30	Jhorahat	157	69	581	807	389	418
31	Jhurkiya	243	132	85	460	367	93
32	Kadamaha	183	97	184	464	367	97
33	Kaseni	352	111	119	582	446	136
34	Katahari	138	75	179	392	426	-34
35	Kerabari	1,133	62	39	1,234	494	740
36	Keraun	255	93	184	532	464	68
37	Lakhantari	228	101	140	469	350	119
38	Letang	699	47	41	787	489	298
39	Madhumalla	442	89	91	622	491	131
40	Mahadewa	206	85	165	456	352	104
41	Majhare	176	58	212	446	340	106
42	Motipur	328	144	99	571	438	133
43	Mrigauliya	396	55	141	592	468	124
44	Nocha	183	126	129	438	344	94
45	Pathari	126	32	59	217	486	-269
46	Patigaun	3,392	64	151	3,607	578	3,029
47	Pokhariya	197	56	195	448	345	103
48	Rajghat	234	103	252	589	470	119
49	Ramitekhola	3,788	45	321	4,154	583	3,571
50	Rangeli	154	54	165	373	400	-27
51	Sanischare	127	41	70	238	485	-247
52	Sidraha	293	85	193	571	426	145
53	Sijuwa	246	158	175	579	453	126
54	Simhadevi	3,601	66	155	3,822	557	3,265
55	Sisabanijahada	217	52	86	355	385	-30
56	Sisbani Badahara	197	115	186	498	391	107
57	Sorabhag	251	89	146	486	377	109
58	Sundarpur	286	56	106	448	479	-31
59	Takuwa	214	89	142	445	358	87
60	Tandi	1,287	69	117	1,473	586	887
61	Tanki Sinuwari	83	36	56	175	425	-250
62	Tetariya	223	98	236	557	398	159
63	Thalaha	217	87	142	446	354	92
64	Urlabari	89	25	52	166	483	-317

65	Warangi	4,080	32	135	4,247	594	3,653
66	Yangshila	2,184	47	63	2,294	586	1,708

'Fuelwood equivalent 'of 1 kg DM of crop residues and dung are 0.4 kg DM and 0.93 kg DM, respectively

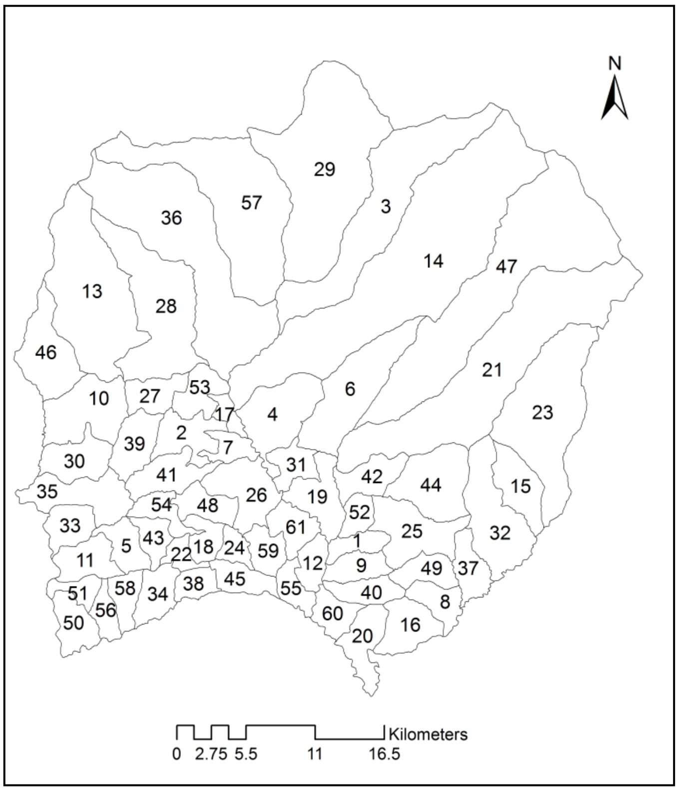

Figure 7.8 Distribution of VDCs with code numbers in the hill district

Table 7.5 Annual per capita biomass supply and demand in terms of the 'fuelwood equivalent' in VDCs of the hill district (kg DM capita^{-1} yr^{-1})

Code no.	VDC	Supply				Demand	Surplus/ Deficit
		Fuelwood	Crop res.	Dung	Total		
1	Archalbot	161	59	358	578	747	-169
2	Baglungpani	289	112	310	711	688	23
3	Bahundanda	291	84	235	610	717	-107
4	Bajhakhet	420	55	254	729	628	101
5	Bangre	332	89	294	715	684	31
6	Bansar	509	58	285	852	761	91
7	Besishahar	9	7	37	53	120	-67
8	Bhalayakharka	256	76	318	650	641	9
9	Bharte	243	55	314	612	713	-101
10	Bhoje	675	79	217	971	763	208
11	Bhorletar	108	42	159	309	618	-309
12	Bhoteodar	34	19	98	151	460	-309
13	Bhujung	1,174	66	271	1,511	792	719
14	Bhulbhule	840	88	246	1,174	761	413
15	Bichaur	350	79	259	688	657	31
16	Chakratirtha	86	55	199	340	593	-253
17	Chandisthan	60	34	304	398	677	-279
18	Chandreshwar	212	98	298	608	598	10
19	Chiti	87	66	193	346	666	-320
20	Dhamilikuwa	101	52	194	337	583	-246
21	Dhodeni	693	55	237	985	775	210
22	Dhuseni	263	85	357	705	586	119
23	Dudhpokhari	474	84	250	808	721	87
24	Duradanda	243	49	296	588	661	-73
25	Gauda	514	129	251	894	707	187
26	Gaunshahar	102	63	160	319	651	-332
27	Uttarkanya	566	67	348	981	775	206
28	Ghanpokhara	547	59	205	811	728	83
29	Ghermu	423	43	255	721	717	4
30	Gilung	487	118	297	902	721	181
31	Hiletaksar	344	94	404	842	757	85
32	Ilampokhari	532	147	263	942	749	193
33	Isaneshwar	137	30	253	420	789	-369
34	Jita	305	105	292	702	575	127
35	Karapu	513	101	260	874	699	175
36	Khudi	267	75	229	571	688	-117
37	Kolki	376	126	249	751	725	26
38	Kunchha	237	56	332	625	494	131
39	Maling	543	107	400	1,050	783	267
40	Mohariyakot	345	93	213	651	769	-118
41	Nalma	454	76	354	884	788	96
42	Nauthar	221	53	334	608	729	-121
43	Neta	232	65	342	639	765	-126

44	Pachok	512	61	282	855	769	86
45	Parewadanda	110	68	268	446	741	-295
46	Pasgaun	575	54	295	924	793	131
47	Phaleni	800	33	335	1,168	790	378
48	Purankot	480	96	365	941	744	197
49	Pyarjung	450	155	335	940	723	217
50	Ramgha	121	36	196	353	772	-419
51	Samibhanjyang	197	29	258	484	576	-92
52	Shribanjyang	134	65	341	540	642	-102
53	Simpani	116	39	208	363	734	-371
54	Sindure	348	114	242	704	698	6
55	Sundarbazar	35	8	122	165	760	-595
56	Suryapal	239	55	337	631	744	-113
57	Tadhring	487	132	334	953	738	215
58	Taksar	106	55	234	395	663	-268
59	Tarku	314	50	415	779	768	11
60	Tarkughat	108	40	238	386	782	-396
61	Udipur	143	62	235	440	784	-344

'Fuelwood equivalent 'of 1 kg DM of crop residues and dung are 0.4 kg DM and 0.93 kg DM, respectively

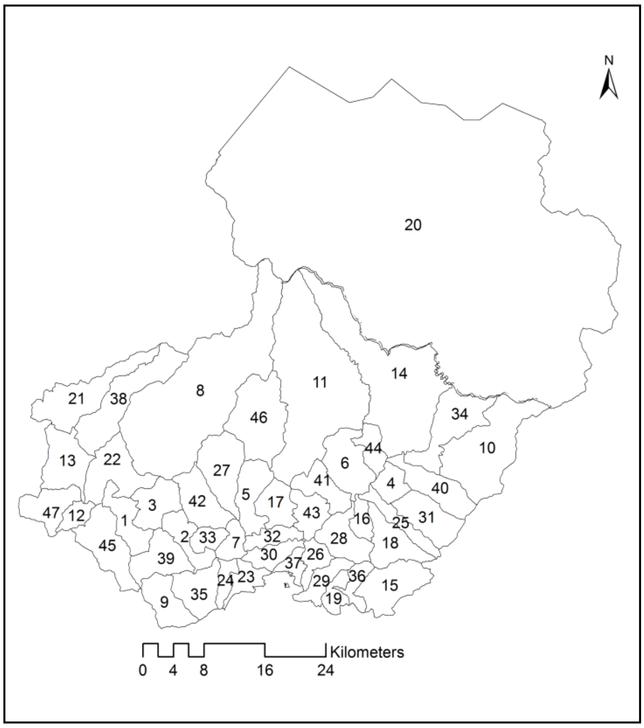

Figure 7.9 Distribution of VDCs with code numbers in the mountain district

Table 7.6 Annual per capita biomass supply and demand in terms of the 'fuelwood equivalent' VDCs of the mountain district (kg DM capita^{-1} yr^{-1})

Code no.	VDC	Supply				Demand	Surplus/ Deficit
		Fuelwood	Crop res.	Dung	Total		
1	Banjh	87	19	105	211	516	-305
2	Bhairavnath	93	6	107	206	516	-310
3	Bhamchaur	133	6	106	245	645	-400
4	Bhatekhola	90	5	123	218	551	-333
5	Byasi	204	6	119	329	551	-222
6	Chainpur	178	4	71	253	516	-263
7	Chaudhari	78	7	167	252	516	-264
8	Dahabagar	481	11	95	587	645	-58
9	Dangaji	162	15	129	306	551	-245
10	Datola	560	7	154	721	645	76
11	Daulichaur	392	7	62	461	645	-184
12	Deulek	56	3	110	169	551	-382
13	Deulikot	95	7	64	166	551	-385
14	Dhamena	910	12	161	1,083	551	532
15	Gadaraya	403	6	155	564	645	-81
16	Hemantawada	41	7	130	178	516	-338
17	Kadel	147	4	90	241	551	-310
18	Kailash	535	13	667	1,215	551	664
19	Kalukheti	84	8	174	266	551	-285
20	Kanda	1,143	26	429	1,598	645	953
21	Kaphalseri	162	6	73	241	551	-310
22	Khiratadi	118	10	70	198	516	-318
23	Koiralakot	105	6	139	250	551	-301
24	Kotbhairab	63	7	140	210	516	-306
25	Kotdewal	127	6	125	258	551	-293
26	Lamatola	206	9	267	482	516	-34
27	Lekgaun	201	3	97	301	645	-344
28	Luyata	221	17	141	379	516	-137
29	Majhigaun	108	4	121	233	551	-318
30	Malumela	109	20	203	332	516	-184
31	Mastadev	338	6	464	808	645	163
32	Matela	123	11	145	279	516	-237
33	Maulali	70	6	155	231	551	-320
34	Melbisauni	444	6	131	581	645	-64
35	Parakatne	161	14	128	303	551	-248
36	Patadebal	140	4	190	334	551	-217
37	Pauwagadhi	118	5	245	368	551	-183
38	Pipalkot	164	8	110	282	551	-269
39	Rayal	107	12	82	201	516	-315
40	Rilu	170	3	81	254	645	-391
41	Rithapata	226	7	147	380	516	-136
42	Senpasela	141	4	80	225	645	-420
43	Subeda	137	5	91	233	516	-283

44	Sunikot	258	4	216	478	551	-73
45	Sunkuda	142	12	74	228	551	-323
46	Surma	267	4	91	362	645	-283
47	Syadi	100	6	85	191	645	-454

'Fuelwood equivalent 'of 1 kg DM of crop residues and dung are 0.4 kg DM and 0.93 kg DM, respectively

As obtained (Tables 7.4, 7.5 and 7.6), the annual per capita demand of biomass (dry matter) in terms of "fuelwood equivalent" in the lowland, hill and mountain districts is 435 kg, 660 kg, and 653 kg, respectively. Based on the different supply-demand variation at VDC level (Tables 7.4, 7.5 and 7.6), the share of households at district level was evaluated (Table 7.7).

Table 7.7 Share of households with biomass surplus/deficit as a percent of biomass supply in the study districts

Biomass surplus/deficit (% of biomass supply)	**Lowland (% of households)**	**Hill (% of households)**	**Mountain (% of households)**
< - 20 %	30	9	95
-10 to -20 %	11	38	1
0 to – 10 %	4	3	1
0 to 10 %	3	11	1
10 to 20 %	16	22	1
> 20 %	38	17	1

In the mountain district, a deficit of biomass for energy generation exists in 97 % of the households, whereas a surplus biomass production was observed in 57 % of the households in the lowland district. The contribution of crop residues and dung for energy production is quite negligible in the mountainous areas due to the low production. Despite the fuelwood deficit, the availability of crop residues and dung is the main reason for the biomass surplus in the lowland district. The situation in the hill district is similar with a lower share of households with biomass surplus.

The supply-demand pattern of biomass is highly uneven in all districts. In the lowland district, for instance, the supply potential of fuelwood is about eight times that of the demand in Bhogateni VDC, whereas the demand is more than three times that of the supply in Urlabari VDC (Table 7.4).

7.5 Conclusions and recommendations

The application of GIS is highly advantageous especially for evaluating the fuelwood supply potential. This can support pragmatic analysis by considering both physical and legal accessibility. Fuelwood is overexploited in most of the areas in all districts. Because of the higher production rate, the contribution of crop residues and dung is observed to be highly significant for maintaining balanced supply of biomass in the lowland and hill districts, whereas no such effect is observed in the mountain district. Such potential contribution is higher in the lowland district to maintain a balanced supply to more than half of the total households, and in the hill district to more than one third of the total households. However, unlike in the lowland district, the contribution of crop residues and dung is negligible in the hill district.

As most households use fuelwood, the foremost challenge is to prevent overexploitation ensuring a balance use of the three biomass types analyzed in this study. The extensive introduction of efficient technologies such as biogas, improved cooking stoves, briquettes, gasifiers, etc., to rural households could not only reduce biomass consumption but also offer clean energy solutions. Furthermore, the implementation of alternative energy sources (LPG, electricity, solar cookers) is necessary in the areas with biomass deficits.

Given the highly uneven distribution of biomass, the transportation of biomass from surplus to deficit areas could be one of the potential solutions to reduce overexploitation of fuelwood. This seems to be relatively unproblematic in the lowland, but because of poor transportation infrastructure this poses a challenge in the hill and mountain districts. As the spatial variation is limited to the VDC level in this study, further research at the micro (village) level could identify convenient transportation routes within the VDCs. The interrelation of energy, environment and economy for transporting the biomass from one place to other place for energy production is essential to ensure sustainability.

The results can be used to support energy planners and policymakers in the prioritization of action plans to the respective VDCs based on the level of biomass deficit.

8 GENERAL DISCUSSION

As elsewhere in developing countries, the rural household energy consumption in Nepal is predominantly supported by biomass, which is utilized in two ways. One is direct burning in almost all households that adopt biomass for energy production, and the other is biogas production in a limited number of households (4 % in the lowland, 10 % in the hill and none in the mountain district). Direct burning occurs with all biomass types, whereas biogas is produced only through the use of dung. Almost all biogas users also burn biomass to fulfill their household energy needs. Despite the predominant role of biomass at the household level in all regions, there is a significant variation in terms of consumption pattern and availability of alternative fuel sources. The variation of biomass consumption is largely defined by availability of forest resources as observed in the lowland district, where an extensive use of crop residues and dung because of the low fuelwood supply was observed. Due to relatively easier access of forest resources, direct burning of crop residues and dung is quite negligible in the hills and mountains.

The district level fuelwood consumption in the hill and mountain districts is three times higher than the supply potential (carrying capacity), whereas consumption is double the supply in the lowland district. The patterns can be considered the same for the other districts in the respective topographical regions except in some urban and peri-urban areas where excessive use of LPG exists. Based on the household distribution of different energy sources (CBS 2012) and the household fuelwood consumption data (Table 6.2, Chapter 6) as obtained from this study, the annual fuelwood consumption on a dry-matter basis is calculated to be 12.04 million t whereas WECS (2014) estimated 17.82 million t for 2011/12. As the WECS study did not clearly explain the methods of the fuelwood consumption assessment, the two values could not be compared.

On the national level, only about 26 % of crop residue production was found to have potential for energy generation[8], which contradicts the earlier national assumption of 50 % (WECS 2010). At present, the utilization of crop residues has the potential to replace 1.6 million MT of fuelwood (1 kg crop residues = 0.4 kg fuelwood), which is equivalent to 28 % of the LPG consumption in 2014/15 (1 kg crop residues = 0.017 kg LPG based on Table 6.1, Chapter 6). The use of crop residues for energy generation in the hill and mountain districts is underutilized, whereas the direct burning of crop residues at the household level in the lowland district is very inefficient. This has a severe impact on both indoor and outdoor air quality. Therefore, there is an urgent need to intervene with modern efficient technologies to convert these residues into energy. Of various technologies, briquetting seems to be quite promising for household energy purposes. The small-scale manual briquetting technology is deemed to be relevant for fuelwood-deficit areas with highly dispersed settlements, especially in the hills and mountains. In the concentrated settlements, mostly in the lowland, a medium-scale technology operated by motors or bullocks may be a viable option. Most of the briquetting technologies are already available in Nepal, but have only very limited use (Practical Action 2009; Bhujel 2013; Singh 2013; AEPC 2014). Therefore, the government should show a strong commitment and political will for wider dissemination of the technologies by especially targeting fuelwood-deficit areas.

Based on daily dung yield by livestock for three different seasons (Table 5.3, Chapter 5) and the national livestock statistics for 2014 (MoAD 2014), the net annual dung (on a dry-matter basis) available for biogas production is found to be 7.64 million t, which is about 50 % of the potential estimated by WECS (2010). Although the increment of livestock between the reference years of the two studies (2008 and 2014) is only around 1 %, different factors led to the discrepancies in the results. WECS

[8] The estimation is based on national annual production data of paddy (5,047,047 t), corn (2,283,222 t), wheat (1,893,482 t), millet (304,105 t) and barley (34,824 t) as obtained from MoAD (2014 in which the RPR values (Chapter 4, Table 4.4) and the proportion of particular crop residues for energy generation (Chapter 4, Table 4.9) were applied.

(2010) did not consider regional and seasonal variations of dung yield vis-à-vis the four different livestock categories as done for this study but only assumed two values of daily fresh dung yield for cattle (10 kg) and buffalo (15 kg). As revealed in this study, the consideration of a single value is highly misguiding. For instance, the daily dung yield by mature cattle in the mountain district was observed to be only about 33 % of that in the lowland district, whereas the daily dung yield in the post-monsoon from young buffalo in the hill district was about 50 % of the yield during the monsoon period. The assumptions of WECS for dung availability for biogas production were 50 %, 75 % and 100 % of the total production in the mountain, hill and lowland areas, respectively, which is also in contrast with the results of the field experiments in this study (mountain 59 %, hill 64 %, and lowland 75 %).

Based on the net dung availability and by considering the energy equivalent under the local conditions (1 m^3 biogas = 0.2 kg LPG), the introduction of biogas even by excluding all households in urban and mountain areas produced an energy equivalent of 97 % (251,759 t yr^{-1}) of imported LPG in 2014/15. The monetary value is 25 billion NPR (Euro 231 million) a year, which can develop hydroelectricity amounting to 850 MW with a potential to replace the national LPG cooking needs in 2014/15 (Bisht 2015) with a simple payback period of 5.4 years (NPR 160 million MW^{-1}).

The lowland is considered as the country's breadbasket where it is, however, repeatedly being reported that the lack of fertilizers has reduced crop production (Shrestha 2010; Shrestha et al. 2013b; Dahal et al. 2015). Chemical fertilizers are not produced in Nepal, and the farmers have not been able to buy sufficient amounts due to lower imports than required (Pant 2013). At the same time, dung is being excessively burnt to fulfill energy needs. Considering the average nitrogen (N), phosphorous (P), and potassium (K) values of 0.93 %, 0.75 % and 0.5 %, respectively, for dung slurry (Gurung 1997), the losses from dung burning on the national level are observed to be 2964 t N yr^{-1}, 2390 t P yr^{-1} and 1593 t K yr^{-1}. This cumulative loss of fertilizers is equal to about 8 % of the government's supply of fertilizers (20-25 % of the total demand) for the year 2013/14 (The Kathmandu Post 2014). Hence, an introduction of biogas in Nepal will not only provide a clean energy solution but also to some extent prevent organic fertilizers from being wasted and reduce imports of chemical fertilizers.

The prevailing energy consumption pattern and the past trends show that a complete replacement of solid biomass burning for energy production with clean energy technologies at the household level is not practically possible in near future. Hence, for the present, there seems to be no alternative to manage available biomass efficiently and effectively. Whilst intensified promotion of improved cooking stoves and biogas for the households is necessary on the one hand, exploration of other suitable technologies such as bio-briquettes and gasifiers taking the technical, economical, social and cultural aspects into consideration is equally important on the other. The findings of the biomass supply-demand analysis in this study can be used by energy planners and policymakers to prioritize the necessary action plans to respective VDCs according to the level of biomass deficit. Based on the biomass supply-demand analysis in this study, energy planning on the VDC level throughout the country can be conducted where the VDCs can be divided into different categories and accordingly necessary interventions can be made. For instance, the results of the analysis can help to identify areas that are likely to be most feasible for further exploitation of fuelwood for commercial distribution to biomass-deficit areas. In the absence of formal fuelwood markets, the households in fuelwood-surplus areas especially in the hill district are consuming more fuelwood than the actual demand. By identifying such areas on the national level, the government could facilitate establishment of formal markets, which could prevent excessive fuelwood consumption. The surplus fuelwood could then be diverted to fuelwood-deficit areas. Some VDCs in the lowland district were found to have sufficient dung production, and this could produce biogas amounts higher than the household demand. By exploring similar VDCs throughout the country, targets could be identified for disseminating optimum-sized biogas plants that could completely substitute the use of fuelwood and crop residues for energy generation. The replaced fuelwood and crop residues could then be supplied to nearby VDCs with a biomass deficit. Additionally, the set-up of small hydropower plants in the biomass-deficit areas could fill the biomass gap. However, past experience in using electricity for cooking in rural areas is not positive (Bell 1994; Gurung et al. 2011; Sanchez et al. 2013). The lack of a market for electric stoves and their unaffordability in rural areas were observed to be the main barriers for using electricity for cooking. The government should therefore explore possibilities for markets for electric stoves, and provide financial tools to motivate households to adopt such stoves. To address the energy issues of the remote and inaccessible areas with both biomass deficit and lack of hydro resources, supplying LPG in smaller cylinders (5 kg) could be a solution which is already successfully practiced in India (Kanagawa and Nakata 2007). Solar cookers can also be considered as an option for cooking and heating in biomass-deficit areas. However, the attempts to promote solar cookers have not been successful in Nepal, and no solar cookers at all were distributed through the AEPC during the period 2013 to 2014 (AEPC 2015b). The cooking time, which is mostly in the evening, in general does not coincide with the sunshine period, which is one of the main drawbacks of solar cookers. Recently, photovoltaic and thermal hybridized solar cookers have been developed in India, and it is reported that the cooker can be used at the user's convenience for more than 300 days a year (Joshi and Jani 2013). Hence, the introduction of such hybridized solar cookers could be the solution for cooking and heating in biomass-deficit areas and in regions where no micro-hydro potential exists.

In Nepal, the annual average rate of urbanization from 2001-2011 was 3.6 % (CBS 2014b) whereas at the same time, the annual growth of livestock (cattle and buffalo) and crop production was 1.03 % and 3.05 %, respectively (MoAD 2013). The proportion of population living in mountains and hills is gradually decreasing while it is continually increasing in the lowland (MoAD 2013). This, of course, has led to the trend of overall reduction of fuelwood consumption in the mountains and hills (Baland, Libois, and Mookherjee 2013). Such population and agriculture dynamics are likely to continue. This means that the current trend of increasing consumption of LPG in urban areas, and inefficient burning of crop residues and dung for energy production in rural lowland areas will also continue. Hence, the distribution of surplus biomass to urban areas together with efficient biomass utilization in rural lowland areas can address both inefficient utilization of of biomass there and the increasing consumption of LPG in urban areas. The methods applied in this study can be a basis to conduct similar spatial analyses on the biomass supply-demand throughout the country to identify feasible areas where biomass can be distributed to urban areas. The surplus biomass in remote locations with difficult terrain can be transported by converting this biomass into small condensed briquettes/pellets. Some initiatives by the government and private sector exist, but because of the lack of biomass and relevant information as well as poor market linkages, the briquette sector in Nepal has not been able to provide a noticeable contribution to the national energy consumption (Singh 2013; AEPC 2014). Therefore, the methods applied in this study can be replicated to other areas to evaluate the biomass supply potential and to identify potential market areas. In line with this, the government should encourage local communities to establish briquetting industries by disseminating briquette technologies and skills, and intervening in the market. Similarly, the traditional use of bio-char for specific crops exists in some areas of the country, and recently a pilot test was initiated involving dual purpose stoves for cooking and bio-char production (Dahal and Bajracharya 2013). By conducting further research on bio-char to identify a suitable technology on the basis of availability of biomass types, a widespread implementation of bio-char programs will become possible. The community forestry in Nepal is considered to be one successful example of participatory management of natural resources (Thoms 2008; Pandit and Bevilacqua 2011; Chhetri et al. 2013), and hence there seems to be great scope to link bio-char programs with community forest users' groups. The promotion of briquette and bio-char at community level will not only create job opportunities but also support the reduction of LPG imports.

Nepal being a net importer of all kinds of petroleum products should focus on indigenous resources, i.e. mainly hydro facilities and biomass for energy production both from an economic and environmental point of view. Despite the huge potential of hydroelectricity (42,000 MW is commercially feasible), the present generation is only about 1.5 % of the total energy production, and there is a lack of about 410 MW during peak load times when demand reaches 1201 MW (NEA 2014). Based on past experience, even with highly optimistic projection, hydroelectricity will only fill the supply-demand gap in the next 8 to 10 years (Nakarmi et al. 2014). Therefore, in the long run, hydroelectricity should be targeted to replace both solid biomass and LPG used for cooking and heating. However, as highlighted by various studies (Agrawala et al. 2003; Pathak 2010; Babel et al. 2011; Bajracharya et al. 2011), water resources and hydropower generation in Nepal are the most sensitive to the impacts of climate change. The development of small-scale dispersed hydroenergy facilities along with the effective deployment of biomass should therefore be intensified in view of domestic energy security. In addition to the damage to the hydroelectric plants (154 MW) and roads (5219 km) through the devastating earthquake in April 2015 (NPC 2015), and because of unofficial blockades on the country's border for more than five months, Nepalese life was severely crippled especially in urban areas due to LPG shortages (BBC 2015; Bell 2015). To cope with the situation, the government had to distribute fuelwood to urban areas including Kathmandu, the capital city (Thapa 2015). This shows how crucial it is to exploit locally available biomass for energy production to address the issues of domestic energy security. There is therefore an urgent need to prepare nationwide inventories of the spatial variation of biomass supply and demand in order to formulate policies and programs for their effective deployment to areas as the need arises.

The production of energy crops on waste land especially in hilly areas can be suitable in view of both energy carriers and measures to prevent soil erosion. Of various energy crops, *Jatropha curcas*, a semi-evergreen shrub or small tree, is considered to be suitable in the context of Nepal (Kumar and Sharma 2008; Adhikari and Wegstein 2011; Shrestha et al. 2013a). By identifying potential land areas, the respective communities can be mobilized for management of such plantations. The promotion of *J. curcas* is also considered as one of the poverty alleviation strategies in the country (Adhikari and Wegstein 2011), which additionally can help to reduce the import of petroleum products to some extent. Forest plantations, especially in the fuelwood-deficit areas, should be highly prioritized by enhancing community activity and responsibility through both financial incentives and conducive regulations with the aim to fulfill future fuelwood requirements. Besides other positive ecological aspects, such forest plantations can provide fuelwood and enhance carbon storage in fuelwood-deficient areas in the future.

The need for efficient exploitation of biomass for energy generation in view of national energy security was revealed in the national report on biomass energy strategies (NEEP 2014). Among four main interventions to meet the vision of transferring the prevailing inefficient biomass utilization to clean energy options by 2030, information on the spatial variation of biomass energy supply and demand for decision makers is given high importance (NEEP 2014). Against the background of the process of drafting a national energy security strategy, it is high time to incorporate biomass energy in the national mainstream energy supply. Information on spatial variation of biomass supply and demand is of foremost importance to implement an energy security strategy for which the procedures followed in this study may be replicated to the other districts in the country.

The procedures adopted in this study along with the discussed ideas are equally applicable to other countries having similar energy patterns, especially South Asia and Sub-Saharan African nations where the general pattern of rural settlements is much the same. Several biomass assessments have been conducted in India (Chhabra 2002; Ramachandra 2007; Hiloidhari and Baruah 2011), where the government initiated electrification in rural areas by deploying biomass for which, based on resource availability, various technologies vis-à-vis subsidies are provisioned (Kumar et al. 2015). In the context of Sub-Saharan nations, various studies revealed an urgent need to implement policies and programs by conducting similar studies to tackle biomass scarcity (Owen et al. 2013; Mograbi et al. 2015; Karlberg et al. 2015). In line with this, fuelwood supply and demand analyses based on the WISDOM model in some African nations already exist. Based on a detailed assessment of agricultural biomass, Mohammedet al. (2013) recommended decentralized bio-energy technologies for rural areas in Ghana recognizing the importance of local planning.

9 OVERALL CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

1. In Nepal, the complete replacement of solid biomass burning for energy production with clean energy technologies at household level is not practically possible in the near future. Hence, for the present, there seems to be no alternative to managing available biomass efficiently and effectively.
2. The variation of biomass consumption is largely defined by availability of forest resources as observed in the lowland district, where an extensive use of crop residues and dung takes place because of the low fuelwood supply. Due to the relatively easier access to forest resources in the hill and mountain districts, the direct burning of crop residues and dung is quite negligible there.
3. At the national level, the energy equivalent of the net annual available dung (cattle and buffalo) and crop residues (paddy, corn, wheat, millet and barley) is about 72 % of the total fuelwood consumption in a year, which is equivalent to more than the total annual LPG imports for household consumption.
4. The uneven distribution of settlements and biomass have led to overexploitation of biomass in densely populated areas and underutilization in areas less densely populated. The identification of such areas is the main step to formulate and implement appropriate energy policies and programs.
5. Nepal being a net importer of petroleum products and located in one of the zones most highly vulnerable to climate change, efficient utilization of biomass for energy uses is the key step to address the three critical issues national economy, energy security and environment-friendly energy.

9.2 Recommendations

1. The key issue in the hills and mountains is to deploy underutilized crop residues and dung for energy production to reduce fuelwood overexploitation. At the same time, the prevailing extensive direct burning of these sources in the lowland has to be

modified into cleaner technologies by intensifying biogas and briquette technologies. For biomass-deficit areas especially in the hills and mountains, policy interventions should promote electric cooking systems using electricity from local hydro resources to fill the biomass supply gap. To address the energy issues of the remote and inaccessible areas with both biomass deficits and lack of hydro resources, special provisions to supply LPG in smaller cylinders should be initiated. Information on the spatial variation of biomass supply and demand is of utmost importance to implement the aforementioned energy strategies for which the procedures developed in this study may be replicated in the other districts of the country.

2. Biomass inventories should be updated regularly and according to energy policies to cope with changing population and agriculture dynamics, as this will have a strong impact on the biomass supply-demand relationship.
3. The government should incorporate the biomass energy sector into the national mainstream energy supply to both urban and rural areas, and establish formal biomass markets for effective energy utilization. This can support the reduction of excessive biomass consumption in biomass-surplus areas, thus meeting the energy needs in biomass-deficit areas. For this, policies related to the enhancement of skills and technologies to convert biomass into portable forms, and incentives to initiate businesses, market linkages and community awareness are needed.

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11 APPENDICES

Appendix 1: General survey questionnaire (Q1)

1. Background Information:

1.1 Household Identification:

1.1.1 District:
1.1.2 VDC:
1.1.3 Village and ward no.:
1.1.4 Geographic coordinate of house:
1.1.5 Household size:
1.1.6 Name of household head:
1.1.7 Name of Respondent:
1.1.8 Sex of Respondent:
1.1.9 Relationship of Respondent to household head:
1.1.10 Type of roof of house: (Galvanized iron, Thatched/Straw, Tile/Slate, RCC)
1.1.11 Distance from the nearest roadside:
1.1.12 Name of Enumerator:
1.1.13 Interview Date:

1.2 Demographic and Socio-economic characteristics:

1.2.1 Please indicate the number of family members living in the household.

Age and Gender	Number of people
Children 0-14 years	
Males 15 + years	
Females 15 + years	

1.2.2 Main occupation of the household head:

	Major Occupational Groups	(√)	Specific occupation
1.2.2.1	Salary/Wage Employment (Civil Service, NGO…etc.)	/-------/	------------------------------
1.2.2.2	Self-employed (Merchant, Mason, Carpenter…etc.)	/-------/	------------------------------
1.2.2.3	Petty trade	/-------/	------------------------------
1.2.2.4	Casual labor	/-------/	------------------------------
1.2.2.5	Unemployed	/-------/	------------------------------
1.2.2.6	Farmer	/-------/	------------------------------
1.2.2.7	Other(specify)	/-------/	------------------------------

1.2.3 What is your annual average income (in Nepali Rupees) from different sources as indicated on 1.2.2?

1.3 Preliminary energy information

1.3.1 What are the energy sources that you have been using to fulfill various energy needs in your house? (Multiple choices are applicable)

Energy sources	Tick '√' for uses	Particular purpose (lighting, heating, cooking etc.)
Electricity (hydro)		
Fuel wood		
Livestock dung		
Crop residues		
Solar		
Kerosene		
LPG		
Any others, specify		

1.3.2 Where do you usually cook food on your stoves (tick more than one as appropriate)?

1.3.2.1 Indoors separate private kitchen /-----------------/

1.3.2.2 Indoors shared kitchen /-----------------/

1.3.2.3 Indoors, living room /-----------------/

1.3.2.4 Outdoors /-----------------/

1.3.2.5 Other (specify) /-----------------/

1.3.3 If you use other commercial sources (except biomass),

1.3.3.1 How far should you have to travel to get kerosene and LPG? (Distance from house in km and time elapsed)

1.3.3.2 For what particular purpose and how often do you use commercial sources of energy for cooking and heating? (The use may be for throughout a year in a seasonal basis)

1.3.3.3 How much should you have to pay in a month?

2 Forest based biomass residues

2.1 What are your needs to use forest products? (Multiple choices are applicable)

a. Cooking and heating
b. Building and construction material
c. Fencing
d. Animal fodder
e. All of the above
f. Any other , specify

2.2 What are your sources of getting these forest products? (Multiple choices are applicable) and how far should you have to visit in terms of distance and time to get forest products from each of the following sources, if applicable?

Types	Tick '√' if collection	Distance (km)	Time spent for fetching (hr)
Private forest			
Community forest			
National/public forest			
Any other, specify			

2.3 Based on answers of question no.2.2, please provide details according to following for fuel wood collection for energy needs. The weight of each bundle should be taken during survey with participation of respondent. In case of difficulty to get month wise data, seasonal basis will be considered according to local context.

Types of forests	Particular	J	F	M	A	M	J	JY	A	S	O	N	D
Private/community/national/ forests	Number of collection												
	Number of bundles on each collection												
	Weight of each bundle												

2.4 Which part of the forest do you collect for energy needs?(Multiple choices are applicable)

- 2.4.1 Log wood
- 2.4.2 Dead wood
- 2.4.3 Leaves, twigs and branches
- 2.4.4 Any other, specify

2.5 How do you transport these to your home (Multiple choices are applicable)?

- 2.5.1 By head load(walking)
- 2.5.2 By cart
- 2.5.3 By bicycle
- 2.5.4 By motor vehicle
- 2.5.5 Any other , specify

2.6 Name 10 major types (species) of trees that you mostly use for energy needs? Any reasons for having preferences.

2.7 How often do you need wood for regular building/construction material (repairing house and Goth[9], fencing, making plough, supporting material etc.)?

- 2.7.1 Once a year
- 2.7.2 Twice a year
- 2.7.3 Any other, specify

2.8 What is the tentative amount (either volume or weight) of wood do you need for regular building/construction material in a year?

[9] Goth is the Nepalese word for the place where cattle are generally kept.

2.9 What is the total amount of wood (either volume or weight) did you use to build your house and barn (Goth) during its new construction phase?

2.10 Did you use forest based products for heating room/house during cold seasons in previous year? If yes, what was the duration of year (in months) and how much forest product did you use per day or /week/ or month?

2.11 How much forest products (in weight) do you consume for energy needs (basis may be per day/per week/per month) in general? The actual weight will be measured by considering local units (count).

2.12 In general, where do you store these forest products?

2.12.1 In open areas with no roof
2.12.2 Inside the house
2.12.3 In cattle living areas
2.12.4 Separate areas with roof
2.12.5 Any others, specify

2.13 What is the maximum storage limit in terms of weight (or how many bundles)? (With actual weighing)

2.14 With maximum storage, how many days can you fulfill your energy needs (or how many days can you fulfill your energy needs through one bundle)?

2.15 Does fuel wood fulfill all your energy needs (cooking and heating) throughout a year? If no, which time of a year do you have shortage and what alternatives have you used to cope with this?

2.16 Have you bought fuel wood for energy needs? If yes, for how many months do you need to buy and what is the cost of fuel wood per kg?

2.17Why are you using forest products for energy? (Tick only one)

2.17.1 No cost and easily available
2.17.2 Cheaper than others
2.17.3 Ease of cooking and heating
2.17.4 No alternatives available

3 Crop residues:

3.1 How much do you have arable land (convert in terms of bigha[10].) and what is the actual area of land that you cultivate (reference may be taken from last year)?

[10] 1 bigha = 0.16 ha.

Area of total arable land	Area of actual cultivated land

3.2 How do you do initial cultivation of soil?
- 3.2.1 Manual dig
- 3.2.2 Plough with cattle
- 3.2.3 Tractor or machines
- 3.2.4 Any other , specify

3.3 Which crops as indicated in table below have you grown last year throughout a year? Mark with **“√”** for entire crop growing period and **“ʌ”** for fallow period. (More than one crop may be cultivated on the same month on different farmland.)

Crops	**Months**											
	J	F	M	A	M	J	JY	A	S	O	N	D
Paddy												
Corn												
Millet												
Wheat												
Barely												
Fallow												

3.4 Last year data

Crops	**Harvested month**	**Area of cultivated land (bigha.)**	**Production (ton)**
Paddy			
Corn			
Millet			
Wheat			
Barely			

3.5 During the past 10 years, (maximum and least production data)

Crops	**Cultivated land**	**Maximum production**	**Least production (ton)**
Paddy			
Corn			
Millet			
Wheat			
Barely			

3.6 Harvesting details

Crops	Harvesting method (manual or mechanical)	Distance between farmland and house (km)	Transport (M:manual C:cart V:motorvehicle, specify for others)	Field (standing)	Field (cut)	House	Factory (mill), if applicable
Paddy							
Corn							
Millet							
Wheat							
Barely							

3.7 How do you use residues of these crops?

o	Residue	Uses (multiple choices are applicable from a to f)**	Utilization ratio (1 to 5)*	Price per kg in case of selling
Paddy	Straw			
	Husk			
Corn	Stalks			
	Cob			
	Husk			
Millet	Stalks			
Wheat	Stalks			
Barley	Straw			

**The ratio of weight of actual use for specific purpose with that of total available, this will be estimated by judgment based interaction from past experiences of users. 1 = up to 20 %, 2 = 20 to 40 %, 3 = 40 to 60 %, 4 = 60 to 80% and 5 = 80 to 100 % and for no use option the ratio should be 0.*

** Uses options

a. Mulching or burning at field
b. building materials
c. Livestock feed
d. Sale to others
e. Energy needs
f. No use at all
g. Any other, specify

3.8 If you do not use crop residues for energy purposes, what may be the ultimate reason? (Tick only one)

3.8.1 Not aware
3.8.2 Difficulty to transport
3.8.3 Fully used for other purposes
3.8.4 No need to use (enough alternatives)

3.8.5 Not suitable with existing stoves
3.8.6 Any other, specify

3.9 If you use crop residues for energy needs
3.9.1 How do you use?

3.9.1.1 Direct burning
3.9.1.2 By converting into briquette, pellets
3.9.1.3 Any other, specify

3.9.2 For what specific purpose, do you use? (Multiple options applicable)

3.9.2.1 Cooking
3.9.2.2 Heating
3.9.2.3 Any other, specify

Livestock dung

4.1 Provide details as per following table:

Livestock category		**Identification code(ID)**	**Age**
Buffalo	Young (≤ 3 yrs)		
	Mature (> 3 yrs)		
Cattle	Young (≤ 3 yrs)		
	Mature (> 3 yrs)		

**For more than one livestock under same category, ID should be given to distinguish among each other. For instance B1 for buffalo observed at first, B2 and so on, Similarly C1, C2, and so on for cattle*

4.2 How do you manage barn (Goth) for keeping livestock in a year in terms of location and duration of utilization? Provide details accordingly :

Location	**Time duration (months)**	**Name of months**	**Distance from house (meter)**
Nearby house			
At field			

Any other, specify			

4.3 Do you bring your livestock for grazing in the field (pasture land)?

a. Yes b. No

If yes, please provide the details how many hours do you let them for grazing in the field per day in different months.

Grazing practices: Only applicable for grazing in field

Identity		**Grazing behavior (hours/day)**											
		J	**F**	**M**	**A**	**M**	**J**	**JU**	**A**	**S**	**O**	**N**	**D**
Buffalo	**Young**												
	Mature												
Cattle	**Young**												
	Mature												

Extra sheet should be used in case of presence of greater number of livestock

4.4 How frequent do you collect dung from Goth?
- 4.4.1 Once a day
- 4.4.2 Twice a day
- 4.4.3 In each drop
- 4.4.4 Any other, specify

4.5 Where do you store dung and how far is it from Goth?

Dung Storage	Distance from Goth (meter)	Storage method (open, cover)

4.6 Do you bring dung to house which is obtained during dropping (grazing) in the field?

a. Yes b. No

4.6.1 If yes, how frequent do you bring?
- 4.6.1.1 Every time
- 4.6.1.2 On average
- 4.6.1.3 Very rare

4.7 If you keep livestock in other places for longer days than nearby house, how do you use dung obtained during the period?
- 4.7.1 bring back almost all to house
- 4.7.2 bring back certain amount to house
- 4.7.3 left all dung in place

4.8 For what purposes, do you use livestock dung?
(Ratio use: The ratio of specific use to that of total collected dung)

a = 70 to 100 %, b = 40 to 70 %, c = 10 to 40 % and d = less than 10 %

Uses	**Put "√ " for use**	**Ratio use**
Fertilizer		
Energy		
Coating house		
Building material		
Any other, specify		

4.9 If you use dung for energy uses,

4.9.1 How do you use dung for energy?

4.9.1.1 Direct burning of dung

4.9.1.2 Biogas

4.9.2 Please indicate with '√' for name of months that you use dung for energy in a year?

Months											
J	F	M	A	M	J	JY	A	S	O	N	D

4.9.3 What is the weight of dung that you use for a day? (The weight should be taken on the basis of response.)Does it change with different seasons? If yes, note the weight according to different seasons.

S.n	Seasons	Weight of dung (kg, air-dried per day)
1	Pre-monsoon	
2	Summer monsoon	
3	Post-monsoon	
4	Winter	

4.9.4 Do you have to bring dung from other areas to fulfill your energy needs as mentioned above? (Yes/No), If yes, answer the followings:

4.9.4.1 From where do you collect dung?

4.9.4.2 Do you have to pay for it? If yes, what is the price? Or any other reimbursement that you should make for it?

****

Appendix 2: Closed survey questionnaire (Q2)

1. Household ID:
2. Cooking and heating experiment (one day)

S.n	List of items for cooking & heating	Start time	Weight of biomass at start (kg)	End use devices	Weight of left biomass (kg)	End time
1						
2						
3						

3. **Crop residues**

   3.1 Crop residues production

Crops	Area of particular(pre-defined) land (local unit)	Crop production (kg)	Crop residues	Residues weight (kg)
Paddy			Husk	
			Straw	
Corn			Cob	
			Husk	
			Stalk	
Millet			Husk	
			Straw	
Wheat			Husk	
			Straw	
Barely			Husk	
			Straw	

3.2 Uses of crop residues

Crop residues	**Building material**		**Energy uses**		**Selling**	
	Number of built material/yr	**Weight of unit built material (kg)**	**Number of units*/yr**	**Weight of units**	**Number of units*/yr**	**Weight of units**

* Units hereby depend upon local context (bundles, bucket or any other form)

4. Livestock fodder and dung (for 24 hours)

Livestock ID	**Time of feeding**	**Name of feed**	**Weight of feed (kg)**	**Time of dropping**	**Weight of each drop (kg)**

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