SUSTAINABLE ENERGY ACCESS PLANNING

A CASE STUDY

AUGUST 2018

ASIAN DEVELOPMENT BANK

SUSTAINABLE ENERGY ACCESS PLANNING

A CASE STUDY

AUGUST 2018

ASIAN DEVELOPMENT BANK

Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO)

© 2018 Asian Development Bank
6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines
Tel +63 2 632 4444; Fax +63 2 636 2444
www.adb.org

Some rights reserved. Published in 2018.

ISBN 978-92-9261-040-1 (print), 978-92-9261-041-8 (electronic)
Publication Stock No. TCS189194
DOI: http://dx.doi.org/10.22617/TCS189194

The views expressed in this publication are those of the authors and do not necessarily reflect the views and policies of the Asian Development Bank (ADB) or its Board of Governors or the governments they represent.

ADB does not guarantee the accuracy of the data included in this publication and accepts no responsibility for any consequence of their use. The mention of specific companies or products of manufacturers does not imply that they are endorsed or recommended by ADB in preference to others of a similar nature that are not mentioned.

By making any designation of or reference to a particular territory or geographic area, or by using the term "country" in this document, ADB does not intend to make any judgments as to the legal or other status of any territory or area.

This work is available under the Creative Commons Attribution 3.0 IGO license (CC BY 3.0 IGO) https://creativecommons.org/licenses/by/3.0/igo/. By using the content of this publication, you agree to be bound by the terms of this license. For attribution, translations, adaptations, and permissions, please read the provisions and terms of use at https://www.adb.org/terms-use#openaccess.

This CC license does not apply to non-ADB copyright materials in this publication. If the material is attributed to another source, please contact the copyright owner or publisher of that source for permission to reproduce it. ADB cannot be held liable for any claims that arise as a result of your use of the material.

Please contact pubsmarketing@adb.org if you have questions or comments with respect to content, or if you wish to obtain copyright permission for your intended use that does not fall within these terms, or for permission to use the ADB logo.

Notes:
In this publication, "$" refers to US dollars.
Corrigenda to ADB publications may be found at http://www.adb.org/publications/corrigenda.

Contents

Figures and Tables

Figures

Tables

Appendix Tables

Foreword

Asia and the Pacific is home to more than 420 million people lacking access to electricity and about 2 billion people without access to clean cooking. Complicating this challenge is the need to deliver these energy services sustainably—utilizing renewable energy resources at an affordable cost and minimum impact to climate and the environment.

In 2015, the Asian Development Bank (ADB) released *Sustainable Energy Access Planning: A Framework* to help planners and policy makers design affordable and clean energy systems that both the poor and nonpoor can access for their basic energy needs.

As a follow-up to its publication, ADB applied the methodologies presented in the sustainable energy access planning (SEAP) framework in a study to develop a sustainable universal energy access plan for households in Pyuthan District, one of the economically poor districts of Nepal.

The case study demonstrates how the SEAP framework can be used by energy planners to develop strategies for providing universal energy access to households using clean energy.

Using primary and secondary data with 2014 as base year, the study identified Pyuthan District's household characteristics and energy patterns and estimated its future energy requirements. Following the SEAP framework, the study conducted assessments of costs, benefits, sustainability, and affordability of energy access options through 2030.

ADB is committed to helping developing member countries in Asia and the Pacific provide sustainable energy for all and supporting their journey to a low-emissions development path. It has made significant contributions to energy development by providing loans and grants in the energy sector—including support for the three pillars of sustainable energy for all: universal energy access, energy efficiency, and renewable energy.

We hope that the methodologies and examples presented in this publication will serve as useful tools for developing member countries, breaking down some of the knowledge barriers and challenges in preparing a sustainable energy plan for all.

We would like to take the opportunity to thank the Government of Nepal as well as the project team and authors for their support for this joint publication of the Sustainable Development and Climate Change Department and South Asia Department of ADB.

Yongping Zhai
Chair, Energy Sector Group
Sustainable Development and Climate Change Department
Asian Development Bank

Acknowledgments

This case study is a joint effort of the Energy Sector Group and South Asia Energy Division of the Asian Development Bank (ADB) as a follow-up to *Sustainable Energy Access Planning: A Framework*, which was published in 2015.

Preparation of this case study was led by Ram M. Shrestha, ADB consultant and professor emeritus of the Asian Institute of Technology in Thailand, and Jiwan Acharya, senior energy specialist, South Asia Energy Division, with inputs from Salony Rajbhandari, Bijay B. Pradhan, Suman Basnet, and Binod P. Shrestha.

Guidance and support was provided by Robert Guild, chief sector officer; Yongping Zhai, chief of Energy Sector Group; and Kee-Yung Nam, principal energy economist, Sector Advisory Service Cluster (SDSC); and Preety Bhandari, director, Climate Change and Disaster Risk Management Division and concurrently chief of Climate Change and Disaster Risk Management Thematic Group of the Sustainable Development and Climate Change Department of ADB.

Extensive inputs and guidance during conceptualization and preparation of this report were also given by Priyantha Wijayatunga, director, South Asia Energy Division, South Asia Department; Gil-Hong Kim, former senior director and concurrently chief sector officer of SDSC; and Anthony Jude, former senior advisor, ADB. Support and guidance was also provided by Mukhtor Khamudkhanov, country director of the Nepal Resident Mission and Ram Dhital, executive director of the Alternative Energy Promotion Centre of the Government of Nepal.

The authors would like to acknowledge the assistance of Niraj Acharya and Shiva Raj Timilsina. They also would like to thank Anantaa Pandey for her editorial support and Sumanta Neupane for his assistance in preparing the survey questionnaire and organizing the household survey for data collection from all 49 village development committees in Pyuthan District in Nepal.

The authors are grateful to Charity Torregosa, Rodel Bautista, and Remife De Guzman for coordinating the publication of this study. Appreciation is also extended to the members of ADB's Energy Sector Group, Pilot Asia-Pacific Climate Technology Finance Center, Nepal Resident Mission, Sustainable Energy for All Regional Hub for Asia and the Pacific Secretariat, the Department of Communications, and the Alternative Energy Promotion Centre of the Government of Nepal for their invaluable inputs and assistance.

Abbreviations

AEPC	Alternative Energy Promotion Centre
BMG	biomass-based power plant
BPC	Butwal Power Company
BSP	Biogas Support Program
CAGR	compound annual growth rate
CBS	Central Bureau of Statistics
CFL	compact fluorescent lamp
CO	carbon monoxide
DDC	District Development Committee
EAP	Energy Access Programme
ELA	electricity access case
ESAP	Energy Sector Assistance Programme
ESMAP	Energy Sector Management Assistance Program
FY	fiscal year
GHG	greenhouse gas
GTF	Global Tracking Framework
HICS	highly efficient improved cookstoves
HOMER	Hybrid Optimization of Multiple Energy Resources
IEA	International Energy Agency
IEAC	Incremental Energy Access Cost
IPP	independent power producer
LED	light emitting diode
LPG	liquefied petroleum gas
MEPI	Multi-dimensional Energy Poverty Index
MICS	moderately efficient improved cookstoves
NEA	Nepal Electricity Authority
NOx	Oxides of nitrogen
O&M	operation and maintenance
PM_{10}	particulate matter (10)
REDP	Rural Energy Development Programme
SEAP	sustainable energy access planning
SE4ALL	Sustainable Energy for All
SHS	solar home system
SO_2	sulphur dioxide
SWERA	Solar and Wind Energy Resource Assessment
SWI	Shannon-Weiner Index
TCS	traditional cookstoves
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat

Weights and Measures

ADT	air dry ton
Ah	ampere hour
GJ	gigajoule
m^3	cubic meter
MJ	megajoule
MW	megawatt
MWh	megawatt hour
Mt	million ton
NRs	Nepalese Rupees
kgoe	kilogram of oil equivalent
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt hour
km^2	square kilometer
t	ton (i.e., a metric ton)
V	volt

Executive Summary

Access to cleaner energy is necessary for economic growth and human development. Sustainable access to cleaner energy means the ability to satisfy basic energy needs and services through the provision and use of reliable, efficient, affordable, and environment-friendly energy resources and technologies.

With the consideration of energy service requirements of both energy-poor and non-energy-poor households, sustainable energy access planning (SEAP) plays a vital role in this context. SEAP considers local and other energy resources in providing energy services and assesses the level of investment requirements and affordability of cleaner energy for poor households.

This study carried out a comprehensive assessment of the options for the provision of sustainable universal access to cleaner energy services to households in the Pyuthan district—one of the economically poor and hilly districts in Nepal.

The study is funded by a regional technical assistance program of the Asian Development Bank (ADB) for Enhancing Knowledge on Climate Technology and Financing Mechanisms. The study has adopted the SEAP framework developed earlier under the same program.

The main objectives of the study are to: (i) assess the current situation of household energy use in Pyuthan district of Nepal; (ii) determine cost-effective, cleaner and climate friendly energy options (in both supply and demand sides); (iii) provide sustainable universal access to cleaner energy services at the village and district levels, as well as the corresponding investment requirements and other costs; and (iv) assess the affordability of poor households to the cost-effective energy access options.

The study also considered the benefits of access to cleaner energy in terms of social well-being, reduction in the emission of local pollutants and greenhouse gas, and reducing energy inequality. Furthermore, the study assessed the sustainability of different technology options for providing access to cleaner energy services.

To fulfill its objectives, this study has carried out seven different assessments following the SEAP framework. These assessments include: energy resource, energy poverty, energy demand, sustainability, cost, benefit, and affordability assessments.

A sample household survey was conducted in 2014 in 49 village development committees (VDCs)[1] of Pyuthan district to get the information necessary to carry out these assessments. Secondary data sources were used to supplement the household survey.

[1] Before the state restructuring in early 2017, a VDC in Nepal was a local government unit at the lowest level comprised of one or more villages.

The household survey showed that around 20.3% of the households in the Pyuthan district are unelectrified while the remaining are electrified either by grid, microhydro, or solar home systems.

The survey revealed that among the total number of households, 41% do not have access to the grid-based power supply.

The survey also revealed that fuelwood accounted for 94.4% of the total residential energy consumption in the district in 2014. Cooking was the major energy service responsible for 60.8% of the total energy consumption in the residential sector. Fuelwood provided 98% of the total cooking energy requirement, while agricultural residue, biogas, liquefied petroleum gas (LPG), and electricity provided the rest.

Electricity was the largest source of residential lighting in the district followed by kerosene and other sources.

Out of the total number of households in the district, 76% used fuelwood for cooking, followed by agricultural residues (9%), LPG (8%), electricity (5%), and biogas (2%). The survey revealed that none of the households used kerosene for cooking.

The analyses were made in the form of seven different assessments:

Energy Resource Assessment. The objective of this assessment was to provide information on the level of economically exploitable cleaner energy resources in each VDC in Pyuthan along with availability patterns and costs.

This assessment determined whether or not enough energy resources were available in the district for reliable and sustainable supply to meet the present and future energy demand. The district level potential of energy resources considered in this study was based on secondary sources.

Limited information exists in the literature about the availability of the micro, mini, and small hydropower potential in the different VDCs.

Energy Poverty Assessment. The main objective of this assessment was to estimate the number of households in each VDC of the district whose energy consumption lie below the basic minimum energy consumption level.

This assessment also estimated the incremental energy that needs to be provided to the energy-poor households to reach different levels of energy access including the one associated with the basic minimum level of energy services.

This study adapted, with some modifications, the concept of multitier framework of the Global Tracking Framework (GTF), outlined by the World Bank/ESMAP and International Energy Agency (IEA) (World Bank/ESMAP and IEA 2013), to identify the basic minimum energy requirement per household for the purpose of separating the energy-poor and non-energy-poor households.[2]

[2] In this study, a rice cooker is considered in place of a washing machine for Tier 3 as defined in GTF by World Bank/ESMAP and IEA (2013). Besides, a rice cooker is added to the devices listed in Tiers 4 and 5 by GTF.

According to the multitier framework for households' electricity access, Tier 1 to Tier 5 levels of electricity access represented the annual electricity consumption per household in the range of at least 3 kilowatt hours (kWh) to at least 2,267 kWh respectively.

In this study, the households with electricity consumption below the Tier 1 level were regarded as electricity poor households. The Tier 1 level of electricity access includes task lighting, radio, and mobile charger with a total electricity consumption of 3 kWh.

This study found that around 20.3% of the households in 49 VDCs have electricity consumption below the Tier 1 level, making them fall in the category of electricity poor households.

Based on the multitier framework of household cooking solutions as presented in the GTF, the study found that 63.7% of the total households using traditional cookstoves in Pyuthan are energy-poor (i.e., they use less than the minimum level of useful cooking energy requirement of 27.2 kilograms of oil equivalent [kgoe] per capita).

Considering this value as the threshold, the study found that the share of energy-poor households in terms of cooking energy use is as high as 93.9% in Dhungegadhi VDC and is as low as 17.4% in Raspurkot VDC.

Based on the multidimensional energy poverty index (MEPI) approach, the study found that 27 out of the total 49 VDCs are in the high level of energy poverty.

Energy Demand Assessment. The objective of the energy demand assessment was to determine the present and future energy demand of all households (energy-poor as well as non-energy-poor) for lighting and cooking services, if a certain minimum level of basic energy services per household is to be provided under a universal energy access program.

To get an idea of the total cost of providing access to electricity and clean cooking, this study estimated the total energy demand of the households (both the energy-poor and non-energy-poor) for consumptive use of energy in each VDC of the district in the base case (i.e., without universal energy access) as well as in a number of universal energy access cases each with a different level of minimum energy consumption per household.

The base year of the study is 2014 and the household electricity demand was projected for 3 snapshot years: 2017, 2022, and 2030.

For the purpose of electricity demand projection, four different cases have been considered in this study for each snapshot year: base case, and three universal electricity access cases with increasing levels of minimum electricity consumption per household called Electricity Access Case 1 (ELA1), Electricity Access Case 2 (ELA2), and Electricity Access Case 3 (ELA3).

The levels of minimum annual electricity consumption per household considered under these universal electricity access cases were: 3 kWh in 2017, 66 kWh in 2022, and 285 kWh in 2030 under ELA1; 66 kWh in 2017, 285 kWh in 2022, and 1,464 kWh in 2030 under ELA2; and 285 kWh in 2017, 1,464 kWh in 2022, and 2,267 kWh in 2030 under ELA3.

In 2014, the total electricity demand of Pyuthan district was estimated to be 11,956 megawatt hours (MWh).

Under the base case, i.e., in the absence of a universal electricity access program, the total electricity demand of the district was estimated to be 1.2 times in 2017, 1.5 times in 2022, and 2.1 times in 2030 as compared to the total electricity consumption in 2014.[3]

In 2017, the electricity demand in ELA1, ELA2, and ELA3 cases would be 3.1%, 9.5%, and 53.1% higher than that in the base case.

In 2022, the electricity demand was estimated at 17,351 MWh in the base case and it would be 8.1% higher in ELA1, 40.9% higher in ELA2, and 369.3% higher in ELA3. In 2030, the demand for electricity was estimated at 25,186 MWh in the base case. It would be 27.1% higher in ELA1, 332.8% higher in ELA2, and 469.6% higher in ELA3. The demand for cooking energy in the Pyuthan district was estimated to increase by 1.4 times during 2014–2030 under the base case.

Sustainability Assessment. The technology and resource options considered for providing energy access in this study were evaluated in terms of five different dimensions. These five dimensions are technical, economic, social, environmental, and institutional sustainability.

The sustainability assessment provided the basis for making comparisons between different options in terms of relevant indicators of different dimensions in order to assess the relative sustainability of each option. For this purpose, this study considered the options of power supply from national grid, solar home system, biomass, and microhydropower.

Among the electricity supply options considered, the sustainability assessment ranked the grid extension as the most preferred alternative (i.e., with highest sustainability index) for providing electricity access in Pyuthan.[4] This is followed by microhydro, solar home system, and biomass-based power generation option in a decreasing order of the sustainability index value.

This study considered six different cleaner cooking options, using moderately efficient and highly efficient biomass improved cookstoves, as well as cooking based on LPG, biogas, electricity, and solar stoves.

The sustainability assessment revealed electricity to be the most sustainable cooking energy option, followed by cooking based on solar energy, biomass use in highly efficient improved cookstoves, biomass use in moderately efficient improved cookstoves, LPG, and biogas.

Cost Assessment. The purpose of this assessment was to determine the level of the total investment requirements and other costs associated with the development and implementation of a least-cost universal electricity access program and the electricity supply technology-mix, generation-mix, and total installed capacity of the electricity supply system.

3 The base case considers the mix of incandescent, fluorescent, CFL, and LED lamps to be the same as that found by the sample household survey in 2014.
4 In Nepal, the national power grid is predominantly hydropower based in terms of electricity generation.

The assessment was extended to obtain information about the incremental costs incurred in providing different levels of universal electricity access in the district. The cost implications of different cleaner cooking options were also assessed.

a. **Cost and Technology Assessment of Electricity Access Options.** This study identified the most cost-effective set of electricity supply options and estimated the corresponding cost of total electricity supply under the base case and three different universal electricity access cases, i.e., ELA1, ELA2, and ELA3 in 3 selected years (i.e., 2017, 2022, and 2030) assuming no preexisting power generation capacity to supply electricity in each case. For this purpose, this study considered four different electricity generation technology options (i.e., grid extension, biomass based power plant, microhydro, and solar photovoltaic). In order to illustrate the role of demand side technologies, total supply side costs as well as system capacity- and generation-mix under different electricity access cases are estimated for three different demand side scenarios each of which considers a different technology option (i.e., light emitting diode [LED], compact fluorescent lamp [CFL], and incandescent lamps) while the technologies for other end use services remain unchanged.

   With the LED lamps for lighting, the total installed capacity of electricity generation options in the district in 2017 would be 2.6 megawatts (MW) in the base case. While the installed generation capacity requirement under ELA1 would also be almost the same as that in the base case, it would be 11% higher under ELA2 and 55% higher under ELA3 than that in the base case. The total installed generation capacity requirement in the district in 2022 would be 3.4 MW and 4.8 MW in 2030; the corresponding values in ELA1 would be 1.1 times in 2022 and 1.3 times in 2030 as compared to the base case values, whereas in ELA3 they would be 4.6 times in 2022 and 5.7 times in 2030. When CFL lamps are considered for lighting instead of LED, the study found that the installed electricity generation capacity requirement would increase by 1.4% under ELA1, 2.7% under ELA2, and 4.1% under ELA3 in 2017. Similarly, when incandescent lamps are considered for lighting, the capacity requirement would increase by 1.7% under ELA1, 23.5% under ELA2, and 30.1% under ELA3.

   Thus the study found that the total power generation capacity requirement in cases with CFL and incandescent lamps for lighting would be substantially higher than that when the LED lamps are considered. This illustrates the importance of considering efficient demand side technology options in the electricity access planning.

   The study found that grid based electricity would be the major cost-effective supply option in the base case as well as in all the universal electricity access cases as most of the VDCs in the Pyuthan district were already partially or fully electrified by the grid in 2014.

   The grid based power supply is found to have the highest share (around 95%) in the total electricity system cost of the district in 2017 in all the electricity access cases; this is followed by biomass-gasifier plant, microhydro, and solar PV system.

   An extension of the power grid was found to be the most economical supply option for the VDCs in close proximity to the grid even at the lower levels of universal electricity access in 2017, 2022, and 2030. In the case of VDCs located relatively far from the grid, an extension of the grid was found to be a cost-effective option at higher levels of electricity demand.

In particular, the grid was found to be the most cost-effective option to supply electricity in all VDCs in the case of ELA3 in 2022 and similarly under ELA2 and ELA3 in 2030. This is because of the significantly higher electricity demand in these cases.

The total electricity supply system cost in the base case would be about NRs1.5 billion in 2017, NRs1.8 billion in 2022, and NRs2.5 billion in 2030 with the use of LED lamps for lighting.[5]

In 2017, the total cost under universal access cases would be higher than the base case: by 6.7% under ELA1, 12.6% under ELA2, and 54.4% under ELA3. The total cost in the electricity access cases in 2022 would increase by 10.1% in ELA1, 43.8% in ELA2, and 329.8% in ELA3 as compared to that in the base case; similarly, the total cost would increase by 30.4% in ELA1, 250.9% in ELA2, and 431.3% in ELA3 in 2030.

In the base case, a total investment of about NRs1.2 billion would be required to provide electricity in 2017; the corresponding figure in 2022 would be NRs1.4 billion and in 2030 it would be NRs2 billion.[6] The additional investment required to provide universal electricity access under ELA1 was estimated to be around NRs69.9 million in 2017, NRs146.4 million in 2022, and NRs607.9 million in 2030.

Similarly the additional investment required under ELA2 would be around NRs136 million in 2017, NRs642 million in 2022, and NRs5.2 billion in 2030, whereas the additional investment requirement under ELA3 would be NRs611.7 million in 2017, NRs4.8 billion in 2022, and NRs8.9 billion in 2030.

In 2022, the unit incremental cost of access to electricity supply per kilowatt hour in the district (considering an increment in electricity demand from the base case to that in a universal electricity access case) was found to be NRs9.2 in ELA1, NRs8.6 in ELA2, and NRs7.2 in ELA3.

Similarly, the incremental cost of access to electricity supply (when an increment in electricity demand between two successive electricity supply cases is considered) was found to vary from NRs9.2 per kWh (between base case and ELA1) to NRs7 per kWh (between ELA2 and ELA3).

b. **Cost and Technology Assessment of Cleaner Cooking Access.** To be in line with the multitier framework for cleaner cooking access of the Global Tracking Framework, this study formulated seven different cleaner cooking access (CCA) scenarios

[5] The total electricity supply system cost (including investment and other costs) in a selected year in this study represents the estimated total present value of the system costs to meet a constant annual electricity demand during a planning horizon of 35 years assuming that there was no preexisting supply capacity. As the primary interest of the cost assessment in this study was to determine the level of supply system cost increments due to a universal electricity access program, this approach has been adopted here mainly for analytical convenience.

[6] Like the total system cost, the investment requirements are estimated assuming no preexisting supply capacity in a selected year; see also Footnote 5.

(CCA1, CCA2, CCA3, CCA4, CCA5, CCA6 and CCA7) for a partial or full displacement of the cooking based on solid biomass using traditional cookstoves (TCS). The different CCAs analyzed in this study include different combinations of cleaner cooking options, i.e., biomass used in moderately efficient improved cookstoves (MICS), biomass used in highly efficient improved cookstoves (HICS), biogas, biomass briquette, electricity, and LPG.

This study estimated the incremental cost of providing access to cleaner cooking [IEAC] in two cases: (i) 100% displacement of the traditional biomass based cooking by cleaner biomass based cooking and (ii) 100% displacement of the traditional biomass based cooking by a combination of cleaner options (both biomass and nonbiomass).

The study found that biomass of around 50,171 tons of oil equivalent (toe) in 2017, 55,148 toe in 2022, and 64,160 toe in 2030 would be required for cooking under the base case. A 100% replacement of the traditional biomass cookstoves by the combination of both cleaner biomass and nonbiomass cooking options (as described by the CCA6 scenario) has the potential to replace biomass by around 35,996 toe in 2017; 39,567 toe in 2022; and 46,032 toe in 2030.

The study showed that replacing 100% of the biomass based cooking using TCS by a combination of cleaner bioenergy options in CCA7 scenario, i.e., biomass use in MICS and HICS each replacing 25% of TCS, biogas replacing 30% of TCS, and biomass briquettes replacing 20% of TCS, would avoid around 63% of the total solid biomass that would be required in the base case. This amounts to avoiding 34,316 toe of biomass in 2017; 37,720 toe in 2022 and 43,884 toe in 2030. Out of the total biomass saved in this scenario, a 30% replacement of TCS using biogas stoves offer the highest share (i.e., about 37%) in the total reduction of biomass. This is followed by biomas briquette (24.9%), HICS (22.3%) and MICS (15.4%). Use of a combination of cleaner biomass and nonbiomass cooking would have a much larger potential for reducing the use of fuelwood in cooking. For example, if MICS, HICS, and biogas were to replace 20% each of biomass based cooking using TCS; briquettes and electricity were to replace 15% each and LPG were to the replace remaining 10% of TCS based biomass cooking (as are considered in the CCA6 scenario); it is estimated that the total biomass requirement for cooking would be reduced by 72% in the district. Like in the case of 100% replacement of TCS with the combination of cleaner biomass options, a 20% replacement of TCS by biogas stoves has the highest potential to abate around 23.8% of biomass use in the CCA6 case as compared to that in the base case in all the snapshot years. Each 15% replacement of TCS by the biomass briquettes and electric stoves has the potential to replace about 17.8% of biomass use individually under the CCA6 case. A 20% replacement of the TCS by HICS could save around 17.0% of biomass whereas a 20% by MICS and a 10% replacements by LPG cookstoves would save around 11.8% and 11.9% of biomass respectively under CCA6 scenario in all the snapshot years.

This study showed that if the options of cleaner biomass based cooking using MICS and HICS were used in place of the cooking based on biomass and TCS, there would in fact be a net cost saving (i.e., there would be a negative incremental energy access cost (IEAC) of NRs8.1 per kgoe with MICS and NRs6.8 per kgoe with HICS).

On the other hand, a switch from cooking based on biomass using traditional biomass cookstoves to that based on biogas, biomass briquettes, electricity, and LPG would be possible with a positive incremental cost. The incremental cost would be 0.7 NRs/kgoe for biogas, 15.4 NRs/kgoe for LPG cookstoves and 4.5 NRs/kgoe each for biomass briquettes and electric cookstoves.

At the prices considered in this study, biomass briquettes for cooking would be a more expensive option than biogas and that the IEAC of switching from cooking based on TCS and biomass to that based on biomass briquette would be the same as that of electric cooking.

The study found that replacing 100% of the traditional biomass cookstoves with MICS, HICS, biogas, briquette, electric and LPG cookstoves would incur additional upfront costs of NRs91.1 million in 2017, NRs99.3 million in 2022, and NRs114 million in 2030.

Similarly, the study found that replacing 100% of the traditional biomass cookstoves by the combination of only cleaner biomass based cookstoves (i.e., replacing 25% of traditional cookstoves by MICS, 25% by HICS, 30% by biogas and another 20% by briquette cookstoves) would increase the upfront cost by NRs128 million in 2017, NRs139.5 million in 2022 and NRs160 million in 2030.

Benefit Assessment. There are several benefits associated with a cleaner energy access program in terms of improved environmental quality, health, energy security, social benefits (such as time savings, education opportunities, and income generation) and reduced energy inequality.

The benefit assessment in this study attempted to quantify such values due to cleaner energy access in terms of both access to electricity and cleaner cooking. These values are as follows:

- **Time saving.** The study found that on an average, a household using electricity instead of other fuels like kerosene, battery, pinewood stick, candle, etc. would have time savings of 35 hours per year considering that a household purchases kerosene at least four times a month. Similarly, it is estimated that a household using LPG instead of fuelwood and agricultural residues for cooking would save 368 hours per year. This would result in an equivalent annual monetary savings of NRs3,297 on an average if electricity is used for lighting instead of kerosene, whereas the households using LPG for cooking would on an average save NRs32,638 per year.
- **Environmental Benefits.** There would be a significant reduction in the emissions of air pollutants and GHGs with an access to cleaner energy. The study estimated that in 2017, a replacement of kerosene, candles, and pinewood sticks by electricity for lighting would reduce emissions of carbon monoxide by around 7,747 kilograms (kg), oxides of nitrogen by 669 kg, particulate matter 10 (PM_{10}) by 4,844 kg, and black carbon (BC) by 41,275 kg. In addition, it would reduce CO_2 emissions by 1,433 ton. Similarly, in the case of a cleaner cooking, the study has estimated reductions in emissions of PM_{10} by about 73% and BC by 72% if the traditional biomass cookstoves are replaced by cleaner options including both biomass and nonbiomass-based options (i.e., replacing 20% of traditional cookstoves by MICS, 20% by HICS, 20% by biogas, 15% by briquette, 15% by electric, and another 10% by LPG cookstoves).

- **Increase in Productive Activities.** The study found that among the surveyed households, 60 households had a family business. Out of this figure, 90% had access to electricity supply, and the remaining 10% did not have access to electricity. This indicates the higher likelihood of productive activities with electricity access.
- **Education.** Students in electrified households in the district were found to have benefited from longer study hours than those in unelectrified households. On an average, the daily study hours of students in electrified households were found to be 1.38 hours while that of the unelectrified households were found to be 0.83 hours.
- **Health.** The study found people having fewer of hospital visits and annual absent days in fully electrified VDCs in the district than those in the partially electrified VDCs. For example, Dakhakwadi is a fully electrified VDC where the average annual absent days from work due to health-related problems was 12 days and the average number of hospital visits per year was 2.4 days. In Damri, a partially electrified VDC with solar home systems at the time the household survey was conducted, the average number of annual absent days due to health problem was found to be 32 days; and the average number of hospital visits per year was found to be 3.3 days.
- **Reduction in Energy Inequality.** A substantial reduction in energy inequality (more appropriately, electricity inequality in the present case) was estimated to take place with higher levels (tiers) of electricity access. The electricity Gini coefficient in the base year, 2014, was estimated to be 0.663. The electricity Gini coefficient is estimated to improve to 0.624 in 2017, 0.533 in 2022, and 0.229 in 2030 respectively, with universal electricity access under ELA1, whereas it would improve to 0.229 in 2017, 0.007 in 2022, and 0 in 2030 under ELA3. This showed that for electricity inequality to reduce significantly, a higher level of electricity access than that considered under ELA1 would have to be provided in 2017 and 2022.

Affordability Assessment. Even if cleaner energy options are available locally, some households may not be able to use them due to affordability. The objective of the affordability assessment is to determine the size of the household population that cannot afford to use a given minimum level of cleaner energy ("basic level of energy services"), e.g., a minimum level of annual electricity consumption per household. The determination of the size of such population would, however, depend both on the definition of the basic level of energy services and the threshold level of energy burden (defined as the maximum permissible level of energy expenditure as a percentage of household income).

"Affordability" in this study has been assessed using the "energy burden" approach as described in the SEAP Framework. Energy burden to a household has been estimated on the basis of the ratio of annual household expenditure on energy to the total annual household incomes; whereas, the residual income is calculated as the difference between the total income and non-energy expenditures of a household.

The energy burden of households was assessed for the basic minimum energy services, which involves the annual electricity consumption of 4.4 kWh per household and annual useful energy consumption per capita of 27.2 kgoe for cooking. In addition, the energy burden considering an access to higher levels of basic energy services (or higher tiers of energy access) was assessed. If the basic minimum lighting and cooking services are provided, 23.5% of the households would have to spend above 10% of their income on the basic minimum energy services considering only the supply side costs, while 25.3% of the households would have to spend more than 10% when considering both the supply and demand side costs.

Similarly, 11.4% households would have the energy burden above 15% while only 4.9% households would have the energy burden above 20% if both supply and demand side costs are considered.

Thus, if the government considers 10% as the threshold energy burden for the purpose of energy access policy, it is implied that 25.3% of households would have an energy affordability problem and would require some kind of assistance.

About 21% of the households would have an energy burden above 10% in 2017 under Tier 1 level of energy access case, if both supply and demand side costs are considered, while a much higher percentage of the households would face an energy burden above 10% under higher levels of energy access, i.e., about 67% of households under Tier 2 level of energy access and about 86% under Tier 3 level of energy access (with LPG used for cooking) are estimated to have an energy burden above 10% in 2017.

If biogas cooking option is considered in Tier 3 level of energy access, 71.2% of the households would face an energy burden above 10%. Similarly, in 2030, 7.5% of the households would have an energy burden above 10% under energy access Tier 1, whereas the percentage of the households with an energy burden above 10% would rise to 45.7% under energy access Tier 2 and 70.4% under energy access Tier 3 (with LPG use in cooking).

At the energy burden threshold of 10%, the average annual financial assistance required per household at different tiers of energy access was estimated to be NRs2,384 under energy access Tier 1, NRs10,665 under energy access Tier 2 and NRs22,101 under energy access Tier 3 (with LPG use in cooking) in 2017.

The support needed per household would decrease in 2030, it would be NRs1,964 in Tier 1, NRs8,746 in Tier 2, and NRs18,440 in Tier 3 (with LPG in cooking). If a higher threshold value of energy burden is considered, the level of support required per household would be lower. For example, at the energy burden threshold of 20%, the support required per household in 2017 would be NRs1,756 in energy access Tier 1, NRs7,957 in energy access Tier 2, and NRs16,607 in energy access Tier 3 (with LPG in cooking).

Likewise, in 2030, the level of support needed per household at the energy burden threshold of 20% would decrease to NRs1,545 in Tier 1, NRs6,204 in Tier 2, and NRs13,945 Tier 3 (with LPG in cooking).

It should be noted that financial support could be provided in different forms to make the use of cleaner energy services affordable (e.g., it could consist of subsidies and/or indirect financial incentives such as soft loans, payment of the initial costs on an installment basis, etc.).

If the option of financial support in the form of subsidies is to be considered, in 2017, the total financial support needed based on the energy burden approach would be in the range of NRs25 million under energy access Tier 1, NRs358 million under energy access Tier 2, and NRs954 million under energy access Tier 3 (with LPG use in cooking), if the energy burden threshold of 10% is considered. At the higher energy burden threshold of 20%, the total support required in 2017 would decrease to NRs4 million under energy access Tier 1, NRs137 million under energy access Tier 2, and NRs502 million under energy access Tier 3 (with LPG use in cooking).

The total support needed in the corresponding tiers at the energy burden threshold of 20% would decrease in 2030 to NRs0.7 million in Tier 1, NRs66 million in Tier 2, and NRs328 million in 3 (with LPG in cooking).

1

Introduction

1.1 Background

Cleaner energy access greatly influences the socioeconomic development of society and country.

The provision of modern fuels for household cooking, electricity for lighting, and energy for running rural industries and microenterprises increases the opportunities for rural people to improve quality of life, productivity, and income generation potential.

In a mountainous country like Nepal, the energy requirement for different energy needs increases with an increase in altitude. As a consequence, cost also increases.

Nepal is one of least developed countries in Asia with per capita gross domestic product in 2016 at $729.5 at current prices (World Bank 2017a). With a Human Development Index of 0.558, Nepal is ranked 144 among 188 countries (UNDP 2016).

More than 81% of the population live in rural areas, where around 25.2% of the population live below the national poverty line (World Bank 2017b and ADB 2017).

Out of the total population, 76% have access to electricity (IEA 2016). Around 97% of the population have access to electricity in the urban area, while 72% have electricity supply in the rural areas (IEA 2016).

In Nepal, 67% of the population are deprived of clean cooking facilities. The main sources of energy in Nepal is traditional biomass including fuelwood accounting for around 80% of total energy consumption (WECS 2014). The total energy consumption of Nepal was 376.3 million gigajoule in Fiscal Year 2011/2012 (WECS 2014). More than 78% of the cooking energy demand in the country is met by fuelwood. Biomass use in traditional cookstoves account for 67% of the total energy consumption of the country.

Pyuthan is one of the economically poor districts of Nepal. As is the case of Nepal as a whole, energy use pattern in the district relies heavily on conventional energies, mostly fuelwood.

Fuelwood accounts for more than 92% of the energy consumption in the residential sector of Pyuthan, followed by agricultural residue (5%). Although the energy resources are abundant, the potential have not been utilized yet (DDC 2012). Only a few of the village development committees (VDCs) have access to microhydro plants and other renewable energy technologies.[1] Out of the total households, 28% do not have access to electricity. The "district

[1] In Nepal a VDC used to be a local government unit in rural areas before the state restructuring in 2017.

energy situation report" of Pyuthan said that only 29% of the households are facilitated by electricity supplied from the grid.

The purpose of this study is to analyze the present condition of electrification and energy use scenario in Pyuthan district. The study also aimed to carry out a comprehensive assessment of the options for the provision of sustainable access to cleaner energy services to households in Pyuthan district.

The present case study is a part of the sustainable energy access activity under the Asian Development Bank regional technical assistance program "Enhancing Knowledge on Climate Technology and Financing Mechanisms" to assess the sustainability, cost-effectiveness, and affordability of different options to provide access to cleaner energy at targeted levels at a community and district level and applies the recently developed sustainable energy access planning framework developed under the program.[2]

1.2 Objectives of the Study

The main objective of this study is to determine sustainable, cost-effective, and climate friendly options to supply energy to the people in individual VDCs and the Pyuthan district as a whole. The specific objectives of the study are:

(i) to assess the present and future levels of total demand for electricity and cleaner energy associated with the different target levels of energy access of the poor households;
(ii) to assess the present and future energy demands of nonpoor households;
(iii) to determine cost-effective clean energy options, taking into consideration spatial distribution of households, local energy resources as well as proximity of the area to the grid connection in case of electricity access;
(iv) to assess financial implications and affordability of poor households to the most cost-effective cleaner energy access options;
(v) to analyze the sustainability of clean energy options to ensure quality and sustainability of the energy access program at the local level; and
(vi) to generate information on the investment required and evaluate benefits of the energy access program in terms of improvement in social well-being, reduction in local level emissions and greenhouse gas, and minimizing energy inequality.

1.3 Plan of the Report

This report consists of 12 chapters. Chapter 2 presents the methodological framework and information on data used in the analysis. Chapter 3 discusses the demographics and energy access status in the district as well as the residential sector energy consumption obtained through field survey. Chapter 4 presents the potential availability of energy resources in the Pyuthan district. Chapter 5 discusses the level of energy poverty in each VDC in the district.

An assessment of the demand of energy or energy services in each VDC of the district is presented in Chapter 6, while an assessment of sustainability of different energy access

[2] For details of the program, see https://www.adb.org/projects/45113-001/main#project-overview.

options is discussed in Chapter 7. Chapters 8 provides information on the additional power generation capacity requirement, its associated total cost, additional investment requirement, and incremental energy access cost of providing access to electricity.

Chapter 9 discusses the cost implications of various cleaner cooking technologies and associated incremental energy access costs for providing access to clean cooking in Pyuthan district.

Different kinds of benefits associated with an access to cleaner energy in the district were analyzed in Chapter 10, while an assessment of the affordability of the poor and other households to electricity and modern cooking options is presented in Chapter 11. Chapter 12 presents the insights and implications for energy access program development and implementation.

2

Methodology and Data

This chapter presents the brief methodological framework and information about the data sources used in this study.

2.1 Methodology

Providing energy access to any particular area or community requires knowledge of the number of households deprived of electricity and level of usage of cleaner forms of fuel for household end use services.

To provide energy access, information about the level of energy poverty, basic minimum energy required, and a comprehensive energy demand assessment of both energy-poor and non-energy-poor households are required.

To provide sustainable energy service access to all, one has to identify economical resources and technology options to be deployed.

Most importantly, one has to identify the level of investment and other cost required to provide a sustainable level of energy services. In an ideal case, energy access solutions should be least expensive and sustainable as well as affordable from the societal viewpoint.

To obtain such prerequisite of providing sustainable clean energy access, this study adopted the methodology presented in the report titled “Sustainable Energy Access Planning: A Framework” (Shrestha and Acharya 2015).

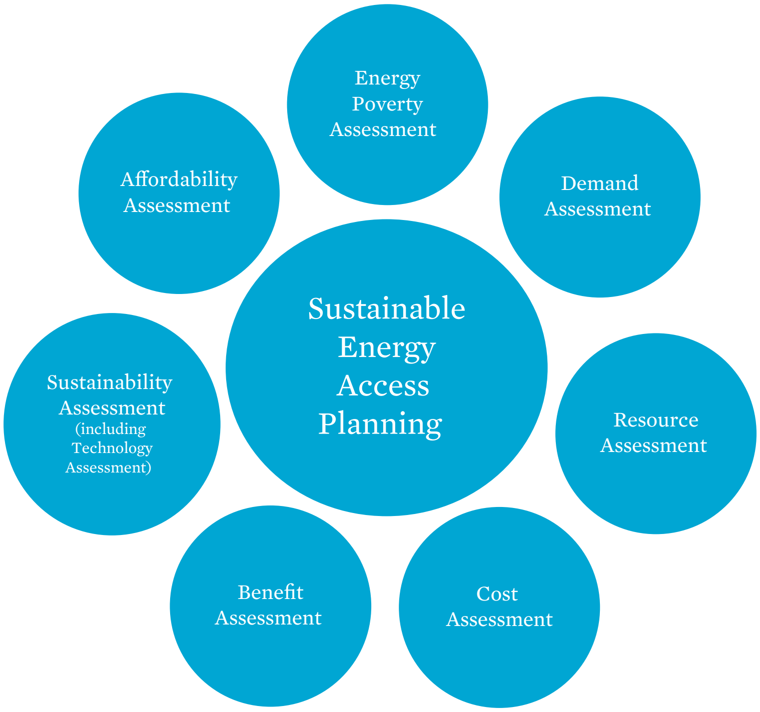
The main objectives of sustainable energy access planning (SEAP) framework are to identify resource and technology options that are cost-effective and sustainable to provide basic energy services to all, and to assess the affordability of using cleaner energy for meeting the basic energy services to energy-poor households.

Based on the SEAP framework, this study considered seven different assessments: energy poverty, demand, resource, cost, sustainability, benefit, and affordability assessments (see Figure 2.1).

The base year considered for the study was 2014. Apart from 2014, this study carried out assessments for the three snapshot years: 2017, 2022, and 2030. These were chosen for the analysis since Nepal has targeted to graduate from the least developed country to a developing country by 2022 (NPC, 2014) and achieve 100% electrification by 2030.[3]

[3] The Government of Nepal has set the target of providing 100% electricity by 2030 (75% from the national grid and remaining 25% from the decentralized renewable energy generation solutions) (AEPC, 2016).

Figure 2.1: Elements of the Sustainable Energy Access Planning Framework



Source: Shrestha and Acharya (2015).

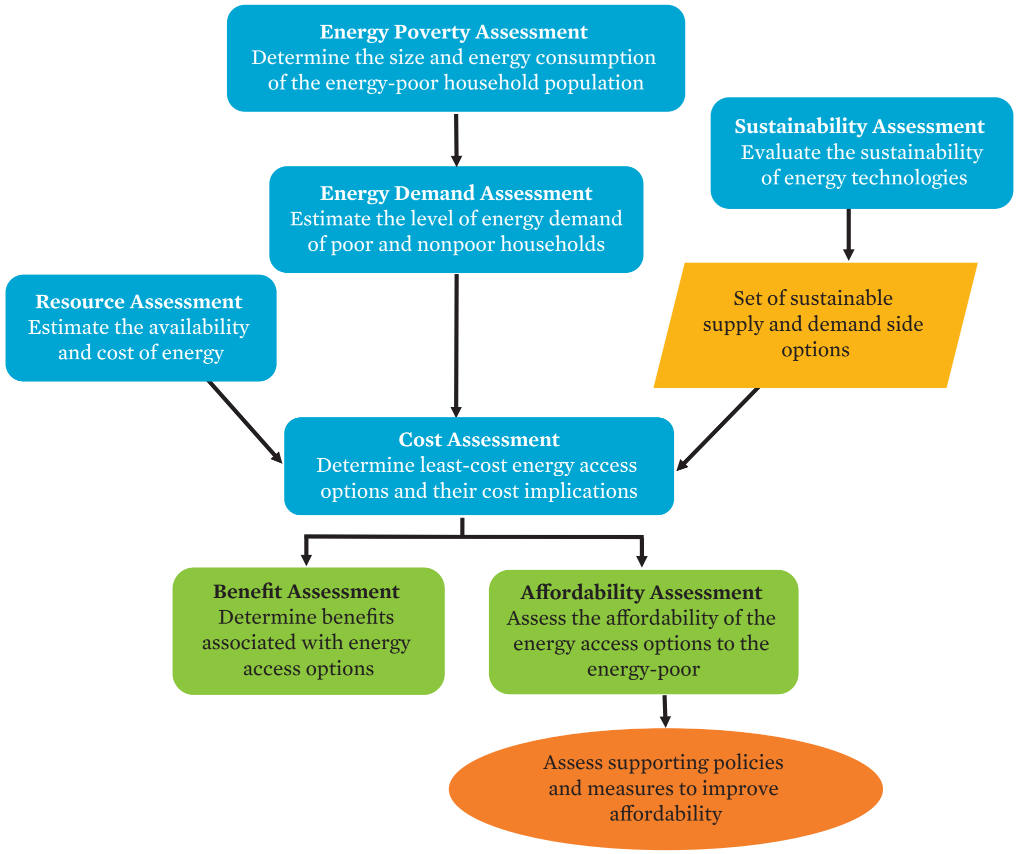
According to the SEAP framework, energy poverty assessment involves determination of the size of the energy-poor households in each VDC of the district, which includes households that have no access to cleaner energy sources as well as the households that are currently using inadequate (i.e., below the acceptable minimum) level of basic energy services.

The overall flow of the various assessments of the SEAP framework is presented in Figure 2.2. The first step in the SEAP framework is the determination of the size of the energy-poor households in each VDC of the district (i.e., energy poverty assessment). The households lacking cleaner energy access as well as without basic minimum level of energy services were considered as energy-poor households.

The energy poverty assessment also estimates the level of energy consumption of those households in each VDC of the district. This provided the basis for the assessment under an energy access program, thus linking up with the energy demand assessment component of the framework.

The cost assessment mentioned in Figure 2.2 determines the least cost technology and resource options for providing cleaner energy access in 2017, 2022, and 2030 of an energy access program in each village development committee (VDC) of Pyuthan district. It also takes into account the life of the various technology options involved.

Figure 2.2: Sustainable Energy Access Planning Framework Overall Flow Diagram



Source: Shrestha and Acharya (2015).

For this purpose, the cost assessment requires information on energy demand (obtained from energy demand assessment) as well as the availability of different energy resource options and their economic potential (based on the resource assessment).

Further, the determination of the least cost cleaner energy access options requires information on different sustainable technology options (identified through the sustainability assessment). The objective of cost assessment is to determine the total investment required to provide the least cost set of energy technology options.

Such information will further lead to an assessment of the level of affordability of the energy-poor and thus can be used to determine the subsidy amount and other financial supports needed to make cleaner energy access affordable.

2.2 Data

Pyuthan district has 49 subdistrict level local government units or VDCs.

This study carried out all the assessments as suggested in the SEAP framework at the individual VDC level. The district level assessments are thus based on the aggregation of these VDC-level assessments. The assessments were conducted based on the household survey data in all the 49 VDCs of the district.

The analysis presented in this report is based both on primary and secondary data. The primary data used in this report are based on the sample survey of households in each VDC of Pyuthan district conducted during February to March 2014.

The survey involved 2,744 households out of which 2,330 samples were found to be useful. The number of households surveyed per VDC varied from 35 to 55 across the VDCs in the district.

The secondary data considered in this study are based on publications of different district and national level government agencies including the Alternative Energy Promotion Centre, Central Bureau of Statistics, Nepal Electricity Authority, Biogas Support Programme, Butwal Power Company, Water and Energy Commission Secretariat, and other organizations.

3

Demographic and Energy Profile of Pyuthan District

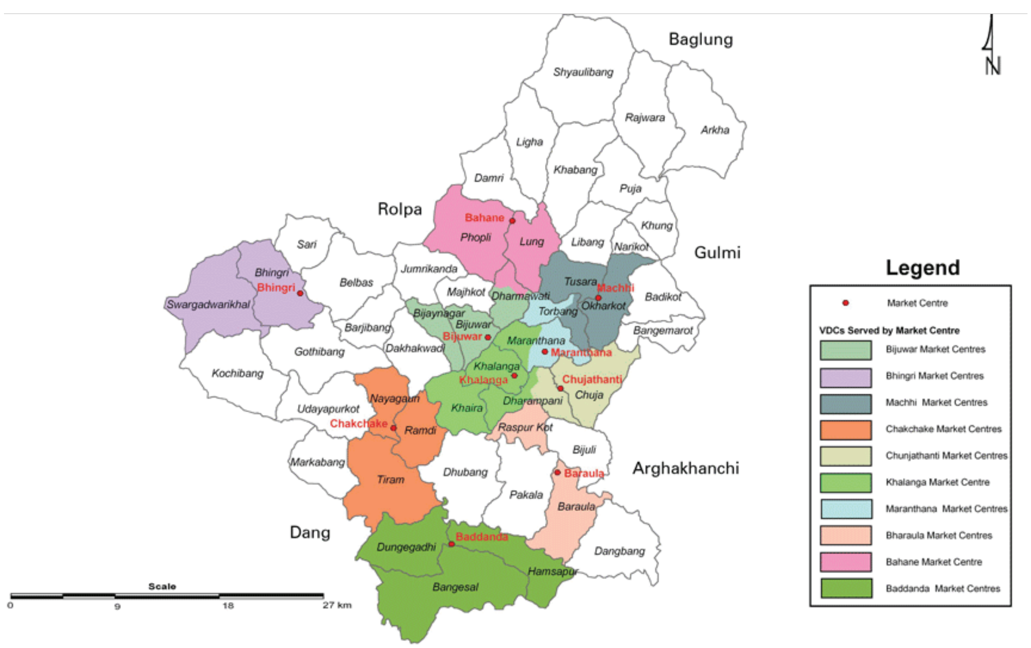
This chapter presents the district demographic profile and the energy access information of the district as well as the status of energy consumption in the residential sector obtained through the household survey.

3.1 Introduction

Pyuthan is a hilly district lying in the midwestern development region of Nepal. It is situated at 27° 55'' to 28° 25'' north latitude and 82° 30'' to 83° 0'' east longitude. The district is around 500 kilometers west of the capital city Kathmandu and covers an area of 1,309 square kilometers (Hamro Pyuthan 2014). The land altitude varies between 305 meters to 3,659 meters. The district is divided into 49 village development committees (VDCs) with high topographic and socioeconomic variation among them. The district headquarter of Pyuthan is located in Khalanga.

The population of Pyuthan was 226,796 as per the census in 2011 (CBS 2014). The population in Pyuthan district increased at a compounded annual growth rate of 0.7% from 2001 to 2011.

Figure 3.1: Map of Pyuthan



Source: MEDEP (2008).

Agriculture is the main livelihood of the district. The total cultivated land of the district is around 33.96%, out of which only 5% of the land has irrigation facilities (DDC, 2012).

The map of Pyuthan district in Figure 3.1 shows all 49 VDCs.

Some demographic indicators of VDCs in the district are shown in Table 3.1. According to CBS, the average household size in the district is 4.78 and the total number of households is 47,716.

Table 3.1: Population, Growth Rate, and Household Size in Village Development Committees of Pyuthan District

Village Development Committee Name	Population in 2011[a]	Growth Rate (2001–2011), %[a, b]	No. of Households[a]	Average Household Size[a]
Arkha	5,651	2.34	900	6.28
Badikot	5,362	−0.65	1,140	4.70
Bangemarot	4,659	0.72	1,004	4.64
Bangesal	6,607	1.80	1,320	5.01
Baraula	4,205	−0.30	883	4.76
Barjiwang	2,423	0.04	596	4.07
Belbas	5,748	0.95	1,318	4.36
Bhingri	5,389	0.82	1,301	4.14
Bijayanagar	3,993	0.37	937	4.26
Bijuli	3,975	−0.04	923	4.31
Bijuwar	7,351	1.30	1,851	3.97
Chuja	5,813	0.38	1,232	4.72
Dakhakwadi	6,077	0.09	1,434	4.24
Damri	4,757	1.07	882	5.39
Dangwang	4,534	−0.23	838	5.41
Dharampani	3,083	−0.48	710	4.34
Dharmawoti	4,883	−0.02	1,132	4.31
Dhungegadhi	4,264	0.81	763	5.59
Dhuwang	3,623	−0.72	708	5.12
Gothiwang	5,460	1.14	1,190	4.59
Hansapur	3,970	0.80	724	5.48
Jumrikanda	4,301	1.21	898	4.79
Khaira	4,087	–1.24	914	4.47
Khalanga	5,860	0.39	1,536	3.82
Khawang	5,977	1.59	1,147	5.21
Khung	3,256	1.71	706	4.61
Kochiwang	3,439	0.81	655	5.25
Ligha	3,545	5.37	588	6.03

continued on next page

Table 3.1 *continued*

Village Development Committee Name	Population in 2011[a]	Growth Rate (2001–2011), % [a, b]	No. of Households[a]	Average Household Size[a]
Liwang	5,014	1.58	933	5.37
Lung	4,669	1.30	1,019	4.58
Majhakot	3,230	0.70	697	4.63
Maranthana	6,285	0.69	1,455	4.32
Markawang	3,118	0.34	606	5.15
Narikot	3,356	0.58	706	4.75
Nayagaon	3,462	0.57	760	4.56
Okherkot	5,732	0.40	1,202	4.77
Pakala	4,622	0.49	936	4.94
Phopli	7,760	1.81	1,537	5.05
Puja	5,135	1.12	1,087	4.72
Rajbara	5,093	2.11	845	6.03
Ramdi	2,434	−0.08	525	4.64
Raspurkot	3,373	−1.17	778	4.34
Saari	3,594	0.48	850	4.23
Swargadwarikhaal	4,887	1.15	1,058	4.62
Syauliwang	3,584	1.18	636	5.64
Tiram	5,907	−0.37	1,122	5.26
Turwang	4,323	−0.26	937	4.61
Tusara	5,771	0.04	1,193	4.84
Udayapurkot	3,155	1.36	604	5.22
Total	**226,796**	**0.69**	**47,716**	**4.78**

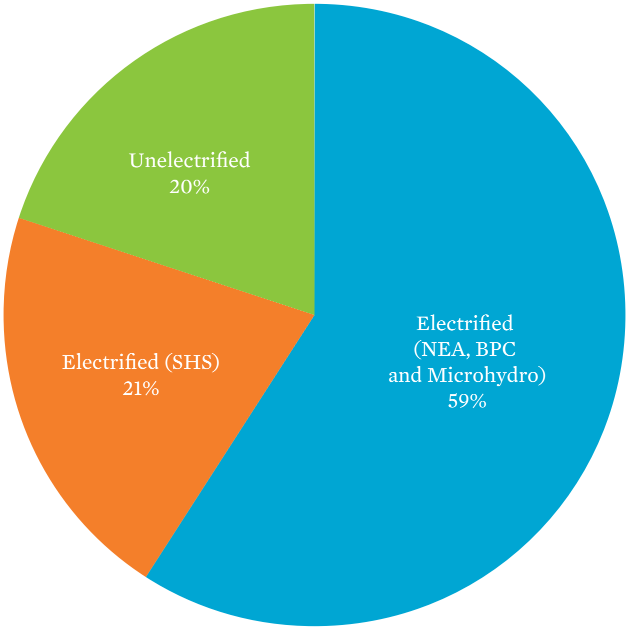
Source: [a] CBS (2014), [b] DDC (2012).

3.2 Energy Access Situation in Pyuthan District

Out of the 47,716 households in Pyuthan district, around 80% are electrified. The source of electrification is dominated by grid supply from the Butwal Power Company (BPC) and Nepal Electricity Authority (NEA), with a significant share from solar home systems and a small share from microhydro power generation. Figure 3.2 presents the status of electricity access in Pyuthan district considering solar home systems. Figure 3.2 shows that around 41% of the households lack access to grid based electricity (among which 20% of the households are completely unelectrified).

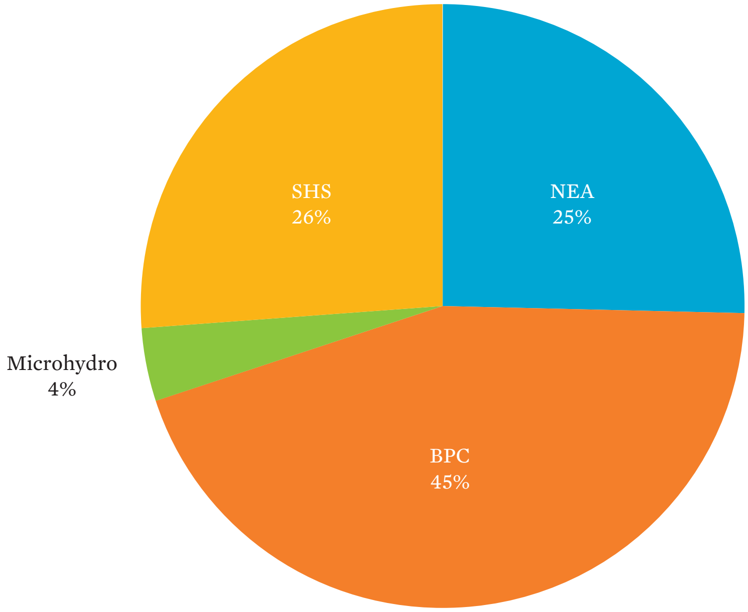
Among the different types of supply system providing electricity access in the district, the share of electricity supplied by the BPC is the highest, followed by solar home systems, the NEA and microhydro (Figure 3.3).

Figure 3.2: Electricity Access Status in Pyuthan District, 2014
(Considering Solar Home Systems)



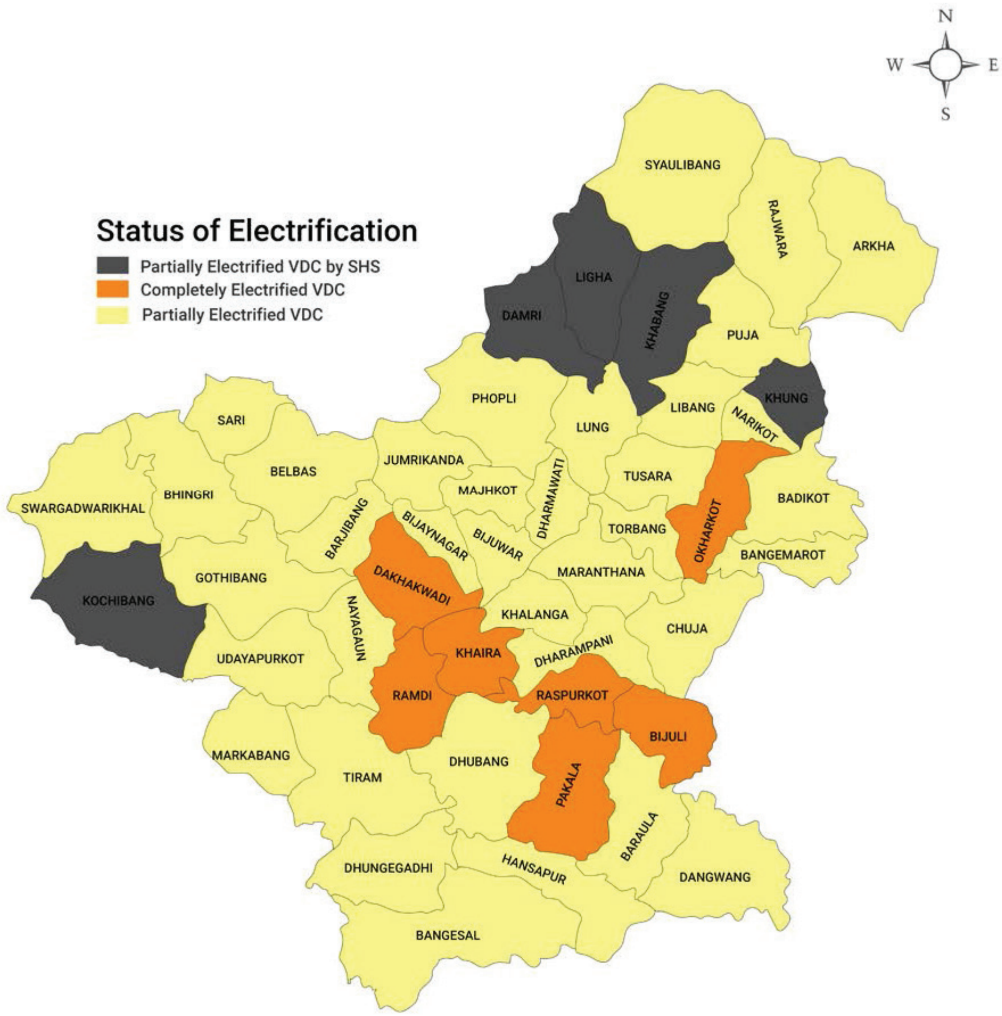
BPC = Butwal Power Company, NEA = Nepal Electricity Authority, SHS = solar home systems.
Source: Based on household survey.

Figure 3.3: Electrification of Households by Type of Supply System, 2014



BPC = Butwal Power Company, NEA = Nepal Electricity Authority, SHS = solar home systems.
Source: Based on household survey.

Figure 3.4: Electricity Access Status in Pyuthan by Village Development Committee



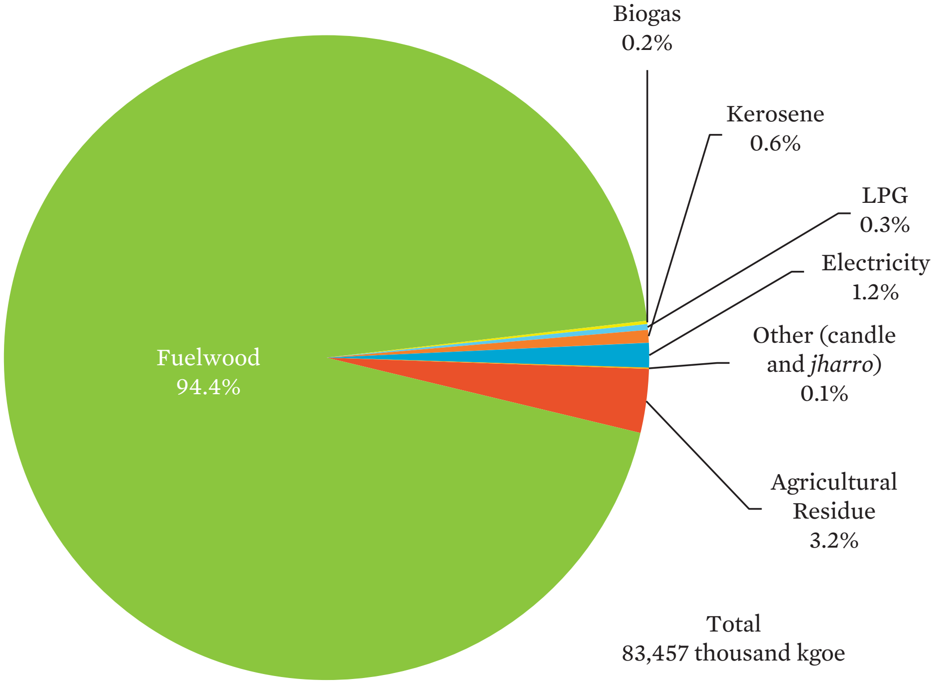
SHS = solar home systems, VDC = Village Development Committee.
Source: Authors (Based on household survey data).

Figure 3.4 shows the electricity access status of VDCs in Pyuthan in 2014. As seen in the figure, most of the VDCs are partially electrified while only five VDCs, Damri, Ligha, Kochibang, Khabang, and Khung are partially electrified with solar home systems.

3.3 Energy Consumption in the Residential Sector

Figure 3.5 shows the energy mix in 2014, by type of fuel in the residential sector. The household survey showed that the residential sector consumed around 83,457 thousand kgoe of energy in 2014. As seen in the figure, the residential sector of the district is largely dependent on traditional fuel resources such as fuelwood to meet energy demand. From the household survey, it was found that the share of fuelwood in the total residential sector

Figure 3.5: Energy Consumption in the Residential Sector by Fuel Type in 2014



kgoe = kilogram of oil equivalent, LPG = liquefied petroleum gas.
Source: Based on household survey.

energy consumption was as high as around 94.4%. This was followed by agricultural residue, electricity, kerosene, liquefied petroleum gas (LPG), biogas, and others (including candle and *jharro*,[4] now onward referred to as "pinewood stick").

In 2014, the consumption of fuelwood in the residential sector increased by around 54% from its 2007–2008 level while that of the agricultural residue decreased by 7% during the same period.

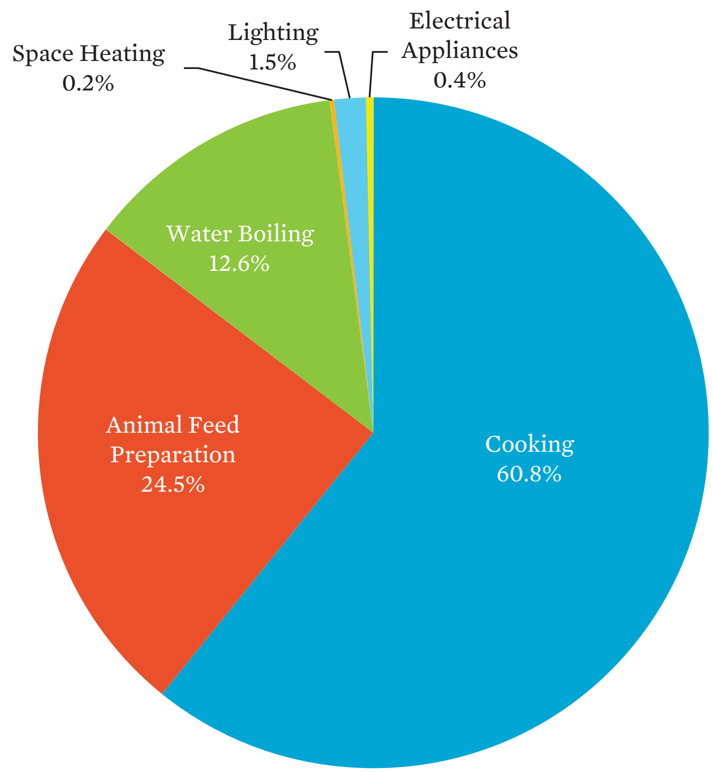
Similarly, the consumption of biogas was estimated to increase by more than twofold as compared to that in 2007–2008. In the case of electricity, large increment (49 kWh in 2007–2008 to 11,957 kWh[5] in 2014) was achieved from the 2007-2008 level (based on the household survey and DDC 2012). One reason for this abrupt increment might be the increase in the level of electrification in 2014 since 2007-2008.

However, due to the lack of electrification data in 2007–2008, a good comparison between these 2 years could not be made in this study. The consumption of kerosene in the residential sector seems to decrease by almost 60% during 2007–2008 to 2014. The household survey

[4] *Jharro* is a stick with high resin content from the Himalayan pine tree. The flame produced by the stick is smoky and just minimally enough for indoor lighting (RIDS-Nepal 2013).

[5] This value is obtained from the household survey estimated from the number of devices, average electricity consumption per device, and hours of use.

Figure 3.6: Residential Sector Energy Demand by End Use, 2014



Source: Based on household survey.

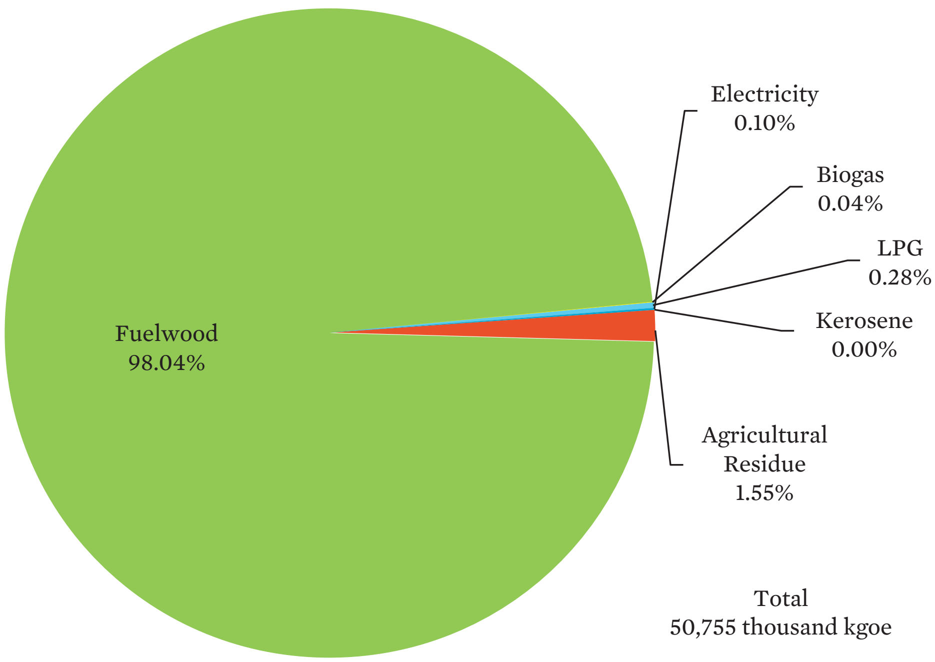
showed that kerosene was consumed in the district only for meeting the lighting energy needs and was not used for cooking.

Figure 3.6 shows the residential sector energy consumption by end use in Pyuthan district. Cooking is the major end use demand and is responsible for about 60.8% of the total energy consumption. This is followed by animal feed preparation and water boiling. Lighting accounted for about 1.5% of the total residential sector energy consumption and the remaining were used for electrical appliances and space heating.

Figure 3.7 and Figure 3.8 show the energy consumption share for cooking and lighting by fuel types in 2014 respectively. The total energy consumption for cooking in Pyuthan in 2014 is mainly dominated by fuelwood with the agricultural residues also being used to a small extent. The survey showed that fuelwood constitutes around 98% of the total energy consumption for cooking with the rest provided by agricultural residues, LPG, electricity, and biogas.

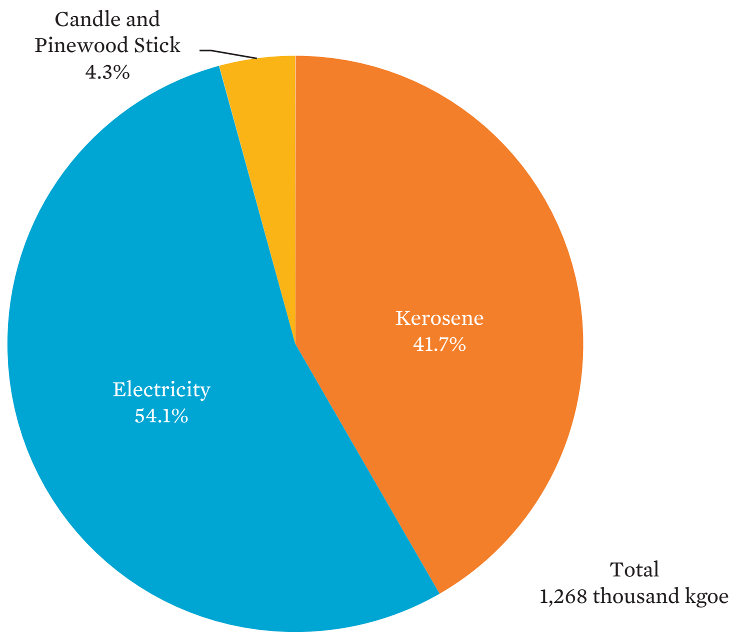
Similarly, electricity is the major source of lighting in the district followed by kerosene and other sources (candle and pinewood stick). The demand for space heating was found to be low. Fuelwood is the major source of energy for space heating; it is followed by biogas, LPG, and agricultural residues.

Figure 3.7: Structure of Fuel Consumption for Cooking in Pyuthan, 2014



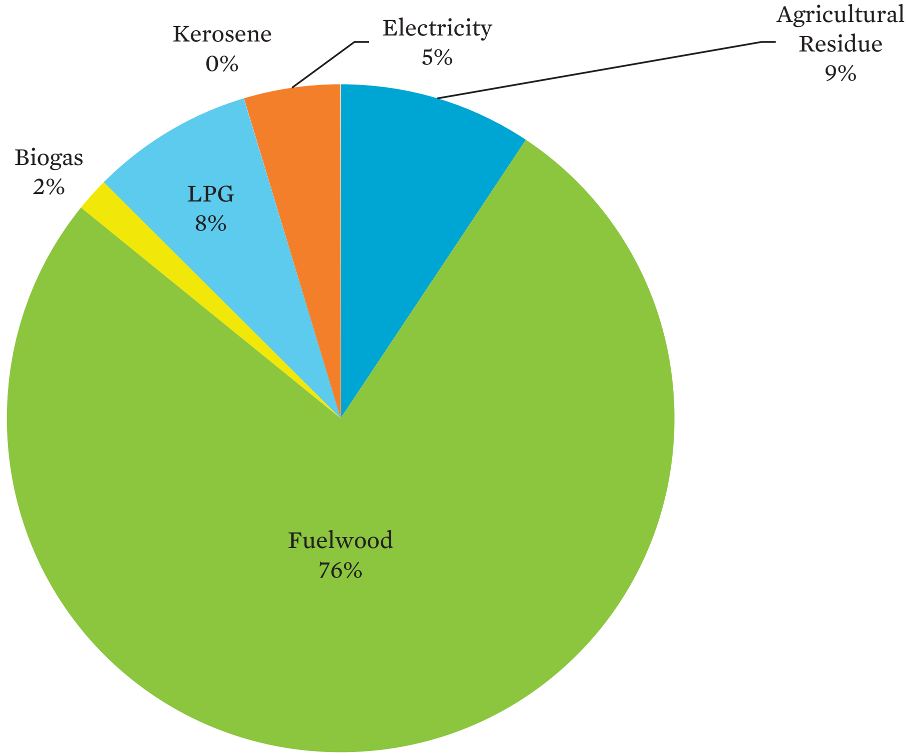
kgoe = kilogram of oil equivalent, LPG = liquefied petroleum gas.
Source: Based on household survey.

Figure 3.8: Structure of Fuel Consumption for Lighting in Pyuthan, 2014



kgoe = kilogram of oil equivalent.
Source: Based on household survey.

Figure 3.9: Percentage of Households by Type of Fuel Used for Cooking, 2014



LPG = liquefied petroleum gas.
Source: Based on household survey.

Around 76% of the households in the district are found to use fuelwood for cooking (Figure 3.9). This is followed by agricultural residue, LPG, electricity, and biogas.

3.4 Key Findings

Out of the total, 80% of the households in Pyuthan district were estimated to have access to electricity.

Grid-based supply is the dominant source of electrification followed by solar home systems and microhydro power generation. Around 43 VDCs in the district are partially electrified while only 6 VDCs are fully electrified with grid connection (i.e., NEA or BPC). Of the partially electrified VDCs, five (Damri, Ligha, Kochibang, Khabang, and Khung) are partly electrified with solar home systems while the others are electrified either with microhydro or grid connection (i.e., NEA or BPC). Fuelwood dominates the residential sector's energy consumption of the district.

The total residential sector energy consumption in 2014 was 83,457 thousand kgoe in which, fuelwood occupied a share of 94.5%. Cooking was the major end use service using energy and accounts for about 60.8% of the energy use in the residential sector. Animal feed preparation and water boiling together occupied a share of 37.1% in the total residential sector energy consumption. Lighting accounted for about 1.5% of energy use and the rest was used for space heating and other uses.

Fuelwood provided 98% of the total energy requirement for cooking purposes. The rest was provided by agricultural residues, biogas, LPG, and electricity. Electricity was the major source of lighting in the district, followed by kerosene and other sources.

4

Energy Resource Assessment

This chapter presents the village development committee (VDC)-wise energy resource potential and alternative energy technology resources available in the Pyuthan district.

4.1 Introduction

The objective of this resource assessment is to provide information on economically viable cleaner energy resources (i.e., solar, hydro, biomass, wind, and other renewables) in each VDC of Pyuthan.

Furthermore, the assessment intends to provide temporal availability patterns as well as costs of each resource. The energy resources of the Pyuthan district comprise both traditional and modern energy resources. Traditional resources include biomass such as fuelwood, agricultural residue, and animal wastes while modern resources include hydropower, biogas, solar, and wind resources.

Other nonrenewable modern energy resources such as petroleum have not yet been found in Pyuthan and the district is totally dependent on imports.

In terms of demand and consumption, biomass is the major energy source of the district.

However, taking sustainability and potential in account, hydropower is the major indigenous energy resource in the district. The 12-megawatt Jhimruk Hydro Electric Power was constructed in the Jhimruk River which is the only hydropower of considerable size in the Pyuthan district. A total of 21 VDCs in the district are connected via the national grid and the other 21 are electrified by the Butwal Power Company (DDC 2012).

The development of microhydro plants started in the early 1980s in the district. Initially, hydropower was constructed for mechanical schemes only, but after the intervention of the Rural Energy Development Programme in 2000, hydropower for electrical schemes gained priority.

Similarly, other technologies like solar plant, improved cookstoves, and biogas are also being disseminated in the district.

The following section presents the methodology used for estimating the energy resources in each VDC and the VDC-wise information on energy resources potential in the district.

4.2 Methodology

The resource assessment in this study focused on primary energy resources. This study made an attempt to estimate the VDC-wise resource availability of fuelwood and agricultural residue based on the secondary information available, and that of animal dung and biogas based on both secondary as well as survey data. The economic potential of other energy resources such as microhydro, solar, and wind used in this study are based on secondary sources (i.e., existing literature) in Nepal.

In this study, the fuelwood potential of each VDC in the district was estimated using the following equation:

$$Fuelwood\ potential\ of\ each\ VDC = \frac{Forest\ Area\ of\ the\ VDC * Total\ Fuel\ wood\ potential}{Total\ Forest\ Area\ of\ the\ district} \quad \text{Eq. 4.1}$$

The agricultural residue potential of each VDC in the district was estimated using the following equation:

$$Agricultural\ residue\ potential\ in\ each\ VDC =$$

$$\frac{Cultivated\ Area\ of\ the\ VDC * Total\ Agricultural\ Residue\ Potential}{Total\ Cultivated\ Area\ of\ the\ district} \quad \text{Eq. 4.2}$$

4.3 Biomass Energy Resources

Biomass plays a vital role in meeting the rural energy demand of Pyuthan. The major biomass energy resources in the district include fuelwood, agricultural residue, and animal waste.

An overview on each of these resources is presented as follows:

4.3.1 Fuelwood

Fuelwood is the major energy source in the district and provides more than 92% of total energy needs (DDC, 2012). Majority of the fuelwood is obtained from the forest. The forest area[6] in 2000–2001 was 82,830 hectare (ha) and the sustainable fuelwood supply from these forests was estimated to be around 3,338.07 thousand air dry ton (ADT) in the same year (DDC 2012).

The forest depletion rate since 1992–1993 to 2000–2001 has been 0.4% per year. The data obtained from the Alternative Energy Promotion Centre (AEPC) in 2014 shows that the total forest area of the district to be 78,049 ha.

In the absence of sustainable fuelwood data, the study considered 3,338.07 thousand ADT as the total fuelwood potential of the district for 2014. Table 4.1 presents the estimated

[6] Includes forest, shrub, and noncultivated area

VDC-wise fuelwood potential in Pyuthan. Based on the calculations, Syauliwang VDC had the highest potential of around 201.4 ADT while the lowest potential was found to be 7.9 ADT in Markawang VDC.

Table 4.1: Village Development Committee Fuelwood Potential in Pyuthan

Village Development Committee Name	VDC-Wise Forest Area, ha[a]	Yearly Fuelwood Potential, ADT[b]	Yearly Fuelwood Potential, GJ[b]
Arkha	2,822.58	120.72	2,022.06
Badikot	789.25	33.76	565.48
Bangesal	3,490.29	149.28	2,500.44
Baraula	1,616.89	69.15	1,158.26
Barjiwang	1,075.71	46.01	770.67
Belwas	2,910.97	124.50	2,085.38
Bhingri	2,249.06	96.19	1,611.18
Bijayanagar	563.00	24.08	403.34
Bijuwar	629.75	26.93	451.08
Bijuli	1,147.97	49.10	822.43
Chuja	1,191.61	50.96	853.58
Dakhakwadi	1,763.44	75.42	1,263.29
Damri	1,537.66	65.76	1,101.48
Dangwang	1,792.41	76.66	1,284.06
Dharampani	652.13	27.89	467.16
Dharmawati	522.57	22.35	374.36
Udayapurkot	2,532.40	108.31	1,814.19
Dhuwang	2,777.08	118.77	1,989.40
Dhungegadhi	2,676.65	114.48	1,917.54
Gothiwang	2,271.29	97.14	1,627.10
Hansapur	1,495.33	63.95	1,071.16
Jumrikada	1,185.63	50.71	849.39
Khaira	1,195.79	51.14	856.60
Khawang	1,730.17	74.00	1,239.50
Khung	652.20	27.89	467.16
Kochiwang	3,023.07	129.29	2,165.61
Ligha	1,742.79	74.54	1,248.55
Liwang	855.62	36.59	612.88
Lung	1,234.88	52.81	884.57
Majhkot	867.24	37.09	621.26
Maranthana	672.34	28.76	481.73
Markawang	183.72	7.86	131.66
Narikot	274.47	11.74	196.65

continued on next page

Table 4.1 *continued*

Village Development Committee Name	VDC-Wise Forest Area, ha[a]	Yearly Fuelwood Potential, ADT[b]	Yearly Fuelwood Potential, GJ[b]
Nayagaon	1,642.06	70.23	1,176.35
Okharkot	1,012.55	43.31	725.44
Pakala	2,335.06	99.87	1,672.82
Phopli	2,855.93	122.14	2,045.85
Puja	689.10	29.47	493.62
Khalanga	1,033.91	44.22	740.69
Rajawara	1,834.41	78.46	1,314.21
Ramdi	1,122.27	48.00	804.00
Raspurkot	1,130.87	48.37	810.20
Sari	1,350.72	57.77	967.65
Swargadari Khaal	2,967.23	126.90	2,125.58
Syauliwang	4,708.74	201.39	3,373.28
Tiram	2,569.32	109.89	1,840.66
Torabang	689.97	29.51	494.29
Tusara	1,332.14	56.97	954.25
Bangemarot	648.89	27.75	464.81
Total	**78,049.13**	**3,338.07**	**55,912.67**

ADT = air dry ton, GJ = gigajoules, ha = hectare, VDC = village development committee.
Source: [a] Based on data collected from Alternative Energy Promotion Centre in 2014, [b] Study estimates.

4.3.2 Agricultural Residues

Agricultural residue is another important source of energy in the district. It accounts for around 5% of the total energy consumption in the district. In fiscal year 2007–2008, the total agriculture residue supply was 104,427.04 ton, which could produce around 1,312 thousand gigajoule (GJ) of energy. The total agricultural residue potential wheat provided was 42%, paddy was 29%, and maize was 27%. Remaining was obtained from millet and barley (DDC 2012).

Using the total potential level of 2007-2008, the agricultural residue potential of each VDC in the district has been estimated using Equation 4.2 mentioned in subsection 4.2. Table 4.2 shows the VDC-wise estimated value of agricultural residue potential in the district.

4.3.3 Animal Wastes

Animal wastes are generally used as fertilizers in Pyuthan district. However, households in the regions of lower altitude in the district have started to produce biogas from animal wastes. The total population of cow and buffalo in the district was around 137,000 in 2007–2008 (DDC 2012).

Table 4.2: Village Development Committee Agricultural Residue Potential in Pyuthan District

Village Development Committee Name	VDC-Wise Cultivated Land Area, ha	Yearly Agricultural Residue Potential, thousand GJ[a]	Yearly Agricultural Residue Potential, t[a]
Arkha	340.0	20.2	1,611.7
Badikot	493.0	29.4	2,336.9
Bangesal	690.0	41.1	3,270.8
Baraula	567.0	33.8	2,687.7
Barjiwang	303.0	18.0	1,436.3
Belwas	577.0	34.4	2,735.1
Bhingri	531.0	31.6	2,517.1
Bijayanagar	375.0	22.3	1,777.6
Bijuwar	658.0	39.2	3,119.1
Bijuli	434.0	25.8	2,057.3
Chuja	409.0	24.4	1,938.7
Dakhakwadi	506.0	30.1	2,398.6
Damri	363.0	21.6	1,720.7
Dangwang	627.0	37.3	2,972.1
Dharampani	291.0	17.3	1,379.4
Dharmawati	394.0	23.5	1,867.6
Udayapurkot	327.0	19.5	1,550.1
Dhuwang	376.0	22.4	1,782.3
Dhungegadhi	441.0	26.3	2,090.4
Gothiwang	492.0	29.3	2,332.2
Hansapur	457.0	27.2	2,166.3
Jumrikada	344.0	20.5	1,630.6
Khaira	429.0	25.5	2,033.6
Khawang	493.0	29.4	2,336.9
Khung	386.0	23.0	1,829.7
Kochiwang	353.0	21.0	1,673.3
Ligha	398.0	23.7	1,886.6
Liwang	528.0	31.4	2,502.8
Lung	431.0	25.7	2,043.0
Majhkot	302.0	18.0	1,431.5
Maranthana	639.0	38.0	3,029.0
Markawang	408.0	24.3	1,934.0
Narikot	278.0	16.6	1,317.8
Nayagaon	316.0	18.8	1,497.9
Okharkot	502.0	29.9	2,379.6
Pakala	532.0	31.7	2,521.8
Phopli	642.0	38.2	3,043.2

continued on next page

Table 4.2 *continued*

Village Development Committee Name	VDC-Wise Cultivated Land Area, ha	Yearly Agricultural Residue Potential, thousand GJ[a]	Yearly Agricultural Residue Potential, t[a]
Puja	544.0	32.4	2,578.7
Khalanga	496.0	29.5	2,351.1
Rajawara	379.0	22.6	1,796.5
Ramdi	314.0	18.7	1,488.4
Raspurkot	402.0	23.9	1,905.6
Sari	416.0	24.8	1,971.9
Swargadari Khaal	436.0	26.0	2,066.7
Syauliwang	393.0	23.4	1,862.9
Tiram	691.0	41.1	3,275.5
Torabang	375.0	22.3	1,777.6
Tusara	483.0	28.8	2,289.5
Bangemarot	469.0	27.9	2,223.2
Total	**22,030.0**	**1,311.6**	**104,427.0**

GJ = gigajoules, ha = hectare, t = ton, VDC = village development committee.
[a] Study estimates.
Source: DDC (2012).

The study conducted by the District Development Committee in 2012 mentioned that out of the total dung produced, only 42,090 Mt of dung is collected. This amount of dung is capable of producing around 458,400 GJ of energy. Based on the household survey conducted in 2014, the average number of cattle per household was found to be 3.38 and the daily amount of dung production in the district was estimated to be 811.5 t.

The household survey reports the total amount of dung produced per household in terms of the total number of *dokos*.[7] The total weight of animal dung per *doko* varies from 20 kilograms (kg) to 50 kg in 49 VDCs. To estimate the total amount of animal dung produced in each VDC of the district based on the sample survey, the following equation was used in this study:

$$Amount\ of\ dung\ produced\ per\ day\ per\ household = \frac{(Amount\ of\ dung\ produced\ in\ doko\ per\ week \times kg\ per\ doko)}{7} \quad \text{Eq. 4.3}$$

Around 86% of the total households in the district have cattle. The average amount of dung collected from each cattle has been found to be 6.47 kg per day. But there is no uniform production of biomass from animal dung in each VDC due to different reasons, such as: geographical conditions, economic status of the family, and environmental condition in different location of the same district.

7 *Dokos* is a kind of basket used in Nepal which is made from bamboo.

Table 4.3 presents the estimated VDC-wise animal dung potential and the corresponding energy production potential. It has been observed that households in the VDCs such as Pakala and Syauliwang has an average of five heads of cattle each. In Dakhakwadi and Maranthana, the average number of cattle per household is two. Average amount of dung collected per cattle per day is above 10 kg in the VDCs like Arkha, Dakhakwadi, Bangemarot, Gothiwang, and Rajbara. However, the amount is around 3 kg in the VDCs like Majhakot, Nayagaon, and Damri. The reason for this might be difficulty in collecting dung when the animals are grazing far from the barn.

Table 4.3: Estimated Animal Dung Production and Associated Energy Potential for each Village Development Committee in Pyuthan District in 2014

Village Development Committee Name	Average Number of Cattle per Household	Amount of Dung Produced, thousand t	Total Energy Production Potential of Dung[a], thousand GJ
Arkha	5	22.2	241.3
Badikot	3	5.5	59.9
Bangesal	2	2.8	30.4
Baraula	3	6.0	65.9
Barjiwang	2	4.0	43.5
Belbas	3	7.1	77.3
Bhingri	3	6.3	68.1
Bijayanagar	3	7.2	78.1
Bijuwar	2	2.9	31.3
Bijuli	4	3.9	42.4
Chuja	3	5.8	62.7
Dakhakwadi	2	8.9	97.3
Damri	4	3.4	37.2
Dangwang	4	8.3	90.3
Dharampani	3	2.9	31.3
Dharmawoti	2	2.3	25.4
Udayapurkot	4	3.5	38.3
Dhuwang	5	3.2	34.9
Dhungegadhi	4	3.9	42.4
Gothiwang	5	18.5	201.7
Hansapur	4	4.0	44.1
Jumrikanda	3	7.3	79.0
Khaira	3	5.0	54.6
Khawang	4	8.2	89.7
Khung	4	7.8	84.5
Kochiwang	5	5.1	55.6
Ligha	4	3.6	39.1

continued on next page

Table 4.3 *continued*

Village Development Committee Name	Average Number of Cattle per Household	Amount of Dung Produced, thousand t	Total Energy Production Potential of Dung[a], thousand GJ
Liwang	4	9.8	106.9
Lung	3	6.7	73.1
Majhakot	3	1.7	18.5
Maranthana	2	5.4	58.4
Markawang	3	3.2	34.8
Narikot	3	2.7	29.7
Nayagaon	3	1.3	13.9
Okherkot	4	7.5	81.4
Pakala	5	9.7	106.1
Phopli	3	4.7	51.2
Puja	4	11.6	125.9
Khalanga	2	2.0	21.9
Rajbara	5	15.8	171.5
Ramdi	3	2.6	28.7
Raspurkot	3	3.7	40.8
Saari	3	3.1	33.6
Swargadwari Khaal	4	4.4	47.7
Syauliwang	5	9.0	97.7
Tiram	4	4.0	43.0
Turwang	3	5.1	55.3
Tusara	2	4.0	43.1
Bangemarot	3	8.8	96.1
Pyuthan District	**3**	**296.2**	**3,225.8**

t = ton, VDC = village development committee.
[a] This potential was estimated assuming that 1 ton of animal dung is capable of producing 10.89 GJ of energy.
Source: Based on household survey.

4.4 New Renewable Energy Sources

Hydropower is the major modern energy resource available in Pyuthan district. However, other sources like solar and wind energy could be feasible in scattered and sparsely populated parts where there is no potential for hydropower.

4.4.1 Microhydro Potential

Rapti is the main river in Pyuthan district. There are also other major rivers like Madi, Jhimruk, Jumri, Gartang, and Arun. Similarly, numerous small and intermittent streams are also running in the district. The total catchment area of 54 rivers and streams is estimated to be around 8,320 square kilometers.

According to the Government of Nepal (2012), around 21 pico and microhydro power plants have been installed in the district with a total capacity of 185 kilowatts (kW) as of mid-July 2012.

Excluding micro- and picohydropower plants, a 12-megawatt Jhimruk hydropower plant is in operation in the district. The Energy Sector Assistance Programme has completed construction of four microhydro plants with a total capacity of 114 kW (DDC 2012).

Only limited information is available in the existing literature about the availability of the micro -, mini, and small hydropower potential in different VDCs of the district. For example, the Rural Energy Development Programme (REDP) has identified 15 microhydro sites with a combined potential of 70 kW.

Although the use of microhydro plants is not significant in Pyuthan district, the electricity supply situation in the district has been reported to be fairly satisfactory (DDC 2012). People have benefited from electricity provided by the Butwal Power Company (BPC) and Nepal Electricity Authority (NEA).

Most of the installed microhydro plants are in non-operational state. Until 1995, 38 microhydro plants with capacity of 335.9 kW were installed for mechanical scheme in the district. The installation of microhydro for mechanical scheme has stopped since then. Under the electrical scheme, 15 microhydro plants with capacity of 120.5 kW have been installed until 2006 in the district (DDC 2012).

In 2014, 78% of total household were connected to some kind of electricity. Of this, around 46% were electrified by BPC, 27% from solar home systems followed by 26% from the national grid and 4% by microhydro power. Some of the households have both solar home systems and grid electricity access.

4.4.2 Solar Power Potential

According to the Water and Energy Commission Secretariat, 78% of the land area of Nepal is considered to have high solar insolation potential. The average solar radiation was in the range of 3.6 kilowatt hour per square meter per day (kWh/m^2/day) to 6.3 kWh/m^2/day and the country has average sunshine for about 300 days in a year. This shows that there is a good possibility to develop solar energy technology in various parts of the country.

The total monthly average solar radiation in Pyuthan was reported to be 2,300 watt/m^2 and the average annual sunshine hours was 2,600 (DDC 2012). The availability of global solar radiation in the district is reported to be 37,072 megawatt hours (MWh) (DDC 2012).

However, the solar potential was estimated considering the very low area of the district i.e., 0.46 square kilometers. As mentioned in the AEPC (2014), Pyuthan district has a direct solar radiation of 5.16 kWh/m^2/day and global solar radiation of 4.17 kWh/m^2/day.

The solar home system is emerging as an important alternative energy source because of its low cost settings. Until 2004, 759 solar home systems were installed in 26 VDCs of the district. Hansapur, with its 213 solar home systems, was the leading VDC in terms of solar installations. In 2014, solar home systems were installed in 36 VDCs of the district. Nearly 21% of households in the district were connected to solar home systems.

4.4.3 Wind Power

According to the AEPC (2014), an average wind energy potential of wind power density equal to 16 watts per square meter (W/m^2) and an average wind speed of nearly 4 meters per second (m/s) has been reported in the district. A wind velocity of 3.76 m/s (20 meters above) and 3.75 m/s has been identified in VDCs of Hansapur and Swargadwari (AEPC 2014 citing DHM 2014). Wind power has not been utilized in the district yet and a more careful technological and economical study is required to develop and disseminate wind energy in Pyuthan.

4.4.4 Biogas

In Pyuthan, there is good scope for developing biogas in the lower plains where the weather is warmer. As of 2007, 762 biogas plants have been installed in the district. The first biogas plants were installed in the district in 1992 and the installation has been increasing at a compounded average growth rate of 26% since then.

The biogas installation program in the district is supported by the District Development Committee and REDP.

Except in a few places, the climate in Pyuthan district has been identified to be inefficient for the production of biogas (DDC 2012). There is a possibility of installing around 8,759 biogas plants of sizes from 4 cubic meters (m^3) to 6 m^3 (DDC 2012). As mentioned in section 4.3.3, around 811.5 ton of dung was produced per day in 2014. Based on the household survey, the total amount of biogas that could be produced from animal dung has been estimated to be 17,854 m^3 or 410,642 megajoule per day from the whole district if all households install biogas plants as per their capacity (ranging from 2 m^3 to 6 m^3 depending on the number of cattles per household).

To estimate the potential of biogas in each VDC of the district, it has been assumed that a kilogram of cattle dung could produce around 40 liters of biogas (BSP 2012).

Based on BSP (2012), this study has considered only 55% of the total dung produced for biogas production. The study considered that a biogas plant with a size of 1 m^3 could produce around 23 megajoule of biogas. To estimate the total amount of biogas per VDC, the following equation was used:

$$Amount\ of\ biogas\ produced\ per\ VDC = Animal\ Dung\ (kg) \times 0.04\ (m^3\ per\ kg) \times 23\ (MJ\ per\ m^3) \qquad \text{Eq. 4.4}$$

Table 4.4 shows the VDC-wise estimated biogas potential in Pyuthan district.

Table 4.4: Estimated Biogas Potential for each Village Development Committee in Pyuthan District in 2014

No.	Village Development Committee Name	Total Amount of Dung Produced, thousand t	Annual Biogas Potential, thousand GJ
1	Arkha	22.2	11.2
2	Badikot	5.5	2.8
3	Bangesal	2.8	1.4
4	Baraula	6.0	3.1
5	Barjiwang	4.0	2.0
6	Belbas	7.1	3.6
7	Bhingri	6.3	3.2
8	Bijayanagar	7.2	3.6
9	Bijuwar	2.9	1.5
10	Bijuli	3.9	2.0
11	Chuja	5.8	2.9
12	Dakhakwadi	8.9	4.5
13	Damri	3.4	1.7
14	Dangwang	8.3	4.2
15	Dharampani	2.9	1.5
16	Dharmawoti	2.3	1.2
17	Udayapurkot	3.5	1.8
18	Dhuwang	3.2	1.6
19	Dhungegadhi	3.9	2.0
20	Gothiwang	18.5	9.4
21	Hansapur	4.0	2.0
22	Jumrikanda	7.3	3.7
23	Khaira	5.0	2.5
24	Khawang	8.2	4.2
25	Khung	7.8	3.9
26	Kochiwang	5.1	2.6
27	Ligha	3.6	1.8
28	Liwang	9.8	5.0
29	Lung	6.7	3.4
30	Majhakot	1.7	0.9
31	Maranthana	5.4	2.7
32	Markawang	3.2	1.6
33	Narikot	2.7	1.4
34	Nayagaon	1.3	0.6
35	Okherkot	7.5	3.8
36	Pakala	9.7	4.9
37	Phopli	4.7	2.4
38	Puja	11.6	5.9

continued on next page

Table 4.4 *continued*

No.	Village Development Committee Name	Total Amount of Dung Produced, thousand t	Annual Biogas Potential, thousand GJ
39	Khalanga	2.0	1.0
40	Rajbara	15.8	8.0
41	Ramdi	2.6	1.3
42	Raspurkot	3.7	1.9
43	Saari	3.1	1.6
44	Swargadwari Khaal	4.4	2.2
45	Syauliwang	9.0	4.5
46	Tiram	4.0	2.0
47	Turwang	5.1	2.6
48	Tusara	4.0	2.0
49	Bangemarot	8.8	4.5
	Total	**296.2**	**149.9**

GJ = gigajoules, No. = number, t = ton, VDC = village development committee.
Source: Based on household survey.

4.5 Petroleum Products

Nepal imports all the petroleum products for its consumption from India. Until now, no fossil fuel reserve has been discovered in the district. The consumption of fossil fuel in the residential sector is not substantial. Kerosene accounts for more than 10% of the total lighting energy requirement and the fuel is not used for cooking in the district. LPG forms a small share (i.e., around 0.28%) of energy used in cooking.

4.6 Other Rural Energy Technologies

Aside from the aforementioned technologies, other micro renewable technologies such as improved cookstove, improved water mill, peltric set,[8] gasifier, solar pumps, solar dryers, and solar cookers are also used in the district. Improved cookstoves (ICS) are designed to reduce fuel consumption and emission as compared to the traditional cookstoves.

At present, various agencies (government and nongovernment) are promoting and disseminating ICS, such as the Women Development Office, Jhimruk Industrial Development Center, ICS National Programme supported by the Alternative Energy Promotion Center (AEPC)/Energy Sector Assistance Programme, and the District Development Committee (DDC). As of 2012, 8,444 ICSs were disseminated in the district.

[8] Peltric set is a single combined unit of induction generator, pelton turbine and simple control mechanism (for details refer to: http://www.aepc.gov.np/?option=renewable&page=subsubrenewable&mid=2&sub_id=14&ssid=9&cat=Peltric%20Set).

4.7 Key Findings and Limitations

The analyses presented in this chapter were largely based on data generated by the sample survey of around 2,330 households from 49 VDCs of the Pyuthan district in 2014.

In the absence of sustainable fuelwood data, the present study considered fuelwood potential for 2000–2001 (i.e., 3,338.1 ADT) as the total fuelwood potential of the district in 2014.

Similarly, the study has considered the total agricultural residue potential of 2007–2008 (i.e., 104.4 thousand t) as the total agricultural residue potential of the district in 2014. In the absence of spatially disaggregated data, the fuelwood and agricultural residue potential in individual VDCs of the district has been derived from the district level potential assuming them to vary in the same proportion as the shares of a VDC in the total district level forest and cultivated areas.

The fuelwood potential per household has been found to be in the range of 0.01 ADT per household in Bijuwar VDC to 0.18 ADT per household in Kochiwang VDC. The agricultural residue potential per household among VDCs has been found to vary from 1.57 t in Chuja VDC to 3.55 t in Dangwang VDC.

For the estimation of the animal waste production in each VDC in the district, the information on the average number of cattle ownership per household and the amount of dung collected per cattle obtained from the field survey in each VDC has been used.

This study has estimated the total daily production of animal dung in the district in 2014 to be around 811 tons. Across the VDCs, the study has found the average number of cattle per household to vary from 2 to 5 and the estimated amount of dung production in the VDCs to vary from 1.3 thousand t to 22.2 thousand t per year (with the corresponding amount of total energy production potential from animal dung in the VDCs varying from 13,900 GJ to 241,300 GJ).

However, the study observed some variation in the amount of dung produced per household even though the households have the same number of cattle. One of the reasons for such a variation seemed to be related to the varying levels of difficulty experienced in collecting dung when the cattle are grazing far from the barn.

Further, the present study estimated the amount of biogas potential in each VDC of the district based on the estimated amount of animal waste produced. The total annual potential for biogas production in the district was estimated at 149,900 GJ.

Apart from its biomass resources, the district also has some potential for developing microhydro, solar, and wind energy. Pico and microhydropower plants with a combined capacity of 185 kW and a 12-megawatt small hydropower plant in Jhimruk operated within the district.

However, this study could not figure out the total microhydro potential in the district based on the secondary information available in the literature.

Further research activities are needed to determine the potential of micro- and mini-hydro plants in the district. A DDC (2012) study has reported the availability of the global solar radiation in the district to be 37,072 MWh. Even though the AEPC (2014) reported the availability of the wind energy potential in Hansapur and Swargadwari VDCs, wind power has not been utilized yet in the district. More careful technical and economic assessments are needed for development of the wind energy in Pyuthan.

5

Energy Poverty Analysis

5.1 Introduction

The purpose of the energy poverty assessment in this study is to find out the number of households with energy consumption that is less than the basic minimum energy consumption level in each village development committee (VDC) of the district and their energy consumption level.

This aids in assessing the level of modern energy (or cleaner energy) to be supplied to provide the energy-poor households with the desired level of energy access.

Following the sustainable energy access planning (SEAP) framework, energy poverty was assessed in two different ways: (i) basic minimum energy requirement approach and (ii) multidimensional energy poverty index (MEPI) approach.

These two approaches have different focus and objectives. The basic minimum energy requirement approach is focused at the energy poverty assessment in terms of energy requirement per household while the MEPI approach is aimed at the assessment of energy poverty at the subdistrict or district level and considers the type of energy-using device (or technology) as well as the quality of fuel.

The following section describes the methodology used for assessing energy poverty using these two approaches and presents the results of the energy poverty analysis based on the two approaches.

5.2 Methodology

Several criteria exist in the literature to identify energy-poor households. As mentioned in the SEAP framework, energy poverty can be assessed in numerous ways, such as: (i) basic minimum energy required, (ii) energy affordability, (iii) demand analysis, (iv) energy or fuel poverty line, and (v) indexes (Shrestha and Acharya 2015). Energy poverty in this study was assessed in two different ways, one based on the basic minimum level of energy requirement approach and the other based on the MEPI approach. The following section discusses these approaches in detail.

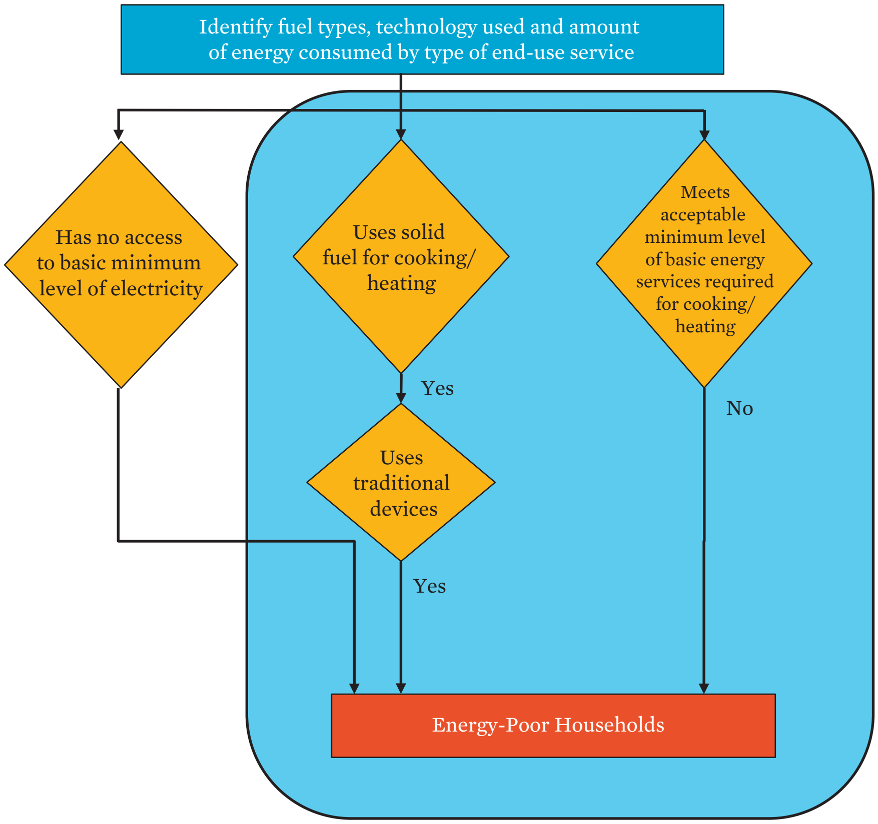
5.2.1 Basic Minimum Energy Requirement Approach

The first step in this approach is to determine the threshold of the basic minimum energy consumption level of households. The estimation of the basic energy needs of an average household requires information on the threshold of basic energy needs (e.g., lumens of lighting service demand, useful energy requirement for cooking, lighting, cooling, space heating, etc.) demanded by an average household.

After determining the basic energy needs for each specific energy service, the end use energy is calculated in useful energy terms.[9] This study adapted the multitier concept of the Global Tracking Framework (GTF) (World Bank/ESMAP and IEA 2013) and Poor People Energy Outlook (Practical Action 2013) to distinguish the energy-poor households from the rest of the population.

Energy-poor households in the district are identified as households that do not have access to electricity or those who consume electricity below a threshold level and/or use solid fuels for cooking using traditional devices. Figure 5.1 illustrates the technique used in this study to identify energy-poor households in the district (For details, refer to Chapter 3 of the SEAP framework document).

Figure 5.1: Flow Diagram to Identify Energy-Poor Households



Source: Shrestha and Acharya (2015).

[9] Useful energy consumption is the product of final energy consumption and efficiency of the device.

As mentioned above, energy poverty in this study was assessed based on the multitier concept of the GTF of the World Bank/Energy Sector Management Assistance Program (ESMAP) and International Energy Agency (IEA). The GTF developed six different tiers (Tier 0 to Tier 5) of household electricity access. Each of these tiers was defined by electricity supply attributes so that moving on from Tier 0 to Tier 5 indicates the continuous spectrum of improved energy supply attributes in terms of quantity, duration, evening supply hours, affordability, legality, and quality.

Similarly, the indicator for household cooking solutions was defined in terms of five tiers (Tier 0 to Tier 4). Each of the tiers of cooking energy access describes the increasing scale of improving energy supply in terms of overall emissions, indoor emissions, fuel use efficiency, safety, and health impacts (Practical Action [2013] and World Bank/ESMAP has more details).

Electricity Access

The GTF grades electricity access in terms of three levels of access, such as "no access," "basic access," and "advanced access." "No access" reflects Tier 0 of the multitier framework and means a complete lack of electricity. "Basic access" reflects Tier 1 which corresponds to a level of supply and electricity services that a solar lantern can provide. "Advanced access" reflects Tiers 2 and above which can be basically obtained from off-grid and grid solutions (World Bank/ESMAP and IEA 2013). The "Total Energy Access" approach of Practical Action has set the minimum standard for lighting services in a household as 300 lumens for a period of at least 4 hours per night (Practical Action 2012).

However, in the absence of the threshold value of minimum energy needs for Nepal, this study considered 3 kilowatt hours (kWh) of electricity as the threshold for electricity consumption, which falls in Tier 1 level of electricity consumption mentioned in the GTF. As such, the households consuming less than Tier 1 level of electricity were considered to be "electricity poor households" in this study.

Table 5.1 shows the multitier framework for household electricity access developed by the GTF except that the use of a 400-watt rice cooker for 1 hour daily was considered in Tier 3 instead of a washing machine since Pyuthan is predominantly a rural area.

Thus, the modified definition of tiers based on the range of household electricity consumption is presented in Table 5.2. As seen from Table 5.1, Tier 1 level of electricity access includes task lighting, playing the radio, and charging mobile phones with a total electricity consumption of 3 kWh.

The Tier 1 level of electricity consumption thus has been regarded as the basic minimum energy requirement in this study to analyze the energy poverty assessment. As such, the households consuming less than 3 kWh per year have been regarded as Tier 0 households. Tier 0 represents that category of households that do not receive electricity by any supply means and is associated with the household electricity consumption less than 3 kWh of electricity per year (World Bank/ESMAP and IEA 2013). Thus, in this study, the households lying in Tier 0 level are regarded as "electricity poor households."

Table 5.1: Multitier Framework for Household Electricity Access

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Appliances	radio	radio	radio	radio	radio
	task lighting	task lighting	task lighting	task lighting	task lighting
	phone charger	phone charger	phone charger	phone charger	phone charger
		general lighting	general lighting	general lighting	general lighting
		air circulator (fan)	air circulator (fan)	air circulator (fan)	air circulator (fan)
		television	television	television	television
			food processors	food processors	food processors
			rice cooker	rice cooker	rice cooker
				washing machine	washing machine
				refrigerator	refrigerator
				iron	iron
					air conditioner
Total kWh per year per household	**3**	**66**	**285**	**1464**	**2267**

kWh = kilowatt hour.
Source: Adapted from World Bank/ESMAP and IEA (2013).

Table 5.2: Definition of Tiers based on Household Electricity Consumption

Tier	Range of electricity consumption (E), kWh
Tier 0	E< 3
Tier 1	3 ≤ E< 66
Tier 2	66 ≤ E < 285
Tier 3	285 ≤ E< 1464
Tier 4	1464 ≤ E< 2267
Tier 5	E ≥ 2267

E = electricity consumption, kWh = kilowatt hour.
Source: Adapted from World Bank/ESMAP and IEA (2013).

Cleaner Cooking Access

According to the GTF, Tier 0 of the multitier measurement for household cooking reflects "no access" and corresponds to the use of traditional cookstoves using solid fuels. Tier 1 corresponds to the use of improved cookstoves with solid fuels, Tier 2 to kerosene cookstoves, and Tier 3 to advanced cookstoves using solid fuels. All three tiers reflect "basic access" according to the GTF. Tier 4 corresponds to the use of biogas, liquefied petroleum gas (LPG), natural gas, and electric cookstoves indicating "advanced access" (World Bank/ESMAP and IEA, 2013). Table 5.3 shows the multitier framework for household cooking solutions that was considered in this study as based on the GTF and the Poor People's Energy Outlook. The "Total Energy Access" approach of Practical Action sets a minimum standard for cooking and water heating.

The minimum level of consumption per person per day is set to be 1 kilogram (kg) of fuelwood or 0.3 kg of charcoal or 0.2 liters of kerosene or biofuel or 0.04 kg of LPG, each of which should not take more than 30 minutes per day to obtain.

According to the minimum standard, the fuel efficiency of improved cookstoves for solid fuels should be 40% higher than that of a traditional three-stone stove (Practical Action 2012). This study has used two different approaches to estimate the percentage of energy-poor households in terms of cooking in each VDC of the district. The first is based on the multitier framework concept set by the GTF, and the second considering the minimum per capita average useful cooking energy consumption by income decile of the Pyuthan district as the threshold.

Table 5.3: Multitier Framework for Household Cooking Solutions

Tier	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
Household cooking solution attributes	Continuous spectrum of improving energy supply attributes including: overall emissions, indoor emissions, fuel use (efficiency), safety, and health impacts				
Possible Energy Supply Technology	Traditional cookstoves +Solid fuels	Improved cookstoves with solid fuels	Kerosene cookstoves	Advanced cookstoves with solid fuels Gaseous fuels such as LPG, natural gas, biogas	Electric

LPG = liquefied petroleum gas.
Source: Practical Action (2013).

5.2.2 Multidimensional Energy Poverty Approach

The MEPI approach estimates the size of energy-poor population and calculates the index value based on technology use rather than the amount of energy consumption. According to Nussbaumer et al. (2012), the MEPI approach captures the set of energy deprivations that can harm the well-being of a person.

To estimate the index using the MEPI approach, first of all, the different dimensions of energy poverty in terms of basic energy services were identified. The next step involved defining one or more indicators for measuring each of the identified dimensions for each basic energy service. Nussbaumer, Bazilian, and Modi (2012) used five dimensions (such as cooking, lighting, household appliances, entertainment/education, and communication) and six indicators in a multicountry energy study of Africa. Considering the climatic condition of Nepal, one more dimension i.e., space heating was considered in this study for calculating the MEPI apart from the dimensions considered by Nussbaumer et al. (2012). For each indicator, relative weights were given and a deprivation cut-off was set. The weightage given to each dimension was obtained from the feedback provided by energy experts in Nepal during a workshop held in 2014. The questionnaires used for gaining experts' feedback are presented in Appendix 1.

Table 5.4 shows the six dimensions and seven indicators considered in this study along with the indicator weights obtained from the experts survey. In addition to this, a cut-off value of MEPI is defined to determine if a person is energy-poor.

In this study, a MEPI cut-off value of 0.3 was considered based on Nussbaumeret al. (2012). The MEPI was estimated as the products of a "head count ratio" and intensity of deprivation. The intensity of energy poverty is the ratio of sum of deprivation count of all energy-poor households to the sum of energy-poor households.

Table 5.4: Dimensions and Respective Variables with Cut-offs, Including Relative Weights

Dimension	Indicator (weight)	Variable	Deprivation cut-off (i.e., poor if...)
Cooking	Use of modern cooking fuel (0.2)	Type of cooking fuel used	Use any fuel other than electricity, LPG, kerosene, natural gas, or biogas
	Indoor pollution (0.08)	Food cooked on stove or open fire (no hood or chimney) if using any fuel other than electricity, LPG, natural gas, or biogas	True
Lighting	Electricity access (0.2)	Has access to electricity	False
Space heating [a, b]	Use of modern fuel (0.14)	Has a space heating device using electricity, LPG, kerosene or biogas	False
Services provided by means of household appliances	Household appliance ownership (0.14)	Has a fridge	False
Entertainment/ education	Entertainment/education appliance ownership (0.08)	Has a radio or television	False
Communication	Ownership of means of Telecommunication (0.14)	Has a phone landline or a mobile phone	False

LPG = liquefied petroleum gas.
[a] Cooling in hot climatic areas.
[b] Cooling demand is met by using electricity.
Source: Adapted and modified from Nussbaumer, Bazilian and Modi (2012).

The head count ratio is calculated as the percentage of households defined as energy-poor. And the deprivation count is the relative measure of household's access to modern energy services. For detailed steps involved in this approach please refer to Nussbaumer, Bazilian, and Modi (2012) and Chapter 3 of the SEAP Framework (Shrestha and Acharya 2015).

5.3 Results

5.3.1 Energy Poverty Assessment Using Basic Minimum Energy Requirement Approach

This section includes the assessment of energy poverty in the district in terms of basic minimum electricity and clean cooking energy requirements.

Energy Poverty Assessment using Basic Minimum Electricity Requirement Approach

This study adopted the concept of multitier framework to identify the basic minimum electricity requirement per household to distinguish electricity poor households from non-electricity poor. For the purpose of this study, the households consuming less than Tier 1 level of electricity i.e., less than 3 kWh of electricity were regarded as "electricity poor households."

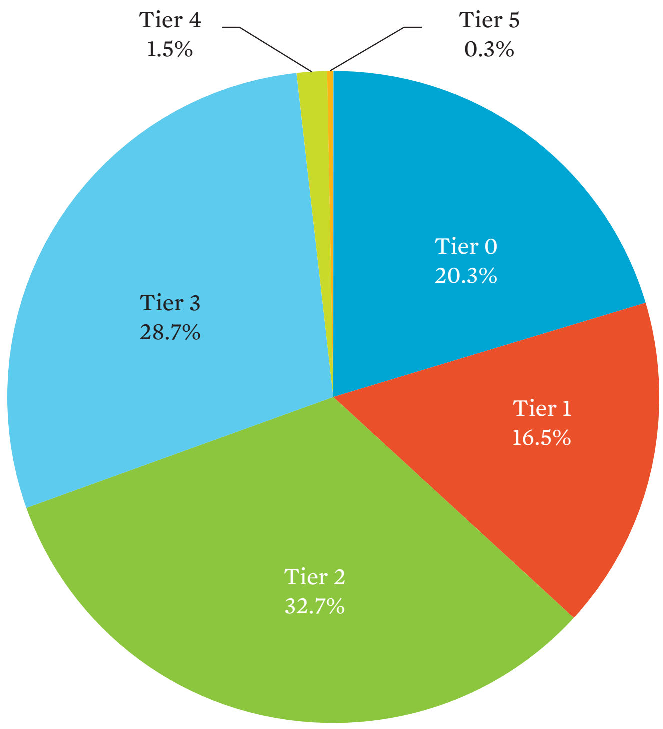
As described in Table 5.1, the Tier 1 level of electricity access includes task lighting, playing the radio and charging mobile phones with a total electricity consumption of 3 kWh. To differentiate between the electricity energy-poor and non-energy-poor households, the Tier 1 level of electricity consumption was regarded as the basic minimum energy requirement in this study.

However, this study estimated the amount of electricity required to meet the minimum criteria of each levels of energy access tiers to be used in Chapter 6.

As can be seen from Figure 5.2, 20% of the households in the Pyuthan district have electricity consumption below Tier 1. Figure 5.3 shows the percentage of households in Tier 0 or electricity poor households in each VDC of Pyuthan district while the estimated number of electricity poor households in each VDC in 2014 is presented in Appendix 2. Table 5.5 shows the distribution of households in the district in terms of their average electricity consumption. As seen in the table, the average electricity consumption of the households in Tier 1 is 27 kWh while that in Tier 5 is 2,349 kWh.

Out of the 49 VDCs, the estimated shares of electricity-poor households were very high in 6 VDCs. The share was highest in Chuja VDC with around 66% of the households being in Tier 0. This was followed by VDCs Hansapur (51%), Dangwang (49%), Damri (46%), Rajbara (45%), and Phopli (44%). Seven VDCs (Bijuli, Dakhakwadi, Khaira, Khawang, Okherkot, Pakala, and Ramdi) were found to have no electricity-poor households, while five were found to have less than 5% households to be electricity-poor. In the rest of 31 VDCs, the share of electricity-poor households was in the range of 5% to 44%.

Figure 5.2: Distribution of Households Based on Electricity Consumption Level in Pyuthan, 2014



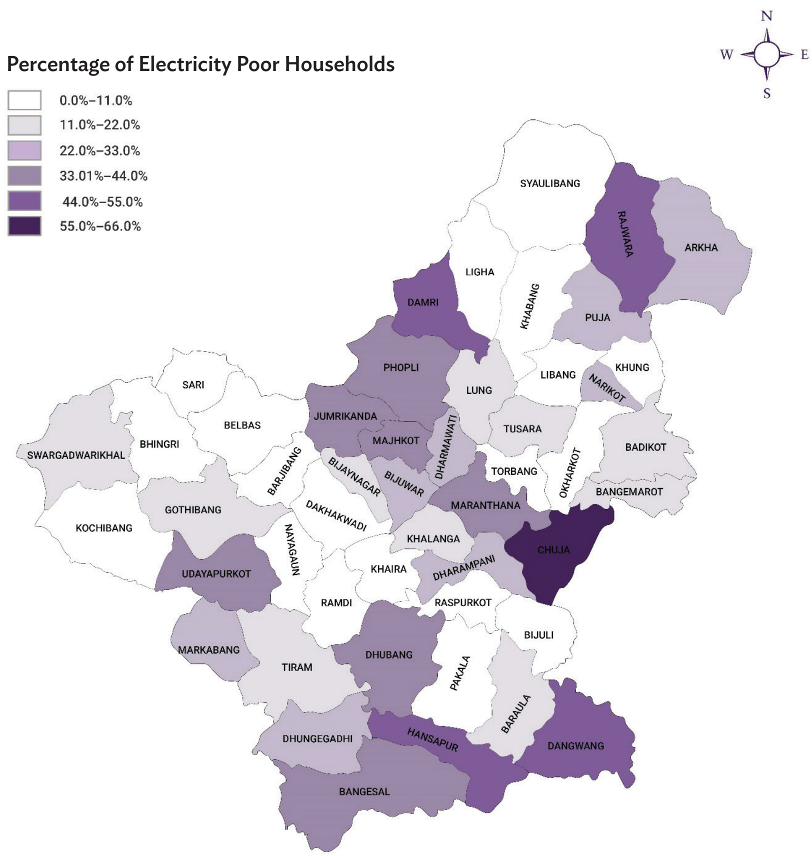
Source: Based on household survey.

Table 5.5: Average Electricity Consumption of Households at Different Tiers in Pyuthan District, 2014

Tiers	Average Electricity Consumption, kWh
Tier 0	0
Tier 1	27
Tier 2	135
Tier 3	358
Tier 4	1300
Tier 5	2349

kWh = kilowatt hour.
Source: Based on household survey.

Figure 5.3: Percentage of Electricity Poor Households in Pyuthan District (Based on Levels of Useful Energy Consumption)



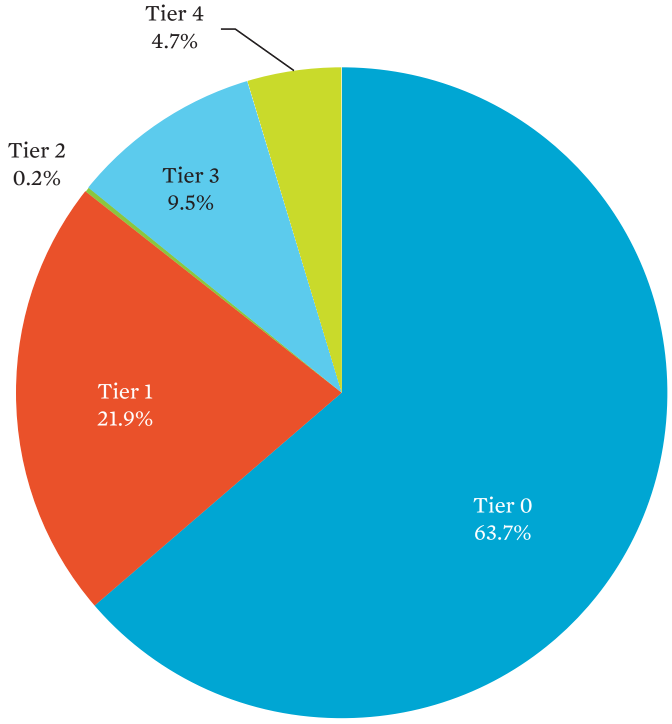
Source: Based on household survey.

Energy Poverty Assessment using Basic Minimum Energy Requirement Approach for Cooking

Based on the multitier framework of the GTF, this study presented the distribution of household by tiers based on the type of cooking stove technology and fuel used by the households. The tiers are defined as follows: the households using traditional cookstoves with fuelwood and agricultural residue were considered to be in Tier 0, those using improved cookstoves with fuelwood and agricultural residue are in Tier 1, those using advanced improved cookstoves with fuelwood are in Tier 2, those using LPG and biogas cookstoves fall under Tier 3, and those using electricity belong to Tier 4.

Figure 5.4 presents the household distribution in terms of the multitier of household cooking solutions. The study found that 63.7% of the total households in the district used traditional cookstoves for cooking and are in Tier 0 of the multitier framework.

Figure 5.4: Distribution of Households by Tier Based on Technology and Fuel Used for Cooking in 2014



Source: Based on household survey.

Table 5.6 presents the useful cooking energy consumption per capita by income decile obtained from the household survey data. The minimum useful cooking energy consumption per capita in the district based on the household survey have been found to be 27.2 kilograms of oil equivalent (kgoe) per capita.

Interestingly, the minimum useful cooking energy consumption does not correspond to the income of the household. This study has estimated the number of energy-poor households in terms of cooking considering 27.2 kgoe per capita as the basic minimum threshold level for cooking. The households with the average cooking energy consumption per capita less than 27.2 kgoe are termed as “energy-poor households.”

Table 5.7 provides the share of energy-poor households and the average cooking useful energy in energy-poor households in each VDC. The average useful energy consumption for cooking in the VDCs was in the range between 11.0 kgoe per capita in Bhingri VDC and 21.2 kgoe per capita in Raspurkot VDC. The share of energy-poor households in the district are found to be as high as 93.9% in Dhungegadhi VDC to as low as 17.4% in Raspurkot VDC.

Table 5.6: Useful Cooking Energy Consumption per Capita by Income Decile

Income Decile	Average Income (NRs)	Useful Energy per Capita (kgoe)
1	36,847	29.6
2	58,954	34.3
3	78,012	29.5
4	99,758	30.0
5	122,919	27.9
6	150,390	29.0
7	186,785	37.9
8	234,881	27.2
9	319,413	36.7
10	561,750	42.1

kgoe = kilogram of oil equivalent.
Note: Income decile in this study refers to groupings that are obtained from ranking all households in ascending order based on their income. The households are then divided into ten equal groups (ABS, 2017).
Source: Based on household survey.

Table 5.7: Percentage of Energy-Poor Households and their Level of Useful Energy Consumption for Cooking for each Village Development Committee

Village Development Committee	Percentage of Energy-poor HHs (%) [a]	Average Cooking Useful Energy Consumption (kgoe/capita)	Village Development Committee	Percentage of Energy-poor HHs (%)	Average Cooking Useful Energy Consumption (kgoe/capita)
Arkha	75.6	14.3	Kochiwang	92.3	14.9
Badikot	45.7	18.7	Ligha	82.0	14.4
Bangesal	52.9	13.2	Liwang	34.0	18.9
Baraula	47.8	12.2	Lung	54.9	17.0
Barjiwang	61.5	18.1	Majhakot	83.0	12.3
Belbas	75.5	15.8	Maranthana	17.5	19.6
Bhingri	82.2	11.0	Markawang	52.3	15.2
Bijayanagar	71.2	13.0	Narikot	47.2	13.2
Bijuwar	71.2	15.3	Nayagaon	78.9	14.5
Bijuli	60.0	17.1	Okherkot	44.2	16.0
Chuja	29.5	19.0	Pakala	33.3	18.7
Dakhakwadi	61.1	12.7	Phopli	76.4	12.5
Damri	58.5	13.7	Puja	88.2	12.4
Dangwang	35.1	18.0	Khalanga	71.7	13.1
Dharampani	40.0	20.0	Rajbara	79.5	15.5
Dharmawoti	73.1	15.0	Ramdi	73.6	14.3
Udayapurkot	51.2	18.7	Raspurkot	17.4	21.2

continued on next page

Table 5.7 *continued*

Village Development Committee	Percentage of Energy-poor HHs (%) [a]	Average Cooking Useful Energy Consumption (kgoe/capita)	Village Development Committee	Percentage of Energy-poor HHs (%)	Average Cooking Useful Energy Consumption (kgoe/capita)
Dhuwang	75.5	15.3	Saari	90.0	12.4
Dhungegadhi	93.9	12.0	Swargadwari Khaal	74.1	14.2
Gothiwang	75.0	11.7	Syauliwang	52.2	15.9
Hansapur	59.2	14.6	Tiram	64.0	15.1
Jumrikanda	70.6	13.6	Turwang	28.9	19.4
Khaira	82.4	15.0	Tusara	53.5	15.7
Khawang	63.8	17.0	Bangemarot	48.9	17.0
Khung	86.8	13.8			

HH = households, kgoe = kilogram of oil equivalent.
[a] This is the percentage of energy-poor households whose electricity consumption is less than Tier 1 out of the total number of households.
Source: Authors.

5.3.2 Energy Poverty Assessment using Multidimensional Energy Poverty Index Approach

In this analysis, the MEPI for Pyuthan district was calculated in two ways: (i) VDC-wise MEPI and (ii) income group-wise MEPI.

The multidimensional energy poverty cut-off (*k*) value was set as 0.3 based on Nussbaumer, Bazilian, and Modi (2012).

Multidimensional Energy Poverty Index of Different Village Development Committees

MEPI values for different VDCs are presented in Table 5.8. The VDCs are classified as acute energy poverty (MEPI > 0.9), high energy poverty (0.9 ≥ MEPI > 0.6), moderately high energy poverty (0.6 ≥ MEPI > 0.4), low energy poverty (0.4 ≥ MEPI ≥ 0.3) and very low energy poverty (MEPI < 0.3). MEPI in five VDCs (Bhingri, Dakhakwadi, Khaira, Nayagaon, and Okherkot) indicate those VDCs facing low energy poverty. A total of 17 VDCs have MEPI from 0.4 to 0.6 indicating moderately high energy poverty. The remaining 27 VDCs have MEPI in the range of 0.6 to 0.9, indicating a high level of energy poverty.

Multidimensional Energy Poverty Index by Income Quintile

In this analysis, following Nussbaumer, Bazilian, and Modi (2012) the households were divided into five income groups, i.e., poorest, poor, middle, rich and richest, and the MEPI for each income group was calculated. Figure 5.5 shows MEPI for different income quintiles. The MEPI value was found to decrease as one moves to a higher income quintile, indicating decreasing energy poverty level with increasing income. The value of MEPI was found to be 0.72 for the lowest income group, 0.53 for the richest income group and 0.65 for the middle income group.

Table 5.8: Categorization of Village Development Committees by Energy Poverty Level based on Multidimensional Energy Poverty Index

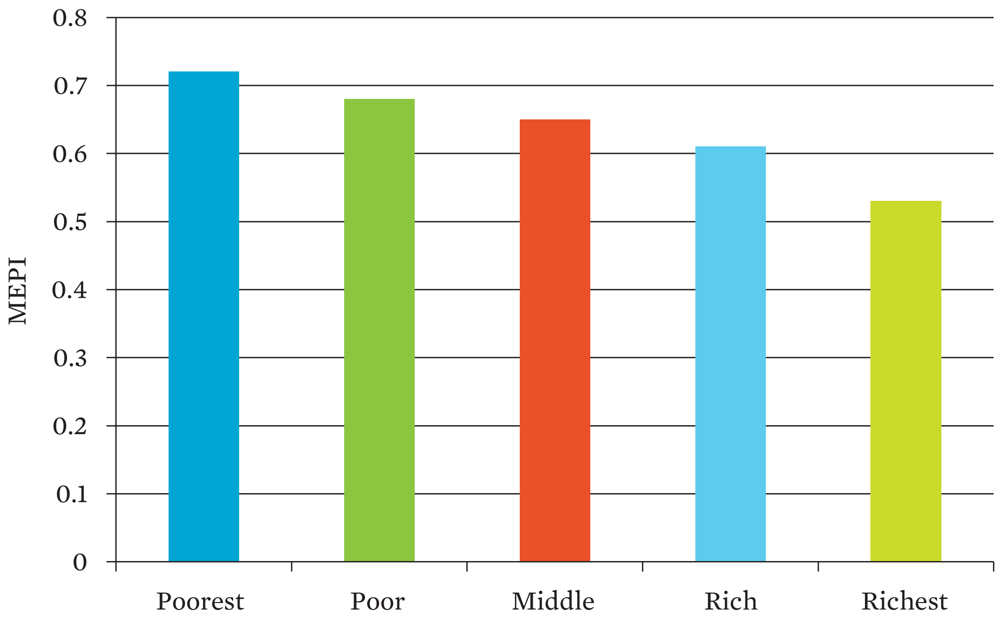
VDC	MEPI	VDC	MEPI
VDCs with low energy poverty (0.3 ≤ MEPI ≤ 0.4)		**VDCs with high energy poverty (0.6 < MEPI ≤ 0.9)**	
Khaira	0.30	Badikot	0.61
Nayagaon	0.31	Swargadwari Khaal	0.61
Dakhakwadi	0.37	Khawang	0.65
Bhingri	0.39	Maranthana	0.65
Okherkot	0.39	Gothiwang	0.66
VDCs with moderately high energy poverty (0.4 < MEPI ≤ 0.6)		Liwang	0.67
Khalanga	0.44	Dharampani	0.68
Dharmawoti	0.48	Tiram	0.68
Bijuli	0.48	Bangesal	0.69
Saari	0.48	Lung	0.69
Turwang	0.51	Markawang	0.69
Ramdi	0.54	Puja	0.69
Raspurkot	0.54	Arkha	0.70
Bangemart	0.54	Khung	0.70
Bijayanagar	0.55	Narikot	0.70
Bijuwar	0.56	Phopli	0.71
Barjiwang	0.57	Dangwang	0.73
Tusara	0.57	Ligha	0.74
Pakala	0.59	Majhakot	0.74
Belbas	0.59	Dhuwang	0.75
Baraula	0.59	Rajbara	0.76
Syauliwang	0.60	Damri	0.77
Dhungegadhi	0.60	Hansapur	0.77
		Jumrikanda	0.77
		Kochiwang	0.77
		Udayapurkot	0.79
		Chuja	0.82

MEPI = multidimensional energy poverty index, VDC = village development committee.
Source: Authors.

In Figure 5.6, headcount ratios for income quintile are plotted against intensity of energy poverty. The headcount ratio refers to the proportion of energy-poor households while the intensity of energy poverty indicates their relative level of energy poverty.

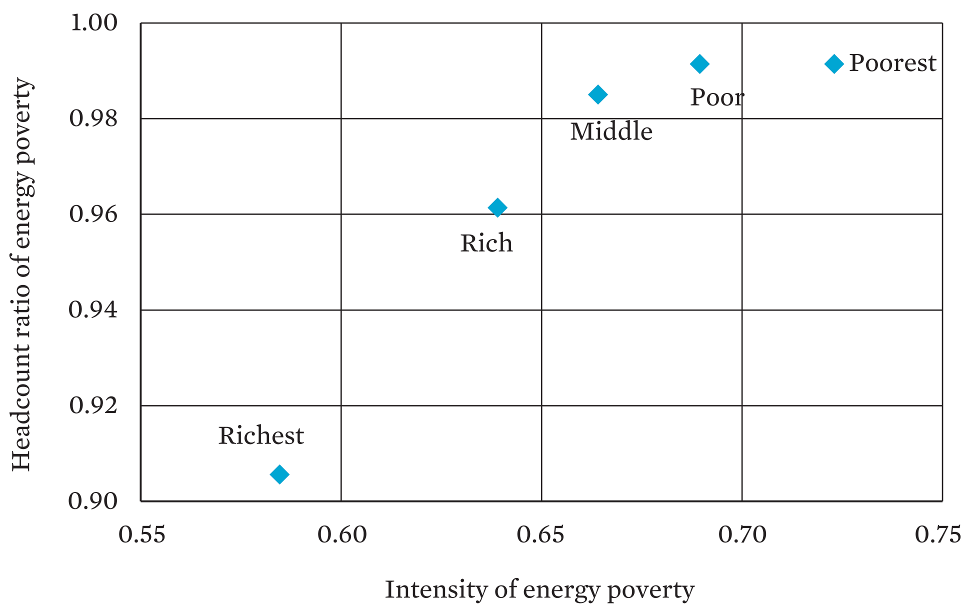
As can be seen, there are higher shares of energy-poor people at higher intensities of energy poverty. It should be noted here that the higher income quintile group has a lower head count ratio (Figure 5.6). Therefore, for lower income groups, the intensity and the share of energy-poor households are also higher.

Figure 5.5: Multidimensional Energy Poverty Index by Income Quintile in Pyuthan District



MEPI = multidimensional energy poverty index.
Source: Authors.

Figure 5.6: Headcount vs. Intensity of Energy Poverty for Income Quintiles in Pyuthan



Source: Authors.

5.4 Key Findings and Limitations

Several criteria exist in the literature to identify energy-poor households. This study has adopted the basic minimum energy needs approach and the MEPI approach to identify energy-poor households in each VDC in the Pyuthan district.

The proportion of energy-poor households and the level of their average energy consumption, however, varies depending upon the criteria chosen. Since there is no universally agreed criterion to evaluate the energy-poor households, the choice of the particular criterion is an issue that needs to be addressed in a manner acceptable to the policy makers and stakeholders.

According to GTF, Tier 1 level of electricity access includes task lighting, playing the radio, and charging mobile phones with a total electricity consumption of 3 kWh per year. In this study, Tier 1 level of electricity consumption has been regarded as the basic minimum energy requirement and thus the households consuming less than 3 kWh of electricity per year are regarded as electricity poor.

The present study found that around 20% of the households in the district have electricity consumption below 3 kWh and hence are electricity poor. The study has also found no electricity-poor household in seven VDCs of the district. In 39% of the VDCs in the district, more than 25% of the households are electricity poor; while in 4% of the VDCs, 50% of the households are electricity poor.

Using the multitier framework for cooking solutions of the GTF, the study found that 63.7% of the total households in the district, who use traditional cookstoves, are energy-poor (i.e., they use less than the minimum level of useful cooking energy requirement).

From the household survey data, the minimum useful cooking energy consumption per capita by income decile in the district was estimated to be 27.2 kgoe per capita. Considering this value of minimum useful cooking energy consumption as the threshold, the study found that the share of energy-poor households in terms of cooking energy use is as high as 93.9% in one of the VDCs (Dhungegadhi) and as low as 17.4% in another (Raspurkot).

In the present study, the energy-poor households based on the MEPI approach were estimated for each VDC in the Pyuthan district by setting the multidimensional energy poverty cut-off value at 0.3.

Based on the MEPI approach, a household in a VDC is considered as energy-poor if, for example, the household does not have any access to clean cooking fuel or access to electricity based energy services. The study found that 27 of the total 49 VDCs have MEPI in the range of 0.6 and 0.9, indicating a high level of energy poverty. Only one VDC (Chuja) has a higher MEPI value, between 0.8 and 0.9. The results showed that none of the VDCs has a MEPI value higher than 0.9, indicating that the energy poverty in the Pyuthan district is below the acute energy poverty level.

The application of the basic minimum energy needs criterion used in this study is not straightforward due to a lack of a universally applicable value of the threshold level of minimum energy needs. This is because the definition of basic energy needs may vary from one region to another due to differences in climate, physiography, as well as socioeconomic and/or cultural and other background.

In the absence of the threshold value of minimum energy needs for Nepal, this study used the multitier concept of the GTF (developed by World Bank/ESMAP and IEA, 2013) to distinguish the energy-poor households from the rest of the population. As discussed, the households whose electricity consumption lies below 3 kWh per year are regarded as electricity poor households.

This value was adopted in the absence of a nationally appropriate threshold value. The MEPI approach used in this study to estimate the size of energy-poor population calculates the index value based on technology use rather than the amount of electricity consumption. The outcome of the MEPI approach may vary with the consideration of different dimensions of energy poverty in terms of service demand, which depends upon the availability of data of different end uses.

The MEPI approach requires definition and identification of the level of “deprivation cut-off” and weights for each dimension in measuring energy poverty, which needs to be derived through a detailed analysis of the relevant information from stakeholders. In the absence of the level of deprivation cut-off, this study drew from Nussbaumer, Bazilian, and Modi (2012), which is a limitation of this study.

6

Energy Demand Assessment

6.1 Introduction

The main objective of the energy demand assessment is to assess the levels of energy services demand. The energy services include lighting, cooking, water heating, space heating, and some other electrical devices. A specific objective of the demand assessment is to assess the energy demand of the poor households in terms of basic minimum energy requirements as discussed earlier in the context of Energy Poverty Assessment.

The demand assessment also involves estimation of the energy service demand of non-energy-poor households considering household number and income as determinants. The level of energy requirement (or demand) is then estimated based on the estimated service demands. In the present study, the energy demand assessment in the case of the poor households was aligned to the Sustainable Energy for All (SE4ALL), Global Tracking Framework (GTF) of the World Bank/ Energy Sector Management Assistance Program (ESMAP) and International Energy Agency (IEA) in considering the levels of minimum energy requirements.

In this chapter, the energy service demand for consumptive use of both the energy-poor and non-energy-poor households has been assessed. The total energy service demand of the households for consumptive use of energy in each Village Development Committee (VDC) of the Pyuthan district is the sum of the service demands of the energy-poor and non-energy-poor households.

The first section in this chapter presents the demand projection for household electricity use in the years 2017, 2022, and 2030 in three different electricity access scenarios. The second section presents the demand projection for household cooking energy use in 2017, 2022, and 2030. The last section presents the key findings along with the limitations of this study.

6.2 Methodology

The objective of this demand assessment is to estimate the increase in the energy demand such as electricity demand and/or other sources of energy for cooking and other uses that would be needed to provide an acceptable minimum level of basic energy services to the energy-poor population.

Generally, the assessment of energy demand of any region or community requires the energy demand assessment of households' energy demand and the energy demand in the production sector and other community services. The households' energy demand can be both for consumptive use and productive use. However, this study only considered the energy service demand for consumptive energy use of households for both the energy-poor and non-energy-poor households. The total demand of households for consumptive use of energy would be the sum of the service demands of energy-poor and non-energy-poor households.

As mentioned in the sustainable energy access planning framework, there are a number of approaches to estimate energy demand. Some of them include the historical consumption pattern, end use, econometric, time-series and neural network techniques. In this study, future energy service demands of non-energy-poor households were estimated using econometric demand relationship considering income and household growth projections as the explanatory factors in the case of both electricity and cleaner cooking energy access.

The energy service demands of energy-poor households were estimated on the basis of the basic minimum energy requirements. The following section describes the detailed methodology used in this study to estimate the energy demand for both electricity and cleaner cooking energy access.

6.2.1 Electricity Demand Projection

As mentioned earlier, the total energy demand for consumptive use of energy would be the sum of energy demand of both energy-poor and non-energy-poor households. The first step involves the determination of energy-poor and non-energy-poor households in terms of their electricity consumption. As mentioned in sub-section 5.2.1.1, as discussed earlier in the context of Energy Poverty Assessment, the households whose electricity consumption lies in Tier 0 are categorized as energy-poor households. The estimated numbers of energy-poor households in each VDC of the district based on the sample household survey have been presented in Chapter 5.

The following section presents the methodology for estimating the electricity demand of energy-poor and non-energy-poor households.

a. Electricity Demand of Energy-Poor Households

The methodology used in this study for estimating the electricity demand of energy-poor households involves three steps as shown in Figure 6.1. The first step is to define the minimum acceptable level of electricity required for basic services. However, there is no universally defined level of electricity required for basic energy services.

As mentioned in Section 5.2.1.1, this study sets 3 kilowatt hours (kWh) of electricity per household (threshold level of Tier 1 of the multitier framework of GTF) as the threshold level to identify energy-poor households.

The second step involves identifying the number of households in each VDC whose electricity consumption is below 3 kWh per year. To find out the total number of energy-poor households, this study needed to find out the energy consumption level of each household in each VDC. The next step involved estimating the amount of energy required for providing the households with at least the basic minimum level of electricity services. This study carried out the following steps to find out the amount of energy consumption per household in the base year 2014 (or survey year) from the survey data:

(i) Identify the total number of lamps and other electrical appliances currently being used by each surveyed household in each VDC.
(ii) Identify the wattage of each lamp per household per VDC.
(iii) Identify the average hours of usage of lamp per day per household per VDC.

(iv) Similarly identify the wattage of all electrical appliances and their average hours of usage per day per household per VDC.

(v) Obtain the total electricity consumed for lighting and other electrical appliance usage of each household in each VDC in the survey year (EC_h) using the following relation:

$$EC_h = \sum_{i=1}^{n} (N_{i,h} \times W_{i.h} \times Hrs_{i,h}) \quad \text{Eq. 6.1}$$

Where, $N_{i,h}$ = Number of devices type i of household h
$W_{i,h}$ = Wattage of device type i of household h
$Hrs_{i,h}$ = Average hours of usage of device type i of household h

(vi) Identify the number of households in Tier 0 to Tier 5 based on their level of electricity consumption. The households whose electricity consumption puts them in Tier 0 are regarded as electricity-poor households.

(vii) Obtain the additional electricity consumption required by the energy-poor household to reach at least the threshold level of higher Tiers (i.e., Tiers 1 to Tiers 5) using the relation given in Equation 6.3.

This study considered the electricity levels defined by each tiers of the multitier framework of GTF as threshold level of electricity and has constructed three different electricity access scenarios each for 2017, 2022, and 2030. The details about the construction of scenarios are discussed later in this chapter.

If $E_{min,i}$ denotes the basic minimum level of useful energy requirement per household in Tier "i" and PP_t is the number of energy-poor households (that is, a household whose actual useful energy consumption per capita is below $E_{min,i}$) in year t, considering that an energy access program would aim at providing the energy-poor with the basic minimum level of energy given in Tier i, the total electricity "demand" of the energy-poor population in year "t" for Tier i ($TEP_{t,i}$) is calculated using the following equation:

$$TEP_{t,i} = PP_t * E_{min,i} \quad \text{Eq. 6.2}$$

The total amount of additional useful energy needed by the energy-poor population in year t for Tier i level would be expressed as:

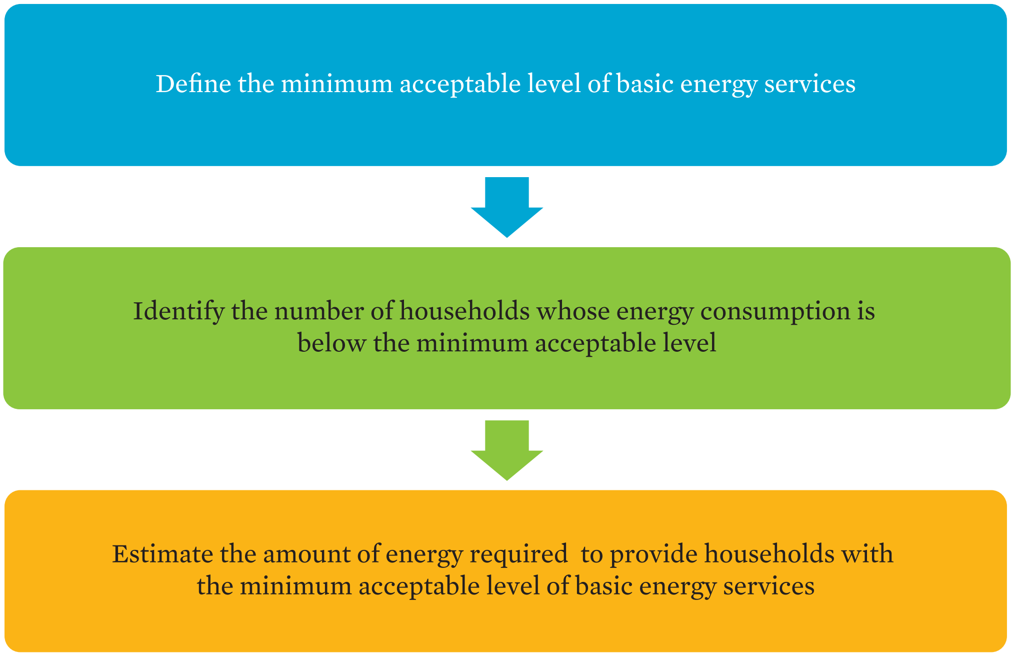
$$\Delta EP_{t,i} = PP_t * (E_{min,i} - EP_t) \quad \text{Eq. 6.3}$$

where,
ΔEP_t = Additional amount of average electricity needed by the energy-poor population
EP_t = Average amount of electricity being consumed in year t

The results of the household survey showed that most of the households lying in Tier 0 did not use electricity and were dependent on kerosene and pinewood stick[10] for lighting. The survey showed that households in two VDCs had an average electricity consumption of 0.6 kWh (Dhungegadi) and 0.01 kWh (Phopli) while the average electricity consumption of the other VDCs were above Tier 0.

[10] A pinewood stick with high resin content is found in high altitude. When burnt, it is smoky and provides minimal lighting (Zahnd 2013).

Figure 6.1: Steps in Estimating the Energy Demand of Energy-Poor Households



Source: Shrestha and Acharya (2015).

b. Electricity Demand of Non-Energy-Poor Households

The methodology used for projecting the demand of the non-energy-poor households is presented in Figure 6.2. The number of non-energy-poor households (i.e., the households whose electricity consumption level is equal to or above the minimum acceptable level) was estimated using the minimum acceptable energy requirement as the basis. As mentioned in Section 5.2.1.1, based on the GTF multitier concept, households whose electricity consumption is below Tier 1 (i.e., 3 kWh) were considered as energy-poor households in this study. The future electricity demand of the non-energy-poor households has been estimated using the following equation:

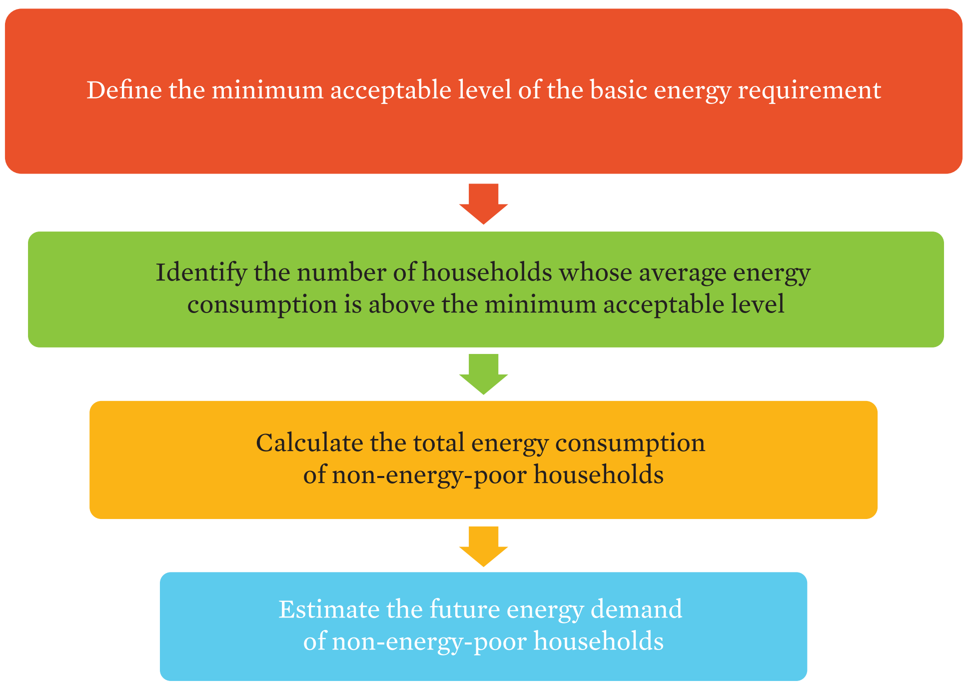
$$SD_{it} = SD_{i0} * \left(\frac{I_t}{I_0}\right)^{\alpha} * \left(\frac{HH_t}{HH_0}\right)^{\gamma} \qquad \text{Eq. 6.4}$$

where,
SD_{it} = demand for energy service i in year t
SD_{i0} = demand for energy service i in the base year
I_t = income per capita in year t
I_0 = income per capita in the base year
HH_t = total number of non-energy-poor households in year t
HH_0 = total number of non-energy-poor households in the base year

In Equation 6.4, the parameters α and γ represent the elasticities of energy service demand with respect to income and total population. In the absence of such elasticities in the context of Pyuthan, this study considered the values of α as 0.84 and γ as 1 based on Bekhet (2011). The average income of households in each VDC was obtained from the household's survey, and thus with the help of this information and the population data, the income per capita in the base year 2014 was estimated. However, the future income per capita in this study was projected to grow at an average growth rate of 3.56% (based on MoF 2014).[11]

There were 47,716 households in the district and it had a total population of 228,102 in 2011 (CBS 2014). The total number of households in the district grew at a compound annual growth rate (CAGR) of 1.73% while the total population grew at a CAGR of 0.71% during 2001–2011 (CBS 2014). The same growth rates have been considered in this study to project the future values of the total number of households and population in each VDC in this study. The estimated VDC-wise number of households is shown in Appendix 3, while Appendix 4 presents VDC-wise population.

Figure 6.2: Estimating the Energy Demand of Non-Energy-Poor Households



Source: Shrestha and Acharya (2015).

6.2.2 Demand Projection for Household Cooking

The future energy demands for household cooking in this study were estimated using the following equation:

[11] This is an average growth rate that was calculated based on the annual growth rates of per capita national income taken during fiscal years 2009–2010 and 2013–2014 (MoF 2014).

$$SD_{it} = SD_{i0} * \left(\frac{I_t}{I_0}\right)^{\alpha} * \left(\frac{HH_t}{HH_0}\right)^{\gamma} \qquad \text{Eq. 6.5}$$

where,
SD_{it} = energy service demand i in year t
SD_{i0} = energy service demand i in the base year
I_t = per capita income in year t
I_0 = per capita income in the base year
HH_t = Total number of households in year t
HH_0= Total number of households in the base year

The parameter α in Equation 6.5 represents the income elasticity while γ stands for the total population elasticity of energy service demand. The values of α considered were 0.45 (fuelwood), 0.84 (kerosene), 0.81 (LPG), and 0.89 (electricity) (Arthur et al. (2012). The value of γ considered was 1.04. The service demand in this study was calculated in terms of useful energy. However, in this study households were categorized in different groups or "tiers" based on their level of energy use and by the type of fuel and technology used. For instance, in this study, the households were categorized into different tiers on the basis of fuel and cooking device used as described by the multitier framework presented in Table 5.3 in Chapter 5.

To estimate the cooking energy demand, the average household energy consumption by fuel type was estimated from the sample household survey data for each individual VDC for 2014. The number of households using different types of fuel per end use in 2014 were estimated from the sample survey data. The average fuel consumption per household is multiplied with the total number of households to obtain the final energy consumption by fuel type and end use in each VDC in 2014. The energy consumption has been multiplied by the efficiency of the cookstoves to obtain the useful energy consumption in 2014. The types of technologies used in cooking and their energy efficiencies are discussed in Chapter 9. The amount of useful energy in 2017, 2022, and 2030 were estimated using Equation 6.5.

6.3 Household Energy Demand

This study estimated the energy demand of both the energy-poor and the non-energy-poor households in the district. To do this, the study used information on the household's average energy consumption, household population, and the household's average income categorized by income groups of both the energy-poor and non-energy-poor households based on the household survey. Secondary sources were used for information on the number of households.

6.3.1 Demand for Household Electricity Use

This section discusses the scenarios with alternative levels of electricity access in selected years till 2030 and estimates of household electricity demand under the different scenarios.

Description of Scenarios of Electricity Access

The base year of the study is 2014 and the household electricity demand was projected for three snapshot years, 2017, 2022, and 2030. For the purpose of demand projection of electricity use, four different cases were considered in this study:

(i) **Base case**. This represents the continuation of the present trend of electricity consumption in 2017, 2022, and 2030 (i.e., continuation of electricity consumption pattern with no electricity access program). In this case, the total electricity consumption of the non-energy-poor households is assumed to increase annually at an average of 4.8% during 2014 to 2030 while that of the energy-poor is assumed to grow at 1.7% during the same period. Electricity consumption of the energy-poor households with no electricity consumption in the base year was assumed to continue to remain the same in the base case. From the survey data, the households were categorized into different tiers according to their average level of electricity consumption. The same shares of electricity-poor and non-electricity-poor households were considered for future years in this study. The average electricity consumption per household of the non-electricity-poor households in each tier is assumed to grow at 3.0% annually during 2014–2030.

(ii) **Electricity access case 1** (ELA1). In this case, electricity consumption of all households is to reach at least Tier 1 in 2017, at least at Tier 2 in 2022 and at least at Tier 3 in 2030. The annual electricity consumption of each electricity-poor household was assumed to reach at least Tier 1 (i.e., at least 3 kWh) in 2017, at least Tier 2 (i.e., at 66 kWh) in 2022 and at least Tier 3 (i.e., at 285 kWh) in 2030. This means that in 2022, non-electricity-poor households whose consumption is less than 66 kWh but above 3 kWh are provided with the additional amount of electricity to reach at least the threshold level of Tier 2 (i.e., 66 kWh). Similarly, in 2030, electricity nonpoor households whose consumption is less than 285 kWh but above 66 kWh are provided with the additional amount of electricity to reach at least the threshold level of Tier 3 (i.e., 285 kWh).

(iii) **Electricity Access Case 2** (ELA2). In this case, electricity consumption of all households is to reach at least Tier 2 in 2017, at least at Tier 3 in 2022, and at least at Tier 4 in 2030. That is, the annual electricity consumption of each electricity-poor household is assumed to reach at least 66 kWh in 2017, at least 285 kWh in 2022 and at least 1464 kWh in 2030. In 2017, the electricity consumption of the non-electricity-poor households whose consumption is less than 66 kWh but above 3 kWh were provided with the additional amount of electricity to reach at least the threshold level of Tier 2 (i.e., 66 kWh). In 2022, the electricity consumption of the electricity nonpoor households whose consumption is less than 285 kWh but above 66 kWh have been provided with the additional amount of electricity to reach at least the threshold level of Tier 3 (i.e., 285 kWh). Similarly, in 2030, the electricity consumption of the electricity nonpoor households whose consumption is less than 1,464 kWh but above 285 kWh have been provided with the additional amount of electricity to reach at least the threshold level of Tier 3 (i.e., 1,464 kWh).

(iv) **Electricity Access Case 3** (ELA3). In this case electricity consumption of all households is to reach at least Tier 3 in 2017, at least Tier 4 in 2022 and at least Tier 5 in 2030. In this case, the electricity consumption of the electricity poor households has been assumed to reach at least Tier 3 (i.e., at least 285 kWh per household) in

2017, at least Tier 4 (i.e., at 1,464 kWh per household) in 2022 and at least Tier 5 (i.e., at 2,267 kWh per household) in 2030. In 2017, the electricity consumption of the electricity nonpoor households whose consumption is less than 285 kWh but above 66 kWh have been provided with the additional amount of electricity to reach at least the threshold level of Tier 3 (i.e., 285 kWh). In 2022, the electricity consumption of the electricity nonpoor households whose consumption is less than 1,464 kWh but above 285 kWh have been provided with the additional amount of electricity to reach at least the threshold level of Tier 4 (i.e., 1,464 kWh). Similarly, in 2030, the electricity consumption of the electricity nonpoor households whose consumption is less than 2,267 kWh but above 1,464 kWh have been provided with the additional amount of electricity to reach at least the threshold level of Tier 5 (i.e., 2,267 kWh).

Table 6.1 provides the description of different scenarios. For each snapshot year, four cases were considered. In 2017, in ELA1, the annual electricity consumption of all the households below Tier 1 was assumed to reach at least Tier 1, while that of the households with electricity consumption above Tier 1 was considered to be same as in 2017. In 2017, all households were assumed to consume electricity at least at Tier 2 in ELA2 while the assumption for ELA3 was at Tier 3. In 2022, in ELA1, the annual electricity consumption of all the households below Tier 2 was assumed to reach at least Tier 2, while that of the households with electricity consumption above Tier 2 was considered to be same. In 2022, all households were assumed to consume electricity at least at Tier 3 in ELA2 and at least at Tier 4 in ELA3. Similarly in ELA1, in 2030, the annual electricity consumption of all the households below Tier 3 was assumed to reach at least Tier 3, while those households with electricity consumption above Tier 3 was considered to be the same. In 2030, all households were assumed to consume electricity at least at Tier 4 in ELA2 and at least at Tier 5 in ELA3.

Table 6.1: Targeted Levels of Electricity Access in Selected Years under Different Scenarios

	Target level of electricity access in different cases[a]			
		Electricity Access Case		
Year	Base Case	ELA 1	ELA 2	ELA 3
2017	Projected levels based on the present consumption pattern, population, and GDP growth	Tier 1	Tier 2	Tier 3
2022		Tier 2	Tier 3	Tier 4
2030		Tier 3	Tier 4	Tier 5

ELA = energy access case, GDP = gross domestic product.

[a] The "tiers" here refer to the levels of electricity as reported in the Global Tracking Framework (WorldBank/ESMAP and IEA, 2013).

The base case scenario in this study considered the continuation of present pattern of electricity consumption in each VDC of the Pyuthan district as described in subsection 5.3.1.1. After obtaining the information on the number of households with electricity consumption above Tier 0 level, the non-electricity-poor households were further classified in different tiers based on their levels of electricity usage. Under the base case, the electricity consumption of the non-energy-poor households was assumed to grow in terms of income and number of households until 2030. The future electricity consumption of the non-electricity-poor households under the base case was estimated using Equation 6.4. The electricity demand of the electricity poor households in each electricity access case was estimated using Equations 6.2 and 6.3. The total electricity demand of non-electricity-poor households under different electricity access cases in year t ($ED_{Tier\ i,\ t}$) was estimated based on the following equation:

$$ED_{Tier\ i,t} = \left[(EPH)_{t,bc} + \left[(EPH)_{Tier\ i} - (EPH)_{t,bc}\right]\right] \times (No.of\ HHs)_{Tier\ i,t} \qquad \text{Eq. 6.6}$$

where,
$(EPH)_{t,bc}$ = Average electricity consumption per household in year t under the base case
$(EPH)_{Tier\ i}$ = Average electricity consumption per household in Tier i
$(No.\ of\ HHs)_{Tier\ i,t}$ = Number of households lying in Tier i in year t

It should be noted that the number of households in each Tier was estimated in the survey year (i.e., base year 2014) and was assumed to be the same in 2017, 2022, and 2030. Further, it should be noted that the electricity demand in this chapter was estimated considering the light emitting diode (LED) lamps as the technology for meeting the lighting demand. The study assumed that each unit of LED lamp is equivalent to 1 watt (World Bank/ESMAP and IEA 2013).

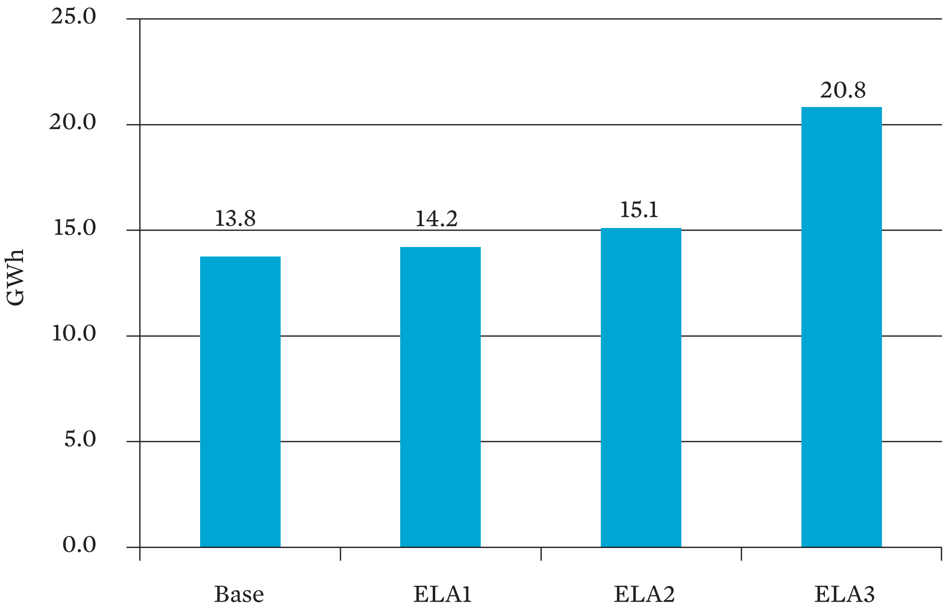
The distribution of households by the level of electricity consumption in the case of the Pyuthan district is presented in Figure 5.2 in Chapter 5 of this report, which shows that the electricity consumption of 20.3% of households in the district lies in Tier 0. In Figure 5.2, Tier 0 represents the electricity-poor households, while Tiers 1 to 5 represent the different categories of non-electricity-poor households. The percentage of households in each VDC lying under different electricity access tiers in 2014 is presented in Appendix 5.

Figures 6.3, 6.4, and 6.5 show the projected electricity demand for Pyuthan district under the base and electricity access cases for 2017, 2022, and 2030. The estimated electricity demand of the district in 2014 was 11,957 megawatt hours (MWh). Under the base case, the electricity demand would be 1.2 times in 2017, 1.5 times in 2022, and 2.1 times in 2030 as compared to the value in 2014.

In 2017, the electricity demand of the district has been estimated to be 1.0 times under ELA1, 1.1 times under ELA2, and 1.5 times under ELA3 as compared to the base case value in that year. In 2022, the electricity demand of the district has been estimated to be 1.1 times under ELA1, 1.4 times under ELA2, and 4.7 times under ELA3 as compared to the value in the base case in the year. Similarly, the electricity demand in 2030 has been estimated to be 1.3 times under ELA1, 3.7 times under ELA2, and 5.7 times under ELA3 as compared to its base case value in that year.

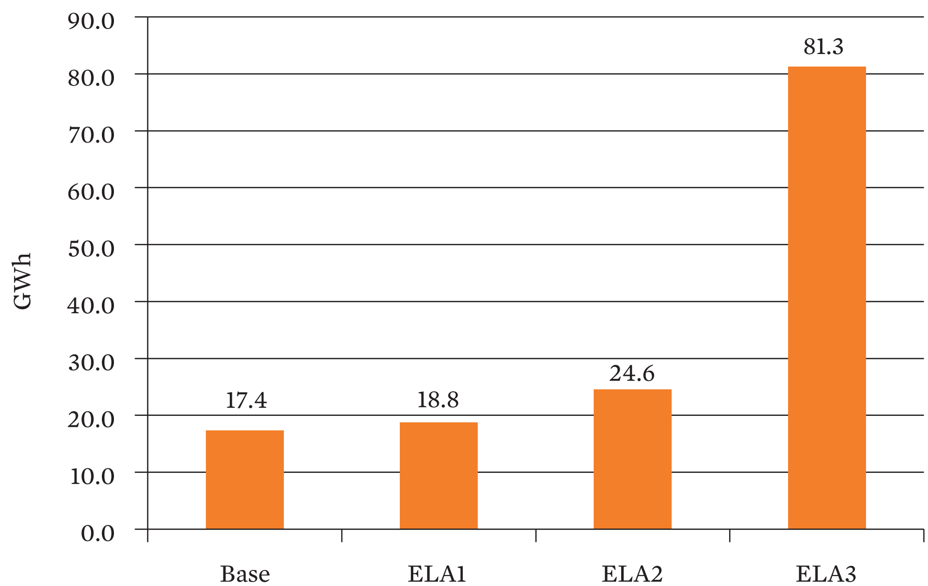
The VDC-wise estimation of electricity demand for all the 49 VDCs under the different scenarios for both the electricity-poor and non-electricity-poor households are presented in the Appendixes 6 to 9.

Figure 6.3: Projected Electricity Demand of Pyuthan District in 2017 under the Base and Electricity Access Cases



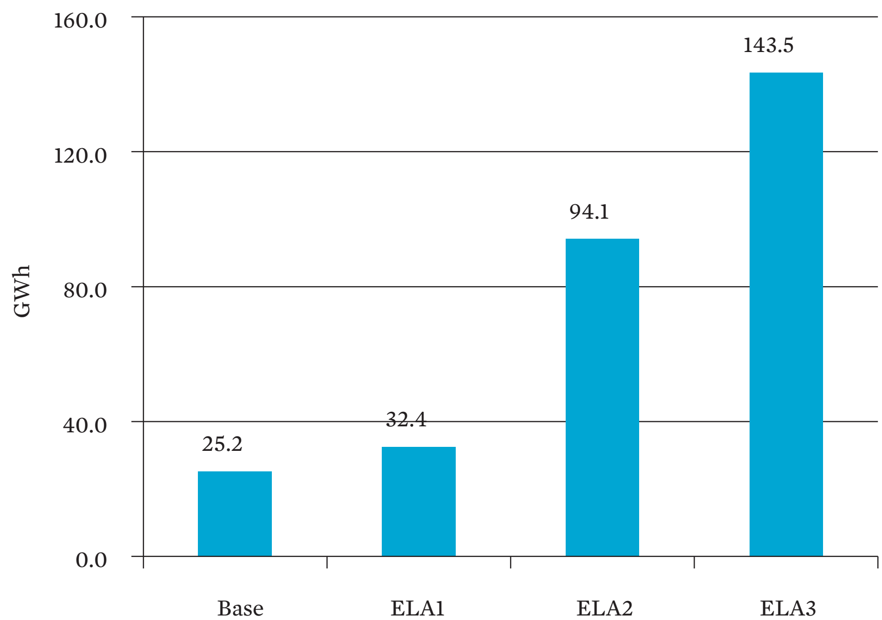
ELA = electricity access case, GWh = gigawatt hour.
Source: Authors.

Figure 6.4: Projected Electricity Demand of Pyuthan District in 2022 under the Base and Electricity Access Cases



ELA = electricity access case, GWh = gigawatt hour.
Source: Authors.

Figure 6.5: Projected Electricity Demand of Pyuthan District in 2030 under the Base and Electricity Access Cases



ELA = electricity access case, GWh = gigawatt hour.
Source: Authors.

6.3.2 Demand for Household Cooking

Table 6.2 presents the total energy consumption for all end uses of the district in 2014 and the selected future years. The total energy consumption of the district is assumed to increase at a CAGR of 3.2% during 2014 to 2030. The data showed that biomass (i.e., fuelwood and agricultural residue) would occupy the majority of the share in the total energy consumption of the district.

Table 6.2: Energy Consumption by Fuel Type under the Base Case (thousand kgoe)

Fuel Type	2014[a]	2017[b]	2022[b]	2030[b]
Agricultural Residue	2,666	2,949	3,488	4,564
Fuelwood	78,803	87,163	101,680	129,824
Biogas	138	158	199	289
LPG	240	276	347	502
Kerosene	528	609	771	1,125
Electricity	1,028	1,182	1,492	2,167
Candle and Pinewood Stick	54	60	71	93
Total	**83,457**	**92,397**	**108,049**	**138,564**

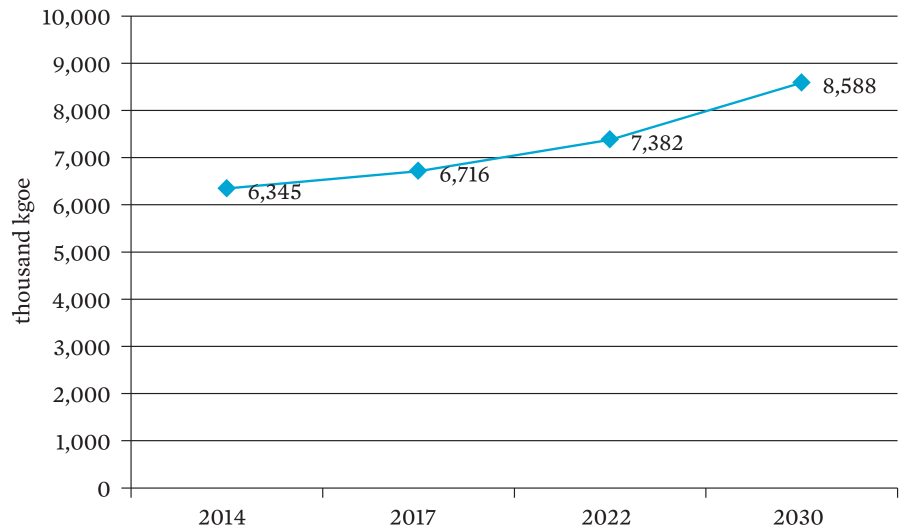
LPG = liquefied petroleum gas, kgoe = kilogram of oil equivalent.
[a] Values estimated based on field survey.
[b] Study estimates.
Source: Authors.

The cooking energy demand of each VDC in the district was estimated based on the average household energy consumption by fuel type as obtained from the household survey data. The structures of the final energy consumption by end use and fuel type for cooking in each VDC of the district based on the sample survey are presented in Appendixes 10 and 11.

Information on average energy consumption per household by fuel and technology type used for cooking in different VDCs of the district are presented in Appendix 12. The cooking energy service demand in this study is expressed in terms of useful energy consumption and was obtained by multiplying the cooking energy consumption by the efficiency of the cookstove used. The amounts of useful cooking energy consumption in 2017, 2022, and 2030 are obtained using Equation 6.5. The values of efficiency of the different types of cookstoves considered in this study are presented in Chapter 9.

Figure 6.6 presents the useful energy demand projection for cooking in the base case for the whole district. The cooking energy demand of Pyuthan district in the base case has been estimated to increase by 40% during 2014–2030. The estimated cooking energy demand by VDCs under the base case is presented in Appendix 13.

Figure 6.6: Cooking Energy Demand Projection for Pyuthan District under the Base Case (thousand kgoe)



kgoe = kilogram of oil equivalent.
Source: Authors.

6.4 Key Findings and Limitations

This study estimated the total energy demand of the households' consumptive use for each VDC of the district (which includes the estimation of energy service demands of both the energy-poor and non-energy-poor households). The base year of the study is 2014 and the household electricity and cooking energy demands were estimated for 3 snapshot years, 2017, 2022, and 2030.

For estimation of the demand for electricity use, four different cases (i.e., base case and three increasing electricity access cases) were considered in this study for each snapshot year.

The electricity access cases considered in the study adopted specific tiers of electricity use as stated in the Global Tracking Framework (GTF) report (World Bank/ESMAP and IEA 2013). The base case in this study refers to the case that considers continuation of the present electricity consumption pattern in the future years without an energy access program.

According to the GTF report, the households with the level of electricity consumption level below Tier 1 i.e., less than 3 kWh, are regarded as electricity poor households.

In this study, the three alternative cases of electricity access in the snapshot years consider the minimum level of electricity use per household to be the same as specified in Tiers 1, 2, and 3 of the GTF in 2017; similarly Tiers 2, 3, and 4 in 2022 and Tiers 3, 4, and 5 in 2030 are called “ELA1,” “ELA2,” and “ELA3”cases in each snapshot years.

The total electricity demand of the Pyuthan district in 2014 was estimated to be 11,957 MWh. Under the base case, i.e., in the absence of an energy access program, the total electricity demand of the district was estimated to grow by 1.2 times in 2017, 1.5 times in 2022, and 2.1 times in 2030 as compared to the base case consumption level in 2014.

In 2017, the electricity demand would be 13,750 MWh in the base case. In the electricity access cases, electricity demand would increase by 3.3% in ELA1, 9.9% in ELA2, and 51.5% in ELA3 cases. In 2022, the electricity demand was estimated to be 17,351 MWh in the base case and in the electricity access cases, the demand was estimated to increase by 8.3% in ELA1, 41.5% in ELA2, and 368.4% in ELA3 cases.

In 2030, the demand for electricity was estimated to be 25,186 MWh in the base case. In the electricity access cases, the demand would increase by 28.7% in ELA1, 273.7% in ELA2, and 469.8% in ELA3 cases in that year as compared to the base case.

The cooking energy demand in the district was estimated to be 6,345 thousand kgoe in 2014. The demand for cooking energy in the Pyuthan district was found to increase by 1.4 times during 2014–2030 under the base case.

Estimation of the total energy service demand of an area should normally include households’ consumptive and productive uses as well as energy used in the production sector and that for community services.

However, only the energy service demand for a consumptive use of both energy-poor and non-energy-poor households was assessed in the study. The productive use of energy by existing households was found insignificant from the household survey; hence, the demand assessment in the study did not include the productive use of energy of the households.

This is in fact a limitation of the study as productive use of energy (e.g., electricity demand) can be an important part of the energy demand (once households have access to electricity supply).

This study considered the electricity demand of both the energy-poor and the non-energy-poor households. The number of energy-poor households out of the total households in each VDC was estimated by considering the per household average annual electricity consumption of 3 kWh as the basic minimum energy requirement in the absence of such information specific to Nepal. This is another limitation of the study as there is no universally adopted value for basic minimum energy requirement level. As the basic energy needs varies among regions and countries based on the climate, physiography, socioeconomic, cultural, and other characteristics, knowledge of the country-specific threshold value is a prerequisite for a more realistic assessment.

7

Sustainability Analysis of Energy Access Programs

7.1 Introduction

The sustainability assessment evaluated the sustainability of energy resources and technology options to be considered for providing energy access in each village development committee (VDC) of the Pyuthan district. As such, the assessment considered multiple dimensions of the use of the options such as technical, economic, social, environmental, and institutional.

To reflect each of the dimensions, it was necessary to identify and use a number of relevant indicators and measure these indicators.

In the study, a number of options for electricity supply (i.e., grid extension, solar home system, biomass-based power plant, and microhydro power plant) were considered to find out the relative sustainability of different electricity supply options.

Similarly, this study assessed the sustainability of different combinations of cooking fuel and device options, i.e., moderately efficient improved cookstoves [MICS], highly efficient improved cookstove [HICS], liquefied petroleum gas [LPG], kerosene, biogas, electric, and solar cookstoves.

Two different approaches, one based on a multiattribute average scoring approach and the other based on the multiattribute utility approach, were used in this study to assess the sustainability of the electricity access options. In the case of cooking, this study adopted only the multiattribute average scoring approach to determine the relative sustainability of different options.

The next section presents the methodology used for assessing the sustainability of the electricity supply and cleaner cooking options in the present study. Section 7.3 describes the results of the sustainability assessment of electricity supply options while section 7.4 similarly describes the results in the case of cleaner cooking options. Section 7.5 presents the key findings and limitations of the sustainability assessment.

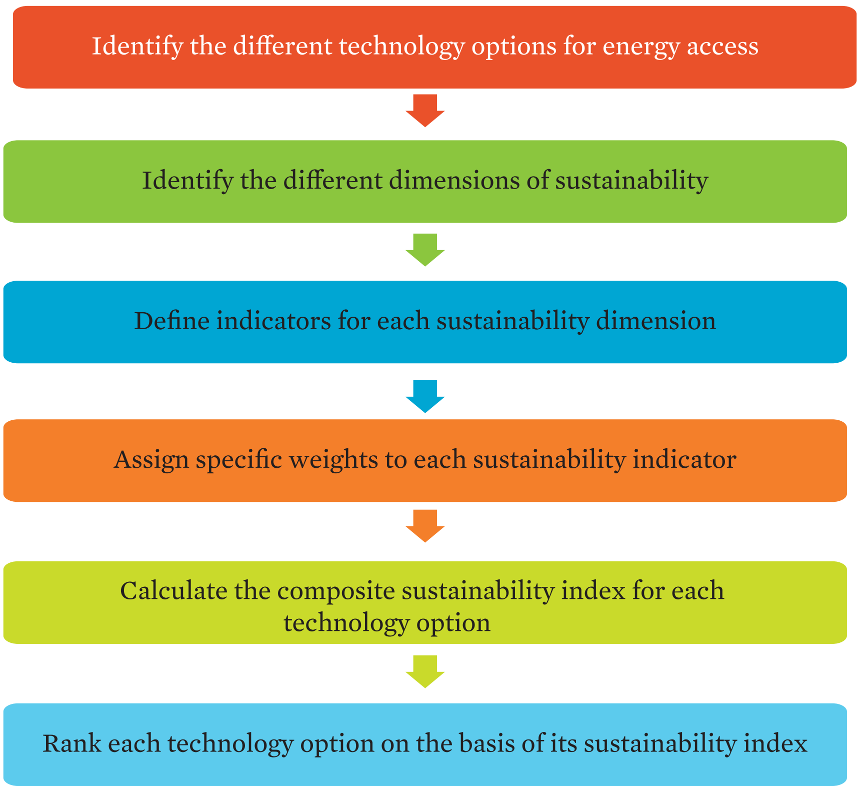
7.2 Methodology

As mentioned in the sustainable energy access planning (SEAP) framework, there are different approaches used in literature for obtaining the overall sustainability index of a technology or an energy access program. All the approaches used for assessing the sustainability of technology or an energy access program, however, involve the estimation of a composite index of sustainability. For details of different approaches, refer to “Chapter 8 Sustainability Assessment” of the SEAP framework (Shrestha and Acharya 2015).

This study has adopted the multiattribute averaging approach of Bhattacharyya (2012) for assessing the sustainability of the energy access programs of both electricity supply and cleaner cooking options. The present study has also used the multiattribute utility method of Maxim (2014) to assess the sustainability of different electricity supply options.

Figure 7.1 shows the major steps involved in the assessment of sustainability of energy access options in this study.

Figure 7.1: Overall Methodological Flowchart for Sustainability Analysis



Source: Shrestha and Acharya (2015).

This study considered four electricity supply options (i.e., grid extension, solar home system, biomass-based power plant, and microhydro power plant) for electricity access and seven sustainable cooking energy and/or technology options (i.e., MICS, HICS, LPG, kerosene, biogas, electric, and solar cookstoves) for sustainability analysis. The different dimensions considered in this study include the ones as mentioned in the SEAP framework such as technical, economic, social, environmental and organizational or institutional. The indicators used for evaluating the sustainability of each dimensions are based on Bhattacharyya (2012) and Maxim (2014).

This study conducted stakeholder surveys to assign specific weights to each indicator to obtain the composite sustainability index and rank the options in order to obtain the most sustainable energy access program or technology option.

The following section describes the methodology adopted in this study using the two different approaches, the multiattribute average scoring approach and the multiattribute utility method in detail.

7.2.1 Multiattribute Average Scoring Approach

As mentioned in the sections above, the sustainability analysis in this study uses multiattribute average scoring method, a framework suggested by Bhattacharyya (2012). Bhattacharyya (2012) considered five sustainability dimensions that include technical, economic, social, environmental, and institutional sustainability.

The technical sustainability deals with whether or not an energy access program can provide reliable and efficient source of clean and renewable energy to meet the present and future energy demand. It also takes into account the case of whether or not the program can meet the present and future needs with reliable and efficient supply of renewable energy; and provide support for maintainance and proper operation of the systems locally.

The economic sustainability deals with whether or not the energy supply option is economical and affordable at present as well as in the future.

Social sustainability deals with whether or not the technology, resource, or energy access programs are accepted by the users and easily accessible to make sure that it reduces human drudgery and improves the quality of life of women and children. Environmental sustainability is concerned with reduction of adverse environmental impacts on the people and community and takes into account pollution (both local and global) and environmental degradation. Institutional sustainability deals with local level management and control of energy supply under energy access programs.

Each of the five sustainability dimensions was defined with several indicators (Appendix 14). Each indicator has been scored on a scale of 1 (poorest) to 7 (highest). These scores were obtained through a questionnaire survey of different experts involved in the energy sector of Nepal.

The overall score is obtained by getting the average, and this value has been used for final ranking of the energy access programs. The option with the highest total score was considered the most sustainable and the one with the lowest total score was considered the least sustainable among the options considered.

7.2.2 Multiattribute Utility Method

The sustainability analysis of energy access programs using the multiattribute utility method follows the approach adopted by Maxim (2014). Unlike the multiattribute average scoring approach, the study conducted by Maxim (2014) considered only four sustainability dimensions: economical, technological, environmental, and socio-political sustainability. These dimensions were measured based on a set of 10 sustainability indicators presented in Appendix 15. A "utility value" was assigned to each indicator following Maxim (2014). The respondents were also asked to rate their familiarity related to the electricity supply options on a scale of 1 to 10 with 1 representing "not at all familiar" and 10 representing "very familiar".

Using the respondents' familiarity scores as weights, a weighted arithmetic average of the ratings for each indicator known as the "indicator weight" was calculated next. A utility score for each indicator was calculated next. The scores of each indicator were obtained through a questionnaire survey of experts involved in the energy sector.

The next step involved the calculation of the total utility score for a technology option which was obtained by multiplying the individual utility score of indicators and the corresponding indicator weights and then summing them up.

The energy technology option with the highest utility score was ranked to be the most sustainable among the selected electricity supply options (See Maxim [2014] for more details).

7.3 Sustainability Assessment of Electricity Supply Options

The following section presents the results of the sustainability analysis based on the Multiattribute Average Scoring Approach and Multiattribute Utility Approach.

7.3.1 Sustainability Assessment Using the Multiattribute Average Scoring Approach

As mentioned in Section 7.2 of this report, the sustainability analysis of the electricity supply options using the multiattribute average scoring method adopted a framework used by Bhattacharyya (2012). For its purpose, this study considered five sustainability dimensions: technical, economic, social, environmental, and institutional sustainability. Each of the five sustainability dimensions was defined with several indicators. The indicators were rated on a scale of 1 (poorest) to 7 (highest). As mentioned in subsection 7.2.1, these scores were obtained through a questionnaire survey of different experts involved in the energy sector of Nepal.

The overall score is obtained by a simple averaging method and this average value was used for final ranking of the energy access programs. The option that obtained the highest score is assumed to be the most sustainable and the one with the lowest score is assumed to be the least sustainable.

Table 7.1 presents the detailed scores for each indicator under different dimensions obtained through the expert questionnaire survey while Figure 7.2 presents the comparison of different electricity supply options according to the average scores obtained for each dimension.

In this analysis, biogas—which can be used both for lighting and cooking options—has only been included under alternatives for providing cooking solution. As diesel is not a cleaner fuel for producing electricity, this study did not consider diesel-based power generation option for providing electricity supply in the district.

As can be seen in Table 7.1, grid extension seemed to be the most preferred alternative for providing electricity in Pyuthan receiving a total score of 152.8, followed by microhydro, solar home system, and biomass-based power generation. In terms of technical, economic, social, and environmental dimensions, grid extension was found to be more sustainable in comparison to other electricity generation options that have been considered.

However, in terms of institutional dimension, electricity generation based on microhydro plant was found to be more sustainable (Figure 7.2).

Table 7.1: Detailed Scores of the Sustainability Analysis using Multiattribute Average Scoring Approach for Electricity Supply Options

		Electricity Supply Options[b]			
Dimension	**Indicator[a]**	**Grid Extension**	**SHS Off-grid**	**Biomass Power Plant**	**Microhydro**
Technical	Ability to respond to peak demand	6.9	3.0	3.7	5.0
	Ability to meet present and future domestic needs	6.7	3.8	3.7	4.5
	Ability to meet present and future productive needs	6.7	2.9	3.7	5.0
	Reliability of supply	6.0	4.7	4.4	4.8
	Reliance on clean energy sources	6.1	5.7	4.7	6.0
	Technical efficiency	3.0	2.0	2.0	4.0
	Reliance on local resources	4.9	5.5	5.6	6.0
	Availability of support services	5.5	4.6	4.4	5.4
Subtotal		**45.8**	**32.2**	**32.2**	**40.7**
Economic	Cost-effectiveness	5.1	4.1	3.8	4.8
	Cost recovery potential	5.1	3.9	3.9	4.4
	Capital cost burden on the user	4.4	4.0	3.9	3.9
	Running cost burden on the user	4.4	3.0	3.4	3.7
	Financial support needs	3.7	4.1	3.8	4.1
	Contribution to income generating opportunities	5.8	3.2	3.7	4.4
Subtotal		**28.5**	**22.3**	**22.5**	**25.3**
Social	Wider usability amongst the poor	4.6	4.6	3.0	4.7
	Need financial support system	3.9	4.3	4.3	4.5
	Potential to reduce human drudgery	4.9	4.2	3.8	4.5
	Potential to reduce adverse effects on women and children	5.0	4.4	3.9	4.3
	Job-years of full time employment created over the entire lifecycle of the unit	4.7	3.7	3.9	4.6
	Risk of supply shock incidence due to fuel imports	4.6	4.4	4.5	4.7
	External costs related to human health	4.0	3.9	3.9	3.7
Subtotal		**31.7**	**29.5**	**27.3**	**31.0**

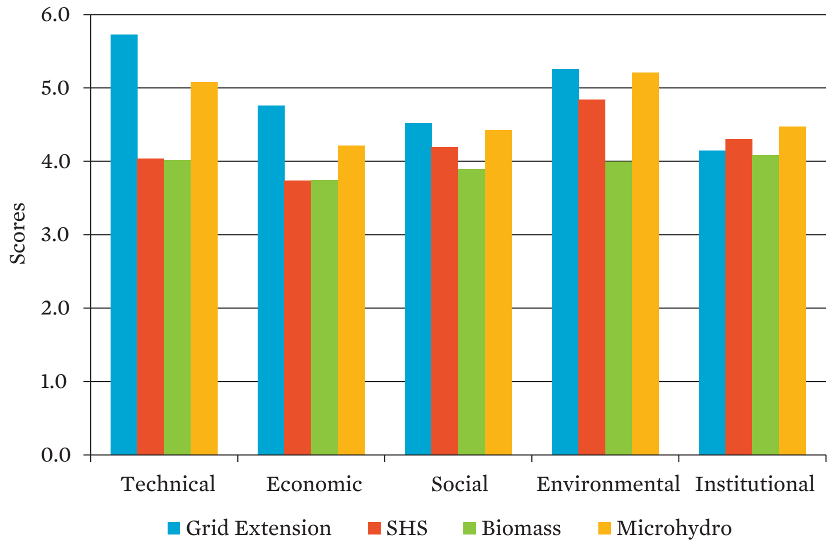
continued on next page

Table 7.1 *continued*

Dimension	Indicator[a]	Electricity Supply Options[b] Grid Extension	SHS Off-grid	Biomass Power Plant	Microhydro
Environmental	Contribution to reduction in carbon emissions	6.0	5.7	4.2	6.1
	Contribution to reduction in indoor pollution	5.8	5.5	4.3	5.6
	Contribution to reductions in land degradation	4.8	4.6	3.9	4.9
	Contribution to reduction in water pollution	4.7	4.4	3.7	4.9
	Cost generated over the entire lifecycle (environmental costs)	4.9	4.0	3.8	4.5
Subtotal		**26.2**	**24.2**	**19.9**	**26.0**
Institutional	Degree of local ownership	3.0	5.0	4.5	5.4
	Need for skilled staff	4.3	4.4	4.5	4.7
	Ability to protect consumers	4.1	3.9	3.6	4.0
	Ability to protect investors	4.5	3.8	3.6	3.8
	Ability to monitor and control systems	4.7	4.4	4.2	4.5
Subtotal		**20.6**	**21.5**	**20.4**	**22.4**
Total Score		**152.8**	**129.7**	**122.3**	**145.4**

SHS = solar home system.
Source: [a] The types of indicators listed here are based on Bhattacharyya (2012) and Maxim (2014); [b] Detailed scores are obtained from experts' survey.

Figure 7.2: Sustainability Comparison of Alternative Electricity Access Options using Multiattribute Average Scoring Approach



SHS = solar home system.
Source: Authors.

7.3.2 Sustainability Assessment Using the Multiattribute Utility Approach

Unlike the multiattribute average scoring approach, this approach considers only four sustainability dimensions: economic, technical, environment, and social.

Different indicators were used to characterize each of the sustainability dimensions, which was applied to four electricity generation technology options. This was done to identify the most sustainable power generation option for providing electricity access.

Table 7.2 presents the average importance scores for each indicator under the four different dimensions calculated based on the scores obtained through a survey of 18 respondents.

As mentioned in subsection 7.2.2, the respondents were asked to rate the indicator for each technology on a scale of 1 to 10.

The average scores in Table 7.2 shows that none of the technology could score 10 out of 10, indicating their weaknesses in certain areas. The respondents were first asked to evaluate their own level of understanding about the matters related to the electricity sector on a scale of 1 to 10, and the scores thus obtained were named as "familiarity scores" (i.e., 1 indicates "not at all familiar" and 10 indicates "very familiar"). The familiarity scores obtained from the respondents varied from 7 to 10 in this study.

These familiarity scores were used to calculate the weighted arithmetic average of the importance ratings for each indicator. Table 7.3 presents the sustainability indicator weights that have been calculated using the familiarity scores obtained from the survey.

Table 7.2: Average Importance Scores Obtained from the Experts Survey

		Technology[b]			
Dimensions	**Indicators[a]**	**Hydro (large)[c]**	**Microhydro**	**Biomass**	**Solar PV**
Economic	Levelized cost of electricity	7	6	5	6
Technical	Ability to respond to demand	8	6	5	5
	Efficiency	8	7	5	5
	Capacity factor	7	7	5	6
Environmental	Land use	7	7	5	5
	External costs (environmental)	6	6	6	5
Social	External costs (human health)	6	6	6	6
	Job creation	8	7	5	4
	Social acceptability	8	8	6	6
	External supply risk	7	7	6	6

PV = photovoltaic.

[c] Large hydro refers to grid supply in this study.

Source: [a] Indicators are based on Maxim (2014); [b] Average scores obtained from the experts' survey.

Table 7.3: Weightage of Sustainability Indicators Based on a Survey of Experts

Dimension	Indicator[a]	Weights[b]
Economic	Levelized cost of electricity	0.098
Technical	Ability to respond to demand	0.101
	Efficiency	0.105
	Capacity factor	0.102
Environmental	Land use	0.095
	External costs (environmental)	0.092
Social	External costs (human health)	0.094
	Job creation	0.100
	Social acceptability	0.112
	External supply risk	0.102

Source: [a] Maxim (2014); [b] The weights for the indicators in this study were obtained from a survey of experts conducted in Nepal in 2014 as a part of the present study.

The importance ratings thus obtained from the survey were normalized and averaged to calculate the weights assigned to the ten sustainability indicators. The average values were then converted into weights so that $\sum Wi = 1$, where $i = 1$ to 10. The detailed steps used in calculating the importance scores and weights in this study is presented in Appendix 16.

Four electricity generation technologies were ranked by the multiattribute utility method for value normalization, based on Maxim (2014), and combined with a weighted sum approach to evaluate the aggregate scores. For each of the 10 indicators selected, the value normalization technique was used in this analysis to calculate utility value.

The calculated normalized value was on a scale of 0 to 1. Some of the indicators directly correlate with the electricity generation utility (e.g., job creation, efficiency, capacity factor, etc.) and others are inversely correlated with the electricity generation utility (e.g., land use, levelized cost of electricity, etc.).

Table 7.4 shows the indicator value for each electricity supply technology based on Maxim (2014). The total scores provide the ranking of different electricity generation options on the basis of their compatibility with sustainable development. Figure 7.3 shows the total aggregated score of the four electricity supply options considered for the district using the multiattribute utility approach for Pyuthan.

As Figure 7.3 shows, electricity generation based on large hydroelectric plants is ranked significantly higher compared to other three options in terms of overall sustainability. The next relatively most sustainable technologies include solar photovoltaic, and microhydro.

The biomass-based electricity generation option was found to be the least sustainable technology. In terms of economic, technical, environmental, and social dimensions, large hydropower[12] generation technology was found to be more sustainable in comparison to other

[12] Since the electricity generation of the national power grid is dominated by medium sized hydropower plants, large hydro here refers to grid supply.

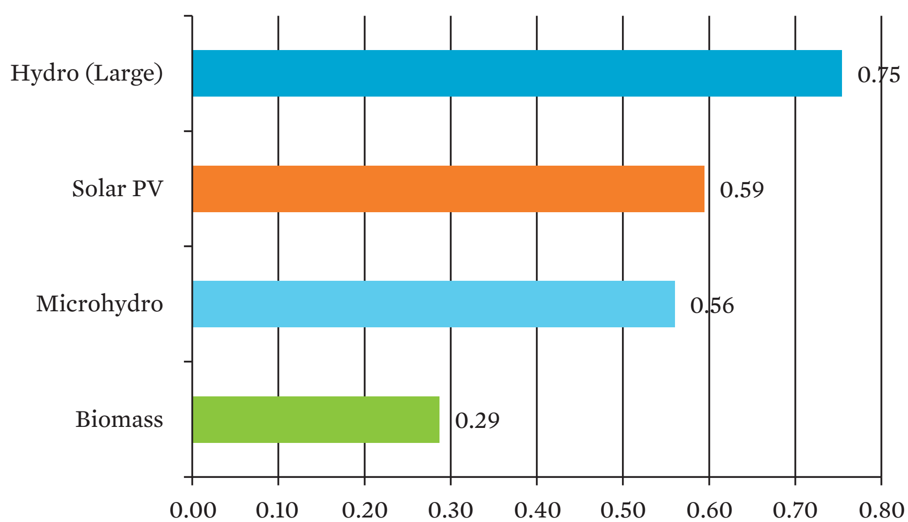
considered options. Even though power generation based on microhydro and large hydro were given the same scores for the environmental dimension, the microhydro technology was considered less sustainable economically, technically, and socially.

Table 7.4: Parameters Considered for Electric Supply Technology

	Electricity Generation Technology			
Indicator	**Hydro (Large)**	**Microhydro**	**Biomass**	**Solar PV**
Levelized cost of electricity at 10% discount rate ($/MWh)	46.66	237.55	97.10	301.89
Ability to respond to demand	Yes, rapid	No	Yes, slow	No
Efficiency ratings (%)	100	100	35	100
Capacity factors	54	50	70	20
Land use (m^2/MWh)	4.10	0.02	12.65	0.33
External costs associated with the environment (€c/kWh)	0.330	0.010	0.750	0.162
External costs associated with the health (€c/kWh)	0.670	0.670	4.250	0.438
Number of employees per unit of electricity produced (job-years/GWh)	0.55	0.27	0.21	0.87
Social acceptability levels	High	High	Medium	High
External supply risk	0	0	0	0

kWh = kilowatt hour, GWh = gigawatt hour, m^2 = meter squared, MWh = megawatt hour, PV = photovoltaic.
Note: €1 = NRs120.62
Sources: Maxim (2014).

Figure 7.3: Energy Sustainability Index of Electricity Generation Technologies



PV = photovoltaic.
Source: Authors.

7.4 Sustainability Assessment of Cleaner Cooking Options

The sustainability assessment of cleaner cooking energy access includes seven options, i.e., MICS, HICS, LPG, kerosene, biogas, electric and solar cookstoves. The assessment followed the multiattribute average scoring approach used by Bhattacharyya (2012) as discussed in this chapter. Like in the assessment of the electricity supply options, the assessment of cleaner cooking options considered five dimensions of sustainability. Each of these sustainability dimensions is defined through relevant indicators. The indicators have been scored individually on a scale of 1 (poorest) to 7 (highest).

These scores have been obtained through a questionnaire survey of several experts involved in the energy sector of Nepal. The overall score was estimated by simple averaging method and this average value has been used for the final ranking of the cleaner cooking options. The option obtaining the highest total score is assumed to be the most sustainable and the one with the lowest total score is assumed to be the least sustainable.

Table 7.5 shows the detailed scores of each indicator under each dimension for the different cooking options considered in this analysis obtained through the experts' questionnaire survey. Figure 7.4 shows the comparison of average scores of each sustainability dimensions for each type of cleaner cooking options. Among the cooking energy options considered, it was found that the electric cooking option was the most sustainable; this is followed by solar cooker, HICS, MICS, LPG, and biogas based cooking in terms of sustainability ranking. Thus, the biogas based cooking energy option is ranked as the least sustainable among the options considered.

Note that electric cooking was found to be more sustainable than the other clean cooking options when considering the technical, economic, social, and environmental dimensions. However, cooking based on MICS has been found to be most sustainable from the institutional dimension.

Table 7.5: Detailed Scores of Different Dimensions of Sustainability of Cleaner Cooking Options

		Cooking Options[b]					
Dimension	**Indicator[a]**	**MICS**	**HICS**	**LPG**	**Biogas**	**Electric**	**Solar**
Technical	Ability to respond to peak demand	2.7	2.8	3.5	2.8	3.2	3.3
	Ability to meet present and future domestic needs	4.0	4.6	5.0	4.0	4.8	5.3
	Ability to meet present and future productive needs	3.0	3.2	3.8	3.0	3.5	5.0
	Reliability of supply	4.0	4.5	4.5	3.5	5.0	5.1
	Reliance on clean energy sources	3.7	4.1	3.7	3.0	5.2	5.9
	Technical efficiency	4.0	5.0	5.0	4.0	6.0	2.0
	Reliance on local resources	4.8	4.8	1.8	1.7	5.4	4.5
	Availability of support services	4.6	4.3	3.8	3.6	4.8	4.6
Subtotal		**30.8**	**33.3**	**31.1**	**25.6**	**37.9**	**35.7**

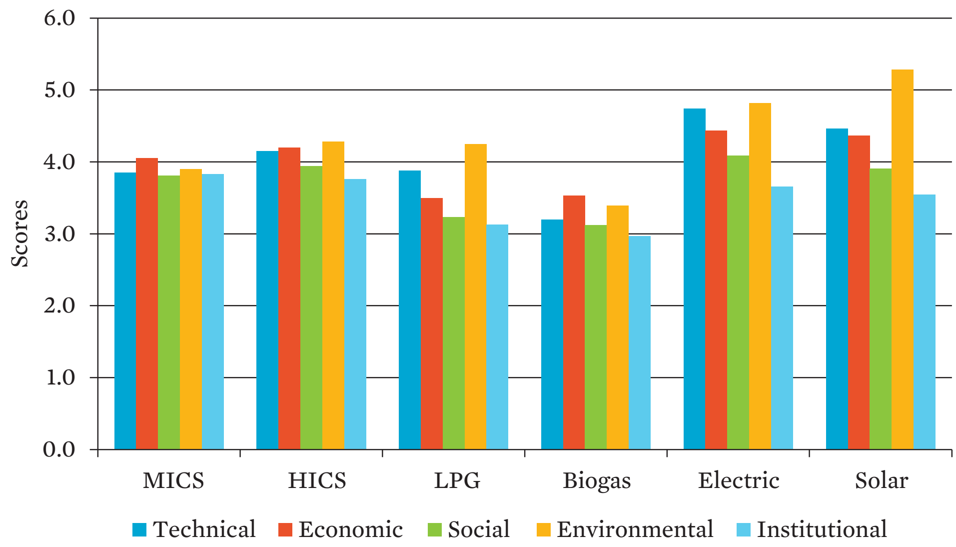
continued on next page

Table 7.5 *continued*

Dimension	Indicator[a]	Cooking Options[b]					
		MICS	HICS	LPG	Biogas	Electric	Solar
Economic	Cost-effectiveness	5.2	5.0	3.2	3.0	5.0	4.6
	Cost recovery potential	4.4	4.4	3.1	2.9	4.9	4.5
	Capital cost burden on the user	4.5	4.6	4.2	4.2	4.2	4.2
	Running cost burden on the user	4.4	4.5	3.9	4.3	4.2	4.3
	Financial support needs	3.8	4.1	3.8	4.2	4.6	4.1
	Contribution to income generating opportunities	2.1	2.5	2.8	2.6	3.6	4.5
Subtotal		**24.4**	**25.1**	**21.0**	**21.2**	**26.5**	**26.2**
Social	Wider usability amongst the poor	5.7	4.8	2.6	3.1	4.0	3.4
	Need financial support system	3.9	4.0	3.3	2.9	4.0	3.4
	Potential to reduce human drudgery	3.4	4.0	4.0	3.7	4.4	4.4
	Potential to reduce adverse effects on women and children	3.7	4.4	4.9	4.2	5.1	5.2
	Job-years of full time employment created over the entire lifecycle of the unit	2.5	2.7	2.4	1.9	2.8	3.0
	Risk of supply shock incidence due to fuel imports	4.0	4.0	2.3	2.4	4.4	4.3
	External costs related to human health	3.5	3.7	3.1	3.5	4.0	3.7
Subtotal		**26.7**	**27.6**	**22.6**	**21.7**	**28.7**	**27.4**
Environmental	Contribution to reduction in carbon emissions	3.8	4.4	3.7	2.9	5.5	6.1
	Contribution to reduction in indoor pollution	3.8	4.6	5.1	3.5	5.6	6.3
	Contribution to reductions in land degradation	4.2	4.4	4.8	4.0	4.7	5.2
	Contribution to reduction in water pollution	3.7	3.7	3.9	3.4	3.8	4.3
	Cost generated over the entire lifecycle (environmental costs)	4.0	4.4	3.8	3.2	4.4	4.5
Subtotal		**19.5**	**21.5**	**21.3**	**17.0**	**24.0**	**26.4**
Institutional	Degree of local ownership	5.0	4.7	3.5	3.3	4.3	3.6
	Need for skilled staff	4.2	4.1	3.3	3.2	4.1	4.2
	Ability to protect consumers	3.2	3.3	2.8	2.5	3.3	3.3
	Ability to protect investors	3.3	3.3	2.9	2.7	3.3	3.2
	Ability to monitor and control systems	3.5	3.4	3.1	3.1	3.4	3.4
Subtotal		**19.2**	**18.8**	**15.6**	**14.8**	**18.4**	**17.7**
Total Score		**120.6**	**126.3**	**111.6**	**100.3**	**135.5**	**133.4**

HICS = highly efficient cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient cookstove.
Source: [a] Types of indicators listed here are based on Bhattacharyya (2012); [b] Detailed scores are obtained from the experts survey.

Figure 7.4: Sustainability Comparison of Alternative Cooking Access Options



HICS = highly efficient cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient cookstove.
Source: Authors.

7.5 Key Findings and Limitations

The sustainability assessment of an energy access program in Pyuthan district was conducted using two different approaches, the multiattribute average scoring approach and the multiattribute utility approach. The electricity access technology options considered in this study include grid connection (or large hydro in multiattribute utility method), solar home system (SHS), biomass-based power generation, and microhydro.

Similarly, the different cleaner cooking technology options considered in the study include MICS, HICS, LPG, biogas, electric, and solar cookstoves. Using the multiattribute average scoring approach, grid extension was found to be the most preferred alternative for providing electricity access in Pyuthan, followed by microhydro, SHS, and biomass-based power generation option in descending order.

While using the multiattribute utility method, large hydro-based power generation technology was found to be the most sustainable, followed by solar photovoltaic, microhydro, and biomass-based power generation options.

Some differences in the ranking of the electricity supply technology options based on the two approaches were observed.

In the case of sustainability analysis of cleaner cooking options using the multiattribute average scoring approach, the electric cooker was found to be the most sustainable option. This is followed by solar cooker, HICS, MICS, LPG, and biogas cookstoves in a descending order.

Assessing the sustainability of energy access options or technologies involves identification of different dimensions and its associated indicators. In the multiattribute utility method used for sustainability analysis, the characteristics of electricity supply options in this study such as levelized cost of electricity, land use, external cost associated with health, and employment per unit of electricity generated were considered to be the same as that given in Maxim (2014). However, such parameters should be country-specific in order to increase the accuracy of sustainability analysis.

Further, the sustainability analysis in this study solely depended upon the expert opinion obtained through the questionnaire survey in the multiattribute average scoring approach unlike the multiattribute utility approach which considers the technical characteristics of the electricity supply options as well.

Cost Assessment and Technology Choice for Electricity Access

8

8.1 Introduction

The main objectives of the cost assessment are to identify the least cost options for providing universal electricity access in each village development committee (VDC) of Pyuthan district and to estimate the costs associated with the options including investment requirements.

The assessment also determined the power generation capacity of the least cost options involved in meeting the electricity demand in selected years and the levels of electricity generation by each of them. Furthermore, it estimated the incremental costs of providing different levels of universal access to electricity supply and utilization.

This chapter is subdivided into five sections. Section 8.2 discusses the methodology used in this study. Section 8.3 presents the technical characteristics and costs of different electricity supply options considered to provide electricity access. Section 8.4 details the capacity requirement and the costs of providing electricity access in the district. Section 8.5 summarizes the key findings and discusses the limitations of the study.

8.2 Methodology

The cost assessment is used to determine the least cost electricity supply and demand side options under different universal electricity access programs each with a target for the minimum level of electricity consumption per household.

The assessment involves an estimation of the total costs of electricity supply with and without a universal electricity access program in Pyuthan. The total cost of the electricity access program is thus the difference between the two total costs. The total cost in this study refers to both the supply and demand side costs associated with providing electricity access in a particular period.

As mentioned in the SEAP framework, a cost minimization model is required to determine the most cost-effective electricity access program. Several models exist in the literature for determining the least cost options for energy system planning and analysis (Shrestha and Acharya 2015).

The modeling framework varies in terms of planning horizon: some models provide an optimal supply technology mix and costs for a snapshot year while others do so for a number of years in a planning period. There are models that consider the diurnal and seasonal variations in the availability of energy resources. Some models even consider the seasonal variations in demand while the others do not. Many of the cost assessment tools used for electricity planning provide the optimum cost of electricity in terms of supply side options. Generally, such planning models do not consider the demand side (or end use) technologies.

However, to determine the least cost approach for energy access, an integrated cost assessment model would be necessary. Further, the model should be capable of considering both the decentralized as well as centralized electricity supply options (Shrestha and Acharya 2015).

In the present study, the total cost of providing universal access to electricity at the district level was estimated using a spatially decentralized bottom up approach involving two steps: In the first step, an estimation of the total minimum cost providing electricity access in each VDC of the district considering both the decentralized energy resource options available in the respective VDC and the centralized grid-based supply option was carried out.

In the second stage, all the individual level total costs are summed up to estimate the total cost at the district level. Figure 8.1 shows the overall methodological framework for cost assessment.

The Hybrid Optimization of Multiple Energy Resources (HOMER) model, has been used in this study. The HOMER model is an optimization tool that minimizes the total discounted cost and considers both the off-grid and grid connected electricity supply options (HOMER Energy and NREL 2011 and Lilienthal 2005). The model requires inputs such as the daily and monthly load profile, amount of energy resources available as well as the costs and technology characteristics of different electricity supply options. The approach used for calculating the load profile in this study is presented in Appendix 17.

The assessment of the cost of an electricity access program requires data on the costs of investment, fuel, and operation and maintenance (O&M) of different technology and resource options in the supply side, as well as the upfront and O&M costs of devices in the demand side. The electricity cost assessment model would estimate the cost of electricity supply system comprising of the total supply side investment requirements, operating costs, and fuel cost.

The cost assessment model also provides information on the mix of electricity generation and generating capacity by the type of technology and energy resource.

The assessment of the costs at a VDC level considered different supply side options, i.e., solar home system, biomass gasification plant, grid extension, and microhydro plant (wherever available).

The base case in this study represents the continuation of the electricity consumption pattern without a universal electricity access program and assesses for levels of electricity consumption considering such a pattern in 2017, 2022, and 2030. In the base case, the total electricity consumption of the non-electricity-poor households is assumed to grow at the compound annual growth rate of 4.8% during 2014–2030 while that of the electricity-poor households (i.e., households with no electricity consumption in the year 2014) is assumed to grow at 1.7% during the same period. Electricity-poor households are assumed to continue using kerosene, pinewood sticks, and candles for the purpose of lighting in the future years in the base case.

The total demand for electricity at a VDC level is derived as the sum of the demand for electricity of both the electricity-poor and non-electricity-poor households. The non-electricity-poor households occupies almost 100% of the share in the total electricity demand in 2014. The electricity-poor households have a negligible share in the total electricity demand in 2014.

Lighting demand of the non-electricity-poor households alone accounted for around 70% of the total electricity demand of the non-electricity-poor households in the base case, while the remaining demand was that of electrical appliances.

It should be noted that there was a mixture of different lighting technologies used: incandescent, fluorescent, light-emitting diode (LED), and compact fluorescent lamp (CFL) in 2014. The base case in this study assumed the same usage pattern of the lamps to continue in the three future years as well.

Apart from the base case, this study considered three universal electricity access scenarios: electricity access case 1 (ELA1), ELA2, and ELA3 in 2017, 2022, and 2030. The details of these scenarios are presented in Section 6.3.1. The minimum level of electricity consumption per household and corresponding electricity access tier in the selected years under each scenario are presented in Table 8.1.

Table 8.1: Minimum Annual Level of Electricity Consumption per Household in Selected Years under Different Universal Electricity Access Scenarios

Electricity Access Scenario	2017 (kWh)	2022 (kWh)	2030 (kWh)
ELA1	3 (Tier 1)	66 (Tier 2)	285 (Tier 3)
ELA2	66 (Tier 2)	285 (Tier 3)	1,464 (Tier 4)
ELA3	285 (Tier 3)	1,464 (Tier 4)	2,267 (Tier 5)

ELA = electricity access case.
Note: The electricity access tier corresponding to the minimum annual electricity consumption per household considered in this study is stated inside the parentheses.
Source: Authors.

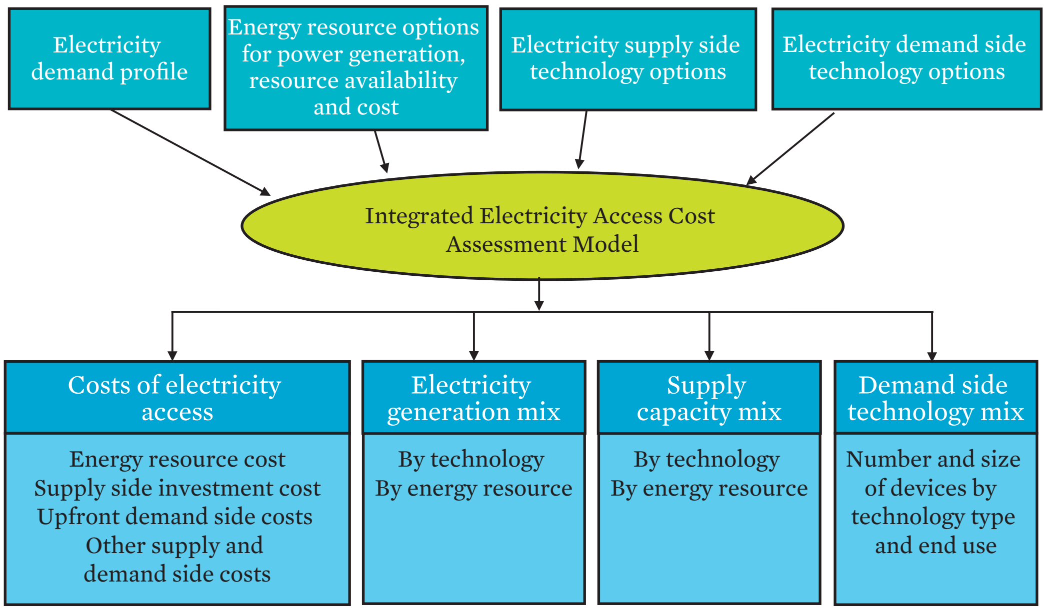
To illustrate the role of demand side technologies in the development of an electricity access program, this study has considered the effect of using three alternative lamp technologies for lighting, i.e., LED, CFL, and incandescent lamp in each case.

In doing so, the total electricity demand for lighting in each case is varied with the type of lamp considered, while electricity demand for all other end uses defined for the respective case would remain unchanged. The share of lighting in the total electricity demand was estimated to be about 52% under ELA1, 42% under ELA2, and 10% under ELA3 in 2017. In 2022, the shares of lighting in the total electricity demand under ELA1 was estimated at around 42%, 10% under ELA2, and 2% under ELA3. For 2030, ELA1 is at 10%, ELA2 is at 2%, and ELA3 is at 1%. The levels of electricity demand associated with the base case and different electricity access scenarios are discussed in Chapter 6.[13]

This study assesses the cost of the three alternative levels of universal access programs (or cases) i.e., ELA1, ELA2, and ELA3, if they were to start their operation in one of the three selected years, i.e., 2017, 2022, and 2030.

[13] In estimating the electricity demand with alternative lighting technologies under different electricity access scenarios, it was assumed that the luminous efficiency of LED lamp is 100 lumens per watt whereas the light output of a 1 Watt LED lamp is equivalent to that of a 2.4 Watt CFL and similarly to that of a 8 Watt incandescent lamp.

Figure 8.1: Overall Methodological Framework for Cost Assessment



Source: Shrestha and Acharya (2015).

Note that the capacity mix, generation mix, and the costs have been determined for the three alternative universal access programs to be started in each of these years (i.e., 2017, 2022, and 2030). Also note that the present study has estimated the costs, generation capacity, and the level of annual electricity generation with the assumption that the total electricity demand in each of the electricity access cases would remain constant throughout the life of the electricity supply system (assumed to be 25 years).

8.3 Electricity Supply Options: Technical Characteristics and Costs

The minimum cost of supplying electricity at the VDC level in this study is obtained by considering different electricity supply options that included solar home system, biomass gasification plant, grid extension and, if available, microhydro plant from the cost assessment model. The technical characteristics and costs of different electricity supply options considered in this study are described in the following section.

8.3.1 Generation Technology Options and Costs

Microhydro Plants

This study considered the sites of microhydro plants in the district as identified by the feasibility study carried out by Nepal's Rural Energy Development Programme Nepal.

Due to the lack of specific cost data in Pyuthan, the study used the average values of the costs of generation and operation and maintenance (O&M) of the microhydro plants operating in the neighboring districts (Dailekh and Rolpa) as the costs of the microhydro plants to be constructed in Pyuthan district.

The minimum discharge of the microhydro plants was based on the District Energy Situation Report of Pyuthan (DDC 2012). The monthly patterns of discharge were considered to be similar to that of other similar microhydro plants such as that of Gudugad and Bajura kholas located in Bajura; and Teliya khola located in Dhankuta districts.

In the absence of load profiles of individual VDCs in the district, this study considered the average value of the load profiles of Gudugad, Bajura, and Teliya khola microhydro plants. The hydrological information of the Gudugad, Bajura, and Teliya microhydro plants were obtained from the "Small Hydropower Promotion Project (SHPP) and Mini-grid Support Programme" of GTZ and AEPC (2004).

The study set the capacity cost of a microhydro plant as NRs360,000 per kilowatt (kW) and the O&M cost per year as 2.5% of the generation cost. The life of the microhydro plant is assumed to be 35 years. The efficiency of the microhydro plants in this study was considered to be 90% following Sanima Hydropower (2012).

Solar Home Systems

The cost of providing electricity through solar home systems (SHSs) includes the cost of solar panel, battery, charge controller, and converter. There is no transmission and distribution cost associated with the SHS. The solar radiation available in the district is assumed to be the same across all VDCs; the information on the radiation was based on the Solar and Wind Energy Resource Assessment in Nepal (SWERA)—a study carried out by the Alternative Energy Promotion Center, Nepal (AEPC 2008).

All the costs associated with the SHS were based on a market survey.[14] The costs considered in the study for a SHS are presented in Table 8.2.

Table 8.2: Technical Characteristics of Solar Home Systems

Items	Initial Cost (NRs)[a]	O&M Costs (NRs)	Life (Years)[a]
Solar PV panel	134,500 per kW	1,063 per kW per year[b]	25
Battery	3,500 per 10 Ah, 12 V 6,500 per 20 Ah, 12 V 10,000 per 40 Ah, 12 V	240 per annum per 10 Ah, 12 V[a]	5
Charge Controller	800 per household	6 per household per year[b]	15
Inverter	800,000 per kW	6,321 per kW per year[b]	15

Ah = ampere-hour, kW = kilowatt, NRs = Nepalese rupees, O&M = operation and maintenance, PV = photovoltaic, V = volt.
Source: [a] SEPL (2014), [b] O&M cost assumed to be 0.8% based on NREL (2016).

[14] Based on Sipradi Energy Pvt. Ltd., Kalimati, Kathmandu, Nepal.

Biomass Gasification Plant

The biomass resources available in each VDC consist of fuelwood and agricultural residues. The VDC-wise information on the availability of the biomass resources were obtained from secondary sources, i.e., DDC (2012) and data collected from AEPC in 2014.[15] The VDC-wise potential of biomass resources are discussed in Chapter 4 of this report.

The costs associated with the power generation from a biomass plant include capital, fuel and O&M costs. The generation cost of a biomass plant was considered to be NRs3.25 million per 11 kW (i.e., NRs295,455 per kW). The gasification efficiency of a biomass plant in this study was considered to be 75% and the specific consumption of biomass was considered to be 2 kilograms (kg) per kilowatt hour (kWh), which is equivalent to an electricity generation efficiency of 11% (Joshi 2014).[16] The energy content of biomass was assumed to be 16.75 megajoule (MJ)/kg (WECS 2010). The price of fuelwood was based on the household survey and was found to vary from NRs4.20 to NRs15.00 per kilogram of oil equivalent across the VDCs.

Grid Extension

The cost of electricity supply to an area from the power grid depends upon the level of power demand, distance of the load center (or demand center) from the grid and unit cost of electricity supply from the grid. Generally, the grid would be extended to the load center via a medium or high voltage line, which is then stepped down to the lower voltage level at the distribution substation and from there distributed to the community. The cost of medium or high voltage line would depend on the length and cross sectional area (or "size") of the conductor used.

The conductor size also depends on the distance between the power distribution substation and the grid. For the distribution of electricity, a radial configuration with overhead cable and three-phase system was considered. Interhousehold distance in each VDC of Pyuthan was considered to calculate the required length of the distribution cable. The interhousehold distance was determined using the geographical information system (GIS) platform.

The costs associated with grid extension involve the costs of a medium or high voltage line, transformer, distribution lines within the VDC, and O&M in addition to the cost (or price) of the electricity at the point of grid extension. The size of the transmission line conductor depends on the distance between the load center and the nearest available grid line as well as the amount of power to be transmitted to a VDC, which depends on the power demand of the VDC.

In this study, an 11-kilovolt line was used for distances less than 10 kilometers , whereas a 33-kilovolt line was used for longer distances. The grid extension cost was considered to be NRs871,000 per km for an 11-kilovolt line and NRs1.3 million per km for a 33-kilovolt line. The cost of grid electricity at the point of the grid extension was considered to be NRs7.20 per kWh, which is the weighted average of the Nepal Electricity Authority buyback rates of power purchased from independent power producers (IPPs) in dry and wet seasons. The O&M cost of transmission line was considered to be 1% of the total cost.

[15] VDC level forest area data was obtained from the AEPC.

[16] The data on biomass gasification plant was obtained from personal communication with Sandeep Joshi of Winrock International, Kathmandu, Nepal.

8.3.2 Local Transmission and Distribution Costs

The assessment of the cost of providing electricity access requires information on the total cost of a power plant as well as the cost of power transmission and distribution. The transmission cost includes the costs associated with the cost of extending an 11-kilovolt or 33-kilovolt transmission line from a decentralized plant to the load center along with the costs of transformer and substation components.

The distribution system in this study is assumed to be a radial, three-phase, and three-wire system. The length of the conductor is calculated based on the interhousehold distance in each VDC and the distance of load center from the power house. The interhousehold distance was determined based on the information obtained from the GIS platform. The selection of the conductor size for electricity supply was determined based on supply voltage and load current. The estimated load current was compared with the standard conductor specifications in order to determine the conductor size.

This study considered that aluminum conductor steel reinforced type of conductors would be used for electrification. Based on the market survey conducted for this study, the cost of distribution conductor considered was NRs300 per km. The price of a transformer considered in the study was NRs700,000 for a 50-kilovolt ampere transformer and NRs1 million for a 100-kilovolt ampere transformer.[17]

8.4 Power Generation Capacity Requirements

This section presents the electricity supply capacity requirement and technology mix in the district under the base case and universal electricity access cases (i.e., ELA1, ELA2, and ELA3) in 2017, 2022, and 2030.

8.4.1 Electricity Supply Capacity Requirement and Technology Mix

The total capacity required under the universal electricity access cases in 2017, 2022 and 2030 (if the electricity access programs were to start in these years) in the Pyuthan district considering alternative lighting technologies of LED, CFL, and incandescent lamps while other end use appliances under an electricity access case remain unchanged are shown in Tables 8.3, 8.4 and 8.5.[18]

Under the base case, the total capacity requirement in 2017 would be around 2,643 kW, which was estimated to reach to 4,797 kW by 2030, i.e., an increase of about 81%. The grid based electricity supply option was found to be the dominant cost-effective option for electricity supply in all three years. This is because most of the VDCs were already partially or fully electrified with grid supply in 2014.

When LED lamps are considered for lighting, the total power generation capacity requirement would increase by 5% under ELA1, 11% under ELA2, and 55% under ELA3 cases in 2017 as

---

[17] The distribution cost associated with a microhydropower plant (i.e., the cost of conductor and transformer) was lumped with the capital cost of the plant while using it as an input to the HOMER model.

[18] Note that these tables show the generation capacity requirements if universal electricity access programs as defined in different cases are started from the stated year.

Table 8.3: Capacity Requirement by Technology Type under Different Electricity Access Cases with Alternative Lighting Options in 2017

(kW)

Cases	Type of Lamps[a]	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	35.0	8.5	25.0	2,574.6	2,643.1
ELA1		70.0	23.0	75.0	2,599.8	2,767.8
ELA2		80.0	29.0	85.0	2,742.7	2,936.7
ELA3		125.0	40.0	130.0	3,809.1	4,104.1
ELA1	CFL	85.0	23.0	65.0	2,633.3	2,806.3
ELA2		1.0	29.0	95.0	2,891.7	3,016.7
ELA3		5.0	23.0	70.0	4,173.7	4,271.7
ELA1	INC	10.0	9.9	40.0	2,755.8	2,815.6
ELA2		40.0	31.1	95.0	3,460.7	3,626.8
ELA3		60.0	23.0	80.0	5,175.3	5,338.3

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, kW = kilowatt, LED = light-emitting diode, PV = photovoltaic.

[a] The total electricity demand for lighting was estimated in terms of the type of the lamp technology specified in the column.

Source: Authors.

Table 8.4: Capacity Requirement by Technology Type under Different Electricity Access Cases with Alternative Lighting Options in 2022

(kW)

Cases	Type of Lamp[a]	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	55.0	10.4	40.0	3,249.3	3,354.7
ELA1		10.0	26.2	40.0	3,495.1	3,571.3
ELA2		100.0	17.0	30.0	4,559.4	4,706.4
ELA3		0.0	0.0	0.0	15,496.8	15,496.8
ELA1	CFL	1.0	31.1	50.0	3,638.5	3,720.6
ELA2		110.0	17.0	40.0	4,790.7	4,957.7
ELA3		0.0	0.0	0.0	15,749.2	15,749.2
ELA1	INC	5.8	72.8	41.4	4,254.8	4,374.8
ELA2		46.4	39.0	49.1	5,919.4	6,053.8
ELA3		0.0	0.0	0.0	17,611.9	17,611.9

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, kW = kilowatt, LED = light-emitting diode, PV = photovoltaic.

[a] The total electricity demand for lighting was estimated in terms of the type of the lamp technology specified in the column.

Source: Authors.

Table 8.5: Capacity Requirement by Technology Type under Different Electricity Access Cases with Alternative Lighting Options in 2030
(kW)

Cases	Type of Lamp[a]	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	18.3	33.8	9.5	4,734.9	4,796.5
ELA1		11.6	44.3	65.8	5,990.5	6,112.2
ELA2		0.0	0.0	0.0	17,785.1	17,785.1
ELA3		0.0	0.0	0.0	27,311.9	27,311.9
ELA1	CFL	37.9	23.0	86.4	6,322.5	6469.7
ELA2		0.0	0.0	0.0	18,358.4	18,358.4
ELA3		0.0	0.0	0.0	27,758.4	27,758.4
ELA1	INC	36.2	44.3	75.0	7,325.1	7,480.6
ELA2		0.0	0.0	0.0	20,111.2	2,0111.2
ELA3		0.0	0.0	0.0	29,511.2	29,511.2

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, kW = kilowatt, LED = light-emitting diode, PV = photovoltaic.

[a] The total electricity demand for lighting was estimated in terms of the type of lamp technology specified in the column.

Source: Authors.

compared to that in the base case. In 2030, the total capacity requirement would increase by 27% under ELA1, 271% under ELA2, and 469% under ELA3 as compared to the capacity requirement in the base case.

The grid based electricity supply was found to be the dominant cost-effective solution for electricity supply in the base as well as universal electricity access cases. In 2022, grid based electricity would account for around 97% of the total electricity supply in the base case, whereas it would be the only supply option in ELA3. In 2030, as shown by Table 8.5, electricity supply would be entirely based on the grid under universal electricity access programs ELA2 and ELA3.

As Tables 8.3, 8.4 and 8.5 show, the capacity requirement for providing electricity access in each of the selected years is the highest when incandescent lamps are considered for lighting and it would be the lowest when LED lamps are considered.

In 2017, the capacity requirement would be higher by 1.4% under ELA1, 2.7% under ELA2, and 4.1% under ELA3 if the LED lamps are replaced by CFL. In 2022, the capacity requirement under ELA1 would be higher by 4.2%, ELA2 by 5.3%, and ELA3 by 1.6% if CFLs are used instead of LED lamps.

The capacity requirement in 2017 would be much higher under ELA1 by 1.7%, ELA2 by 23.5%, and ELA3 by 30.1% if incandescent lamps are used instead of LED lamps. The corresponding increase in the capacity required in 2022 would be 22.5% under ELA1, 28.6% under ELA2, and 13.6% under ELA3.

In 2030, the capacity requirement under ELA1 would increase by 5.8%, ELA2 by 3.2%, and ELA3 by 1.6% if CFLs were used in place of LED lamps. The capacity requirement would increase by 22.4% under ELA1, 13.1% under ELA2, and 8.1% under ELA3 if incandescent lamps were used instead. The VDC-wise information on the capacity requirement in 2017, 2022, and 2030 under the different electricity access cases using LED equivalent lighting technology are presented in Appendixes 18, 19, and 20.

Each of these appendixes have four subappendixes that show the capacity requirement under the different electricity access cases in partially off-grid electrified, partially grid electrified, and completely grid electrified VDCs.

It should be noted that the capacity requirement would be noticeably higher if CFL and incandescent lamps were considered for lighting instead of LED lamps. Also the grid based electricity supply was found to be the cost-effective as well as the dominant electricity supply option in each of the selected years. As Tables 8.3, 8.4, and 8.5 show that at higher electricity demand, the capacity mix would shift from the solar and microhydro based supply options toward the grid based supply.

8.4.2 Electricity Generation Mix

Tables 8.6, 8.7, and 8.8 present the least cost electricity generation mix by technology type in the district under the base and electricity access cases in 2017, 2022, and 2030. The tables also show the variation in the generation mix if alternative lamp technologies are considered for lighting, while all the other appliances considered in a case remain unchanged.

Under the base case, the total electricity generation would increase from 13,750 MWh in 2017 to 25,186 MWh in 2030, i.e., at a compound annual growth rate of 4.8% during 2017–2030. It is important to note that the share of grid extension in total electricity supply would increase with the increase in the level of electricity access per household.

With LED lamps considered for lighting, electricity generation under ELA1 would be higher by 4%, 11% under ELA2, and 53% under ELA3 than that in the base case in 2017 (Table 8.6). Similarly, it would be higher by 9% under ELA1, 41% under ELA2, and 366% under ELA3 in 2022 (Table 8.7) and 29% under ELA1, 273% under ELA2, and 469% under ELA3 in 2030 (Table 8.8). The total generation requirement would increase by 1.1% and 4.5% under ELA1 in 2017 if CFLs and incandescent lamps are used instead.

The electricity generation requirement in 2017 would increase by 4.8% under ELA2 and 6.1% under ELA3 in 2017 if LED lamps are replaced by CFL.

In 2030, the electricity generation requirement would be higher by 24.2% under ELA2 and by 30.8% under ELA3 if incandescent lamps are used instead of LED lamps. In general, for the same level of electricity access, total electricity generation requirement would be higher with the use of incandescent and CFL lamps than the requirement with the use of the LED lamps.

The VDC-wise information on the electricity generation mix in 2017, 2022, and 2030 under different electricity access cases considering LED lamps for lighting are presented in Subappendixes 21.1 to 21.4, 22.1 to 22.4, and 23.1 to 23.4 respectively.

Table 8.6: Electricity Generation Mix in 2017 under Different Electricity Access Cases with Alternative Lighting Technologies
(MWh)

Cases	Type of Lamp[a]	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	51.7	97.1	137.1	13,559.2	13,845.1
ELA1		106.6	272.0	110.1	13,950.2	14,438.9
ELA2		121.9	339.1	150.6	14,708.6	15,320.2
ELA3		188.5	437.6	540.9	20,020.4	21,187.4
ELA1	CFL	137.1	272.0	304.6	13,886.6	14,600.3
ELA2		1.5	339.1	352.9	15,356.1	16,049.6
ELA3		7.6	232.7	300.2	21,937.2	22,477.7
ELA1	INC	146.5	277.9	525.9	14,137.0	15,087.4
ELA2		15.2	362.7	209.9	18,437.1	19,025.0
ELA3		91.4	232.7	334.9	27,057.4	27,716.4

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, MWh = megawatt hour, PV = photovoltaic.

[a] The total electricity demand for lighting was estimated in terms of the type of lighting technology specified in the column.

Source: Authors.

Table 8.7: Electricity Generation Mix in 2022 under Different Electricity Access Cases with Alternative Lighting Technologies
(MWh)

Cases	Type of Lamp[a]	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	81.5	122.3	193.9	17,078.4	17,476.0
ELA1		22.9	350.9	249.7	18,369.9	18,993.3
ELA2		30.5	0.0	170.0	24,402.5	24,602.9
ELA3		0.0	0.0	0.0	81,450.1	81,450.1
ELA1	CFL	8.8	362.7	599.9	18,846.2	19,659.9
ELA2		167.6	204.9	224.8	25,474.5	25,777.5
ELA3		0.0	0.0	0.0	84,959.2	82,778.0
ELA1	INC	30.5	382.6	217.6	22,363.3	22,994.1
ELA2		243.7	204.9	258.1	31,112.2	31,819.0
ELA3		0.0	0.0	0.0	92,568.3	92,568.3

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, MWh = megawatt hour, PV = photovoltaic.

[a] The total electricity demand for lighting was estimated in terms of the type of lighting technology specified in the column.

Source: Authors.

Table 8.8: Electricity Generation Mix in 2030 under Different Electricity Access Cases with Alternative Lighting Technologies
(MWh)

Cases	Type of Lamp[a]	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	96.1	177.6	50.2	24,886.6	25,210.5
ELA1		60.9	232.7	346.0	31,794.0	32,433.6
ELA2		0.0	0.0	0.0	94,145.2	94,145.2
ELA3		0.0	0.0	0.0	143,551.4	143,551.4
ELA1	CFL	15.2	0.0	243.6	33,230.9	33,489.7
ELA2		0.0	0.0	0.0	94,751.9	94,751.9
ELA3		0.0	0.0	0.0	144,207.2	144,207.2
ELA1	INC	190.4	232.7	394.3	38,500.7	39,318.1
ELA2		0.0	0.0	0.0	105,704.3	1057,04.3
ELA3		0.0	0.0	0.0	155,111.0	155,111.0

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, MWh = megawatt hour, PV = photovoltaic.
Note: [a] The total electricity demand for lighting was estimated in terms of the type of lighting technology specified in the column.
Source: Authors.

8.5 Cost of Providing Electricity Access

This section presents the total electricity supply cost, operating cost, and investment requirement in the district in the base case and three universal electricity access scenarios if the electricity access programs were to start in 2017, 2022, and 2030 assuming there was no preexisting supply capacity in each of the years.

The effects on costs of the demand side technology are partially analyzed in this section considering three alternative technologies for lighting, i.e., LED, CFL, and incandescent lamps while all other appliances under a scenario remain the same. It should be noted here the cost figures in the base case represent the costs associated with the supply system without universal access.

The costs under ELA1, ELA2, and ELA3 cases are different in that they represent the total costs of electricity supply to provide universal access with different levels of the minimum electricity consumption per household. The increment in costs in the ELA cases thus represents the additional cost associated with the provision of universal access to electricity supply.

Also note that the costs presented under each of the selected years in this section represent the corresponding life time costs for meeting a constant annual electricity demand for a period of 25 years assuming no preexisting supply capacity.

8.5.1 Total Cost of Electricity Supply

The life time costs of electricity supply by different supply technology options are shown in Tables 8.9, 8.10, and 8.11 for different electricity access programs starting in 2017, 2022, and 2030. The total cost of electricity supply under the base case is NRs1,456 million in 2017, NRs1,780 million in 2022, and NRs2,514 million in 2030.

Since the grid extension was found to be the predominant option in all the cases, the total costs are dominated by the cost of grid extension. The grid based supply would account for around 95% of the total supply system cost in 2017, whereas it would account for the entire cost of supply under ELA2 and ELA3 in 2030.

In 2022, the total electricity supply cost under ELA3 would be 4.3 times higher than that in the base case when LED lamps are considered for lighting (Table 8.10). The total electricity supply cost would be even higher if the use of CFL or incandescent lamps were considered: the total electricity supply cost under ELA3 would increase by 4.5 times if CFL lamps are used and 4.9 times if incandescent lamps are used. Note that grid extension was found to be the least-cost option for providing electricity under the high access cases (i.e., Tiers 4 and 5) in 2022 and 2030.

As in 2022, it can be seen from Table 8.11 that the total electricity supply cost would be dominated by grid extension as the option seems to be more attractive with increasing electricity access in 2030. The total electricity supply cost in 2030 would increase by 5.3 times

Table 8.9: Total Electricity Supply Cost in 2017 under Different Cases with Alternative Lighting Technologies
(million NRs)

Cases	Type of Lamps	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	15.6	14.2	26.4	1,400.3	1,456.4
ELA1	LED	12.0	22.0	54.8	1,465.6	1,554.4
ELA2	LED	13.4	25.8	66.0	1,535.4	1,640.6
ELA3	LED	43.4	31.7	113.9	2,060.0	2,249.1
ELA1	CFL	14.7	22.0	38.4	1,502.4	1,577.5
ELA2	CFL	1.0	25.8	59.5	1,634.8	1,721.2
ELA3	CFL	11.6	18.5	72.7	2,272.0	2,374.8
ELA1	INC	48.6	22.9	73.3	1,510.1	1,654.8
ELA2	INC	3.9	26.2	32.3	1,936.5	1,998.9
ELA3	INC	139.6	168.2	408.7	2,744.3	3,460.8

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, NRs = Nepalese rupees, PV = photovoltaic.
Source: Authors.

Table 8.10: Total Electricity Supply Cost in 2022 under Different Cases with Alternative Lighting Technologies (million NRs)

Cases	Type of Lamps	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	17.9	16.7	39.0	1,706.7	1,780.2
ELA1		4.7	25.2	41.1	1,888.1	1,959.2
ELA2		4.8	0.0	25.8	2,530.0	2,560.5
ELA3		0.0	0.0	0.0	7,651.1	7,651.1
ELA1	CFL	7.1	27.1	98.6	1,914.9	2,047.7
ELA2		34.3	13.2	74.0	2,580.9	2,702.4
ELA3		0.0	0.0	0.0	8,005.2	8,005.2
ELA1	INC	5.6	27.4	44	2,073.0	2,376.3
ELA2		39.9	13.2	40.4	2,882.4	3,259.9
ELA3		0.0	0.0	0.0	7,654.5	8,674.6

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, NRs = Nepalese rupees, PV = photovoltaic.
Source: Authors.

Table 8.11: Total Electricity Supply Cost in 2030 under Different Cases with Alternative Lighting Technologies (million NRs)

Cases	Type of Lamps	Solar PV	Microhydro	Biomass	Grid	Total
Base	LED	23.6	18.1	46.7	2,425.4	2,513.8
ELA1		19.5	18.5	87.0	3,152.0	3,277.0
ELA2		0.0	0.0	0.0	8,820.7	8,820.7
ELA3		0.0	0.0	0.0	13,354.9	13,354.9
ELA1	CFL	23.0	18.5	95.6	3,311.5	3,453.8
ELA2		0.0	0.0	0.0	9,100.3	9,100.3
ELA3		0.0	0.0	0.0	13,575.2	13,575.2
ELA1	INC	17.1	0.0	40.2	3,734.4	3,791.7
ELA2		0.0	0.0	0.0	9,130.5	9,130.5
ELA3		0.0	0.0	0.0	13,756.0	13,756.0

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, NRs = Nepalese rupees, PV = photovoltaic.
Source: Authors.

under ELA3 case as compared to the cost in the base case when LED lamps are considered for lighting. If CFL and incandescent lamps are used instead, the total electricity supply cost under ELA3 would be 1.6% and 3.0% higher respectively than the total cost when LED lamps are used for lighting.

The VDC level electricity supply costs and the associated least cost electricity supply options in 2017, 2022, and 2030 with the LED lamps considered for lighting are presented in Subappendixes 24.1 to 24.4, 25.1 to 25.4, and 26.1 to 26.4 respectively.

The grid extension was found to be the dominant least cost option to provide electricity access under the base and universal electricity access cases in all VDCs. For VDCs that are currently supplied by off-grid electrification, the level of demand growth, distance from the grid and available technology options determine the cost-effectiveness of the grid extension. Seven VDCs in the district, i.e., Arkha, Damri, Khawang, Khung, Kochiwang, Ligha, and Syauliwang, were completely off-grid electrified. Among the VDCs, Arkha and Syauliwang VDCs were partially electrified by microhydropower plants in 2014 while other VDCs were electrified by solar home systems.

The distance from the grid to VDCs varies from 8.5 km in the case of Kochiwang VDC to 20.8 km in the case of Arkha VDC. Interesting to note is that grid extension seems to be the most cost-effective option for Kochiwang VDC even at a lower level of electricity access. This is partly because of the short distance between the VDC and the grid.

In the case of the VDCs located at relatively long distance from the grid, grid extension was found to be the cost-effective option to provide electricity supply at higher levels of electricity access per household in 2022 and 2030.

8.5.2 Breakdown of Total Cost into Demand and Supply Side Costs

With the change in technology options in the demand side, the total cost would change due to changes in both the supply and demand side costs. The total amount required to provide universal access to electricity supply and use by households is thus the sum of the supply and demand side costs. The total costs (i.e., supply and demand side costs combined) in 2017, 2022, and 2030 are presented in Tables 8.12, 8.13, and 8.14 respectively.

Note that each of these tables presents the effect on the total cost of considering alternative technologies for lighting while there is no change in other electrical appliances considered.

In 2017, the share of demand side cost remains around 2.2% under the base case. The share of demand side related costs would remain the same in ELA1 as that in the base case using LED lamps. The share, however, increases to around 4.5% under ELA2 and 14.2% under ELA3. This is because of the increase in the number and type of electricity using appliances under ELA2 and ELA3 in 2017.

The total supply side cost in the base case is NRs1.5 billion while demand cost is NRs32.6 million. The total cost of the supply and demand sides together would increase by 6.7% under ELA1, 15.4% under ELA2, and 76.1% under ELA3 when LED lamps are considered for lighting as compared to the base case.

Table 8.12: Supply and Demand Side Costs in 2017 under Electricity Access Cases with Alternative Lighting Technologies (million NRs)

Cases	Type of Lamps	Supply Side Costs	Demand Side Costs	Total
Base	LED	1,456.4	32.6	1,489.0
ELA1		1,554.4	34.9	1,589.3
ELA2		1,640.6	77.8	1,718.3
ELA3		2,249.1	372.5	2,621.6
ELA1	CFL	1,577.5	37.6	1,615.2
ELA2		1,721.2	86.6	1,807.8
ELA3		2,374.8	381.4	2,756.2
ELA1	INC	1,654.8	42.1	1,697.0
ELA2		1,998.9	100.7	2,099.6
ELA3		3,460.8	395.5	3,856.3

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, NRs = Nepalese rupees, PV = photovoltaic.
Source: Authors.

Table 8.13: Supply and Demand Side Costs in 2022 under Electricity Access Cases with Alternative Lighting Technologies (million NRs)

Cases	Type of Lamps	Supply Side Costs	Demand Side Costs	Total
Base	LED	1,780.2	53.9	1,834.1
ELA1		1,959.2	102.8	2,062.0
ELA2		2,560.5	431.2	2,991.7
ELA3		7,651.1	630.8	8,281.9
ELA1	CFL	2,047.7	113.2	2,160.8
ELA2		2,702.4	441.5	3,143.9
ELA3		8,005.2	630.3	8,635.5
ELA1	INC	2,376.3	129.1	2,505.4
ELA2		3,259.9	457.4	3,717.3
ELA3		8,674.6	654.2	9,328.8

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, NRs = Nepalese rupees, PV = photovoltaic.
Source: Authors.

Table 8.14: Supply and Demand Side Costs in 2030 under Electricity Access Cases with Alternative Lighting Technologies
(million NRs)

Cases	Type of Lamps	Supply Side Costs	Demand Side Costs	Total
Base	LED	2,513.8	94.6	2,608.3
ELA1		3,277.0	581.1	3,858.1
ELA2		8,820.7	845.3	9,666.0
ELA3		13,354.9	1,796.0	15,151.0
ELA1	CFL	3,453.8	594.8	4,048.5
ELA2		9,100.3	848.1	9,948.4
ELA3		13,575.2	1,809.8	15,385.0
ELA1	INC	3,791.7	616.8	4,408.5
ELA2		9,130.5	881.0	10,011.5
ELA3		13,756.0	1,831.7	15,587.8

CFL = compact fluorescent lamp, ELA = electricity access case, INC = incandescent, LED = light-emitting diode, NRs = Nepalese rupees, PV = photovoltaic.
Source: Authors.

It has been observed that replacing LED lamps with CFL in that year would increase the total cost of supply and demand sides by 8.4% under ELA1, 21.3% under ELA2, and 84.9% under ELA3. With the use of incandescent lamps it was estimated that the total supply and demand side cost would increase by up to 158.4% under ELA3.

In 2022, the share of demand side device costs in the total cost would be higher than that in 2017. The demand side appliances would account for about 2.9% of the total cost in the base case; the share would increase up to 7.6% in ELA3 when LED lamps are considered for lighting.

In 2022, the total cost of the supply and demand sides (considering LED lamps for lighting) would increase by 12.4% in ELA1 and 351.5% in ELA3 compared to the cost in the base case. If CFL was considered for lighting, the total cost would increase by 17.7% in ELA1 and 370.3% in ELA3. When incandescent lamps are considered for lighting, the total cost would increase in the range of 36.2% in ELA1 to 407.1% in ELA3.

In 2030, the demand side cost was estimated to account for around 3.6% of the total cost in the base case when LED lamps are considered for lighting. The share of the demand side cost rises by more than 11.9% in ELA3. This is because there are more units of electrical appliances of different types in ELA3. The total cost under ELA3 would be 489.0% and 495.3% higher than that in the base case when CFL and incandescent lamps are considered for lighting.

8.5.3 Investment Requirements

Table 8.15 shows the level of the investment required for providing electricity supply in Pyuthan district under universal ELA1, ELA2, and ELA3 using LED lamps for lighting in

Table 8.15: Investment Requirement for Providing Electricity Access in Different Cases Considering Light-Emitting Diode Lamps for Lighting
(million NRs)

Cases	Year	Investment Cost	Operating Cost	Total Supply Cost
Base	2017	1,176.0	280.5	1,456.4
ELA1		1,245.9	308.5	1,554.4
ELA2		1,311.9	328.7	1,640.6
ELA3		1,787.6	461.4	2,249.1
Base	2022	1,435.1	345.2	1,780.2
ELA1		1,581.4	377.8	1,959.2
ELA2		2,077.0	483.5	2,560.5
ELA3		6,235.7	1,415.5	7,651.1
Base	2030	2,029.6	484.2	2,513.8
ELA1		2,637.4	639.6	3,277.0
ELA2		7,188.8	1,631.8	8,820.7
ELA3		10,884.3	2,470.7	13,354.9

ELA = electricity access case, NRs = Nepalese rupees.
Source: Authors.

2017, 2022, and 2030. Note that the base case does not consider universal access to electricity supply; so the investment in the base case represents the supply system without such an access.

The investment requirements under ELA1, ELA2 and ELA3 are different in that they include additional investment needed for providing different minimum levels of universal electricity access per household as compared to the base case.

Also, note that the amount of investment here represents the total investment required for developing an electricity system capable of meeting the entire demand for electricity under a universal access program in the respective year; that is, these estimates are made assuming no preexisting power supply capacity in the year. Further, the annual electricity demand in each case is assumed to remain unchanged over the planning period of 25 years. In 2017, the investment required for providing electricity access under the base case was estimated to be around NRs1.2 billion. This figure would increase by 5.9%, 11.6%, and 52.0% in the universal electricity access cases of ELA1, ELA2, and ELA3.

In 2022, the investment requirement would increase by 10.2% under ELA1, 44.7% under ELA2, and 334.5% under ELA3; in 2030 there would be an increase in the investment requirement by 30.0% under ELA1, 254.2% under ELA2, and 436.3% under ELA3. The additional investment requirement in 2017 would vary from NRs69.9 million under ELA1 to NRs611.7 million under ELA3.

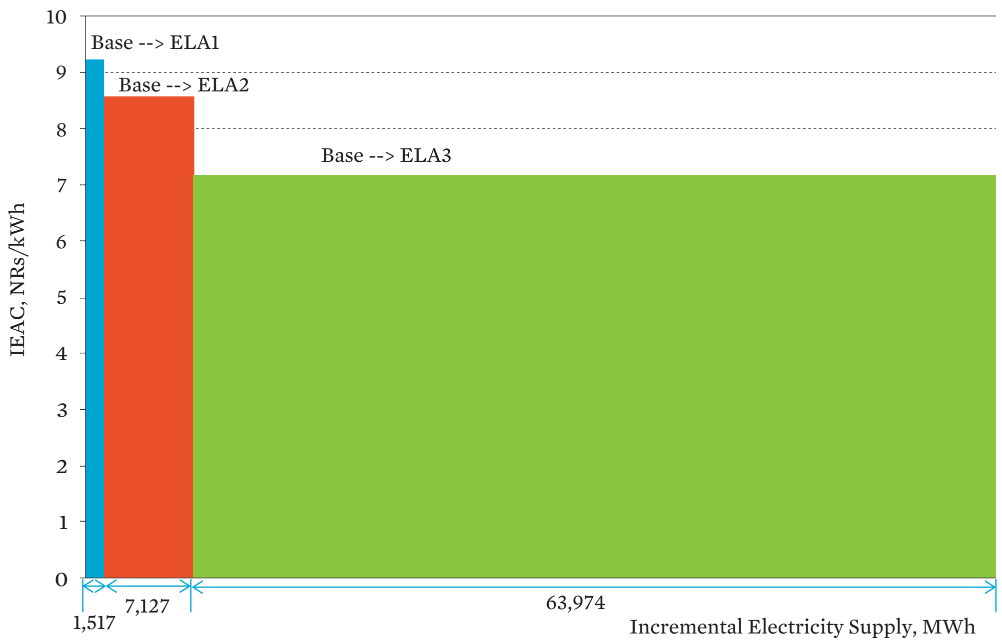
If a universal electricity access at Tier 3 level (i.e., under ELA3 scenario) is to be provided in the district, the additional investment requirement would be as high as NRs4.8 billion in 2022 and NRs8.85 billion in 2030.

It is interesting to note that at the district level, grid extension was found to be the only cost-effective solution for electricity access at very high levels (i.e., Tiers 4 and 5) in 2030 whereas both decentralized and grid options would be cost-effective when the aggregate demand for electricity at the district level is not big enough (i.e., at the lower levels of electricity consumption per household in Tiers 1, 2, and 3 in 2017 and 2022) under universal access scenarios.

8.5.4 Incremental Cost of Electricity Access

Figure 8.2 shows the incremental cost of electricity supply for Pyuthan district if electricity supply is increased from the base case level to higher levels in ELA1, ELA2, and ELA3 cases in 2022. The horizontal axis in the figure shows the level of incremental electricity supply under a universal electricity access case, while the values in the vertical axis represent the corresponding incremental electricity access cost (IEAC) per unit (kWh) of electricity supplied.

Figure 8.2: Incremental Electricity Access Cost for Pyuthan in 2022 (Considering Demand Increment from the Base Case)
(NRs/kWh)



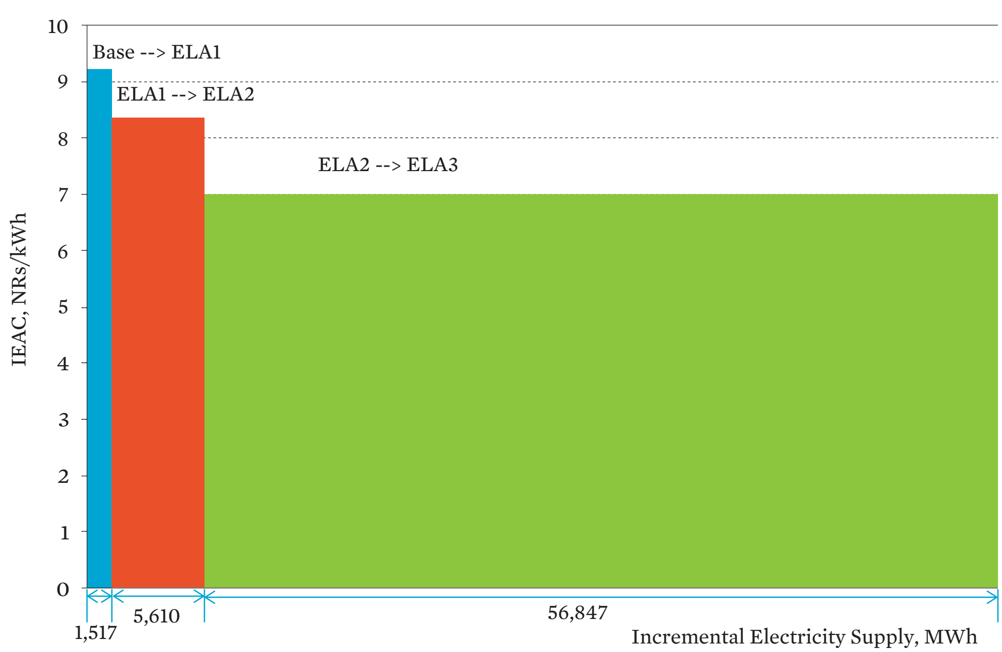
ELA = electricity access case, IEAC = incremental electricity access cost, kWh = kilowatt hour, MWh = megawatt hour, NRs = Nepalese rupees.
Source: Authors.

As can be seen from the figure, the IEAC decreases as the electricity consumption per household increases. The IEAC would be NRs9.20 per kWh for an increase in the electricity supply in the base case to that in the Tier 2 level under ELA1. The IEAC would decrease to NRs8.60 per kWh when the universal electricity access per household is increased to Tier 3 level (i.e., in ELA2) and would decrease to NRs7.20 per kWh when the access is increased further to Tier 4 level (i.e., in ELA3).

Figure 8.3 presents the incremental electricity access cost in 2022 when the increment in electricity supply was considered from one level of access to the next higher level. As can be seen, the IEAC would be NRs9.20 per kWh with the increase in electricity supply from the base case level to the level in ELA1; it would decrease to NRs8.40 per kWh when the minimum electricity consumption per household in ELA1 is increased to that in ELA2, it would further decrease to NRs7.00 per kWh when the minimum consumption per household is increased from ELA2 to ELA3.

Table 8.16 presents the incremental electricity access cost per unit for the Pyuthan district for 2017, 2022, and 2030. Note that in most cases, the incremental cost was found to decrease with the increase in the level of universal electricity access, i.e., the per unit cost is found to decrease as the level of minimum per household electricity consumption under a universal access program increases, indicating the presence of some economy of scale in the level of universal access.

Figure 8.3: Incremental Electricity Access Cost for Pyuthan in 2022 (Considering Total Demand Increment from One Level of Access to the Next Higher Level)
(NRs/kWh)



ELA = electricity access case, IEAC = incremental electricity access cost, kWh = kilowatt hour, MWh = megawatt hour, NRs = Nepalese rupees.
Source: Authors.

Table 8.16: Incremental Electricity Access Cost for Pyuthan in 2017, 2022, and 2030
(NRs/kWh)

Cases	Year		
	2017	2022	2030
Considering Demand Increment Relative to the Base Case			
Base Case to ELA1	13.8	9.2	8.3
Base Case to ELA2	10.2	8.6	7.2
Base Case to ELA3	8.3	7.2	7.2
Considering Successive Demand Increment in Different Cases			
Base Case to ELA1	13.8	9.2	8.3
ELA1 to ELA2	7.7	8.4	7.0
ELA 2 to ELA3	7.8	7.0	7.2

ELA = electricity access case.
Source: Authors.

8.6 Key Findings and Limitations

This study assessed the costs of electricity supply under the base case and different universal access cases in selected years assuming a uniform annual electricity demand over the following 25 years and no preexisting supply capacity. Under the base case, the total capacity requirement would increase from 2,643 kW in 2017 to 4,797 kW by 2030, an increase of approximately about 81%.

The study found that the total installed capacity requirement for providing electricity access in 2017 would increase by 5% under ELA1, 11% under ELA2, and 55% under ELA3 as compared to the base case capacity when LED lamps are considered for lighting.

The study also analyzed the effects on the electricity capacity requirements, generation capacity mix and costs when the use of alternative lighting options are considered in the demand side while the levels of electricity consumption of other demand side appliances are kept constant.

When CFL lamps are considered for lighting and all other demand side devices remaining the same, the study finds that the installed electricity generation capacity requirement in the district in 2017 would increase by 1.4% under ELA1, 2.7% under ELA2, and 4.1% under ELA3 as compared to the corresponding capacity when LED lamps are considered.

Similarly, if incandescent lamps are considered for lighting, with other demand side appliances remaining the same, the capacity requirements in 2017 under ELA1, ELA2, and ELA3 would increase by 1.7%, 23.5%, and 30.1% respectively as compared to the corresponding capacity when LED lamps were used.

In 2022, the total installed electricity generation capacity of the district would be 10% higher in ELA1 and 360% higher in ELA3 than the base case capacity when LED lamps are used for lighting. Similarly in 2030, the increase in the total installed capacity of the district would be in the range of 30% in ELA1 to 470% in ELA3 than that in the base case.

The analysis showed that in the base and universal electricity access cases, the grid extension was found to be the major cost-effective electricity supply option in the Pyuthan district. This is because most of the VDCs were already partially or fully electrified by grid in 2014. Note that grid extension seems to be the most cost-effective option for a VDC located close to the grid (e.g., Kochiwang) even at a relatively lower level of electricity access.

For VDCs located relatively far away from the grid, electricity access with grid extension was found to be cost-effective in cases with higher levels of electricity access in 2022 and 2030.

Since grid extension was found to be the most cost-effective supply option in the base and electricity access cases in the district, the total system cost is dominated by the cost of grid extension. In 2017, the grid extension would have the highest share (around 95%) in the total electricity supply system cost in the base as well as electricity access cases; this is followed by biomass-gasifier plant, microhydro, and solar PV system.

In 2022, the total electricity supply cost under ELA3 (considering LED lamps for lighting) would be 4.3 times higher than that in the base case. The total supply cost was found to be the cost of grid based supply in ELA3 as all the VDCs would have to be electrified exclusively through grid extension.

Thus the grid-based supply was found to be increasingly more cost-effective with the increase in total electricity demand. In other words, the grid extension would be a more economical option if higher levels of universal electricity access are to be provided.

In the base case, the total cost would increase from NRs1.5 billion in 2017 to NRs2.5 billion in 2030. In 2017, the total cost in ELA1 case (with LED lamps for lighting) would be 6.7% higher than that in the base case, whereas it would be 54.4% higher under ELA3. Similarly, in 2022 the total cost would be 10% higher in ELA1 and 330% higher in ELA3 as compared to that in the base case; in 2030 the total cost would be 30% higher in ELA1 and 431% higher in ELA3.

The total investment requirement in the base case would be NRs1.2 billion in 2017 (with LED lamps considered for lighting). The additional investment required in the year to meet the additional electricity demand under universal electricity access cases was estimated to be in the range of around NRs69.9 million in ELA1 to around NRs611.7 million in ELA3.

In 2022, total investment requirement was estimated to be around NRs1.4 billion in the base case. The total investment required was estimated to increase by more than 10% in ELA1 and 44% in ELA2 to meet the additional electricity demand. The additional investment required under ELA3 in 2022 was estimated to be around NRs4.8 billion. In 2030, an investment of around NRs2.0 billion would be required under the base case. Under the universal electricity access cases, it was estimated that an additional investment requirement would vary in the range of around NRs607.9 million under ELA1 to NRs8.8 billion under ELA3 in that year.

The study has assessed the incremental cost of electricity access in terms of cost per unit of electricity supply under a universal electricity access case. In 2022, when the total electricity supply is increased from the base case level to a level in a universal access case, the incremental cost of electricity access at the district level was found to be NRs9.2 per kWh in ELA1; the incremental cost was found to decrease with the increase in the level of access and would be NRs7.2 per kWh in ELA3.

On the other hand, when the increase in total electricity supply was considered from a level of electricity access to the next higher level, the incremental electricity access cost was found to be NRs9.2 per kWh (when the electricity supply is increased from the base case level to that in ELA1); it would decrease to NRs7.0 per kWh (if an increase in total electricity supply from the level in ELA2 to that in ELA3 was considered).

Ideally, an integrated resource planning model is required to identify the least cost mix of supply and demand side technologies and energy resources. Such a model would directly provide cost information on both supply and demand sides.

For the purpose of the cost assessment, the present study has used the HOMER model. However, the model considers only the supply side technological parameters and fails to consider the demand side data.

This study illustrated the effect of demand side options on total costs by considering alternative lamp technologies for lighting (while keeping the other appliances unchanged) and modifying the total electricity demand in each scenario accordingly. Clearly the results would be different if different demand side options for all electricity end uses were considered.

The present study used the available information on energy resources that shows very small (almost insignificant) micro and minihydro power generation potential in the district. However, the apparent low hydropower resource potential at present could be a result of an inadequate assessment of the micro and minihydro power potential in the district. It is imperative to allocate adequate resources and efforts toward an assessment that would provide more reliable information on the micro and minihydropower potential of the district.

9 Cost and Technology Assessments of Cleaner Cooking Options

9.1 Introduction

The main objective of this chapter is to analyze the cost implications of various cleaner cooking options and programs in areas under each village development committee (VDC) of the Pyuthan district. This assessment aims to provide information on the total investment needed as well as other costs, which are important for the development and implementation of cleaner cooking access programs in the district. The cost assessment also aims to provide an estimation of the incremental costs of providing different cleaner energy services for cooking.

9.2 Methodology and Data

Assessing the cost of various cooking technology options requires the information on the capital cost, operation and maintenance cost (O&M), fuel cost, discount rate, as well as energy efficiency and life of cooking devices. This study followed the methodology given in the sustainable energy access planning (SEAP) framework for estimating the total cost associated with providing cleaner cooking access. The total cost of providing access to cleaner cooking was estimated using the following equation:

$$\textit{Total Cooking Cost} = \textit{Fuel Cost} + \textit{Annualized Cost of Cooking Device} \qquad \text{Eq. 9.1}$$

The annualized cost of the cooking device also includes the O&M costs of the device. Apart from the fuel and the annualized cooking device costs, the SEAP framework also mentions the consideration of inconvenience costs to obtain the total cooking cost. The inconvenience cost considers the nonmonetary aspects of the preferences of households associated with procuring and using different fuels (Pachauri et al. 2013). However, the inconvenience cost associated with using fuelwood or other types of fuels was not considered in the present study.

To estimate the cost of cleaner cooking, the cooking energy demand of each VDC in the district was estimated for 4 different years, i.e., 2014, 2017, 2022, and 2030, under the base case. The cooking energy demand for the base year (2014) was estimated using the data on average energy consumption per household by fuel type obtained from the sample survey of 2,330 households covering all VDCs.

The data on average energy consumption per household for cooking by fuel type obtained from the survey is presented in Appendix 12. The projected demand for household cooking under the base case is presented in Chapter 6.

Fuelwood is the dominant fuel used for cooking in Pyuthan; it is followed by agricultural residues, liquefied petroleum gas (LPG), electricity and biogas. Biomass-based traditional cookstoves account for a major share in the total cooking technology mix of the district, followed by biomass-based improved cookstoves, LPG, electricity and biogas cookstoves. The minimum useful cooking energy consumption per capita in the district based on the household survey was found to be 27.2 kilograms of oil equivalent (kgoe) per capita.

As discussed in Chapter 5, the households with the average cooking energy consumption per capita less than 27.2 kgoe were considered as "energy-poor" in this study. However, it is interesting to note that the minimum average energy consumption for cooking in useful energy terms among the different income categories of households obtained in this study is much higher than that specified by the "Total Energy Access" approach of Practical Action, which is calculated to be around 14.2 kgoe per capita[19] for fuelwood based cooking (based on minimum standard for cooking at 1 kilogram (kg) of fuelwood per person per day) [Practical Action 2012].

Description of Scenarios

As mentioned in the Global Tracking Framework (GTF), Tier 0 of the multitier measurement for household cooking corresponds to the use of traditional cookstoves using solid fuels and represents "no access" to cleaner energy (World Bank/ESMAP and IEA 2013).

To be in line with the GTF, this study has presented the incremental cost of providing access to cleaner cooking energy by considering 100% replacement of biomass use with traditional cookstoves under different cleaner cooking scenarios.

These scenarios are of two categories: cleaner biomass scenarios and hybrid scenarios (that consider a combination of both cleaner biomass and nonbiomass options).

Aside from the base case, this study considered seven different cleaner cooking access (CCA) scenarios for replacing the biomass used with traditional cookstoves with the cleaner cooking options. It should be noted that the base case considers the continuation of the present pattern of energy and technology use for cooking in the future. The different CCA cases analyzed in this study are:

- (i) **Cleaner Cooking Access Case 1 (hereafter "CCA1"):** Replacing 20% of traditional cookstoves (TCS) by moderately efficient improved cookstoves (MICS).
- (ii) **Cleaner Cooking Access Case 2 (hereafter "CCA2"):** Replacing 20% of TCS by MICS and another 20% by highly efficient improved cookstoves (HICS).
- (iii) **Cleaner Cooking Access Case 3 (hereafter "CCA3"):** Replacing 20% of TCS by MICS, 20% by HICS and another 20% by biogas cookstoves.
- (iv) **Cleaner Cooking Access Case 4 (hereafter "CCA4"):** Replacing 20% of TCS by MICS, 20% by HICS, 20% by biogas and another 15% by briquette cookstoves.
- (v) **Cleaner Cooking Access Case 5 (hereafter "CCA5"):** Replacing 20% of TCS by MICS, 20% by HICS, 20% by biogas, 15% by briquette and another 15% by electric cookstoves.
- (vi) **Cleaner Cooking Access Case 6 (hereafter "CCA6"):** Replacing 20% of TCS by MICS, 20% by HICS, 20% by biogas, 15% by briquette, 15% by electric and another 10% by LPG cookstoves.

[19] This value was calculated considering the energy content of fuelwood as 0.39 kgoe/kg (WECS, 2010).

(vii) **Cleaner Cooking Access Case 7 (hereafter "CCA7"):** Replacing 25% of TCS by MICS, 25% by HICS, 30% by biogas and another 20% by briquette cookstoves.

It should be noted that replacement of biomass use with TCS in cooking with cleaner biomass options and hybrid of biomass and nonbiomass options were considered to assess the potential for reduction of biomass use as well as the total energy requirement for cooking. It is, however, well recognized that the biomass and nonbiomass options for cooking are imperfect substitutes and that there are different levels of inconvenience associated even in the use of different biomass options (i.e., biomass, biogas, and briquettes).

Cost and Technical Parameters of Cooking Devices

Table 9.1 shows the initial cost, energy efficiency, and life of different cooking devices along with the information on the type and price of fuel involved. The table also shows the estimated annuitized costs of different stoves or devices at the discount rate of 10%. The annuitized cost of a biogas stove is NRs198 while a digester costs NRs12,103, resulting in the combined cost

Table 9.1: Cost and Technical Parameters of Different Cooking Options

Cooking Option	Fuel Type	Initial cost, NRs	Annuitized Cost of devices, NRs[a]	Life, years	Stove Energy Efficiency %	Fuel Price, NRs/kgoe
Traditional cookstove[a]	Fuelwood/ Agricultural Residue	250	250	1	10	Fuelwood: 8.3[d] Agri. Residues: 6.2[d]
Moderately efficient improved cookstove[b]		1,000	402	3	20	
Highly efficient improved cookstove[b]		6,000	1,583	5	35	
Biogas stove (including digester)[b]	Annimal Waste as Primary Energy Source/Biogas	81,750	12,301	5 (for stove), 20 (for digester)	55	
LPG stove[c] (including gas cylinder cost)	LPG	5,000	813	10	60	133.2[d]
Kerosene stove[c]	Kerosene	1,000	264	5	45	134.4[d]
Electric stove[c]	Electricity	4,000	750	8	80	8.6[e,f]
Briquette stove[c]	Biomass Briquette	800	322	3	33	41.9[c]

NRs = Nepalese Rupees, LPG = liquefied petroleum gas.
[f] unit is NRs/kWh
Source: [a] Estimated by the authors; [b] Technology data based on Winrock International Nepal; [c] Technology data based on market survey; [d] Average price based on sample household survey; [e] Obtained from cost assessment model of this study.

of NRs12,301. This study considered annual O&M cost of NRs30 for biomass cookstoves and NRs50 for electric and LPG cooktoves. In the case of the biogas digester, it has considered the O&M cost to be 3% of the initial cost.

Note that the annuitized cost of a LPG cookstove is lower than that of the HICS; however, cooking with LPG is still more expensive due to the higher cost of LPG.

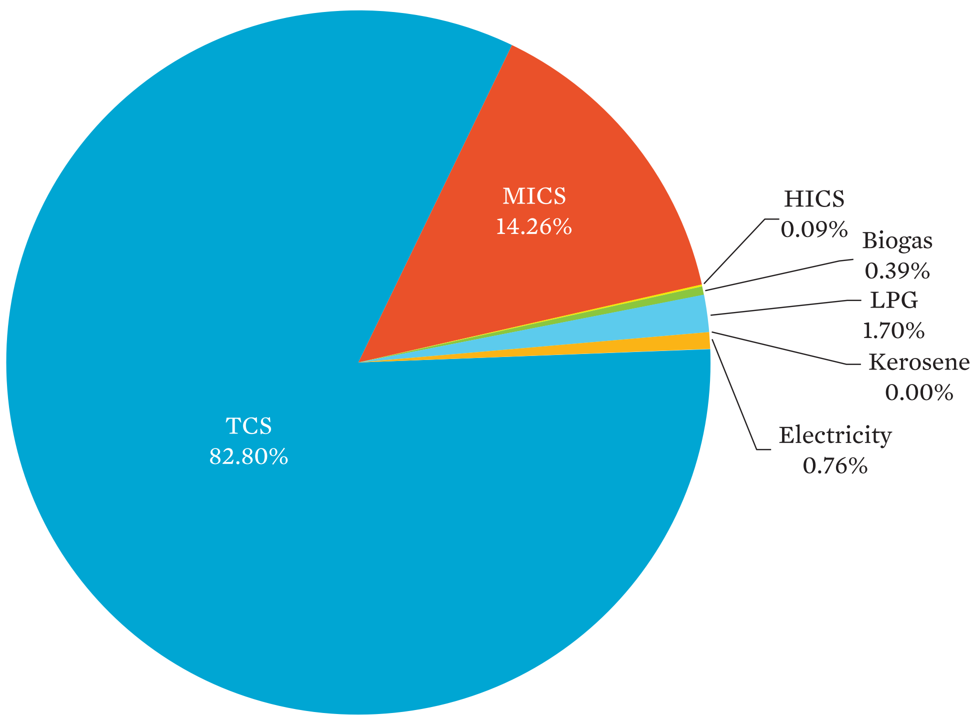
9.3 Results

9.3.1 Energy Mix in Cooking under Different Scenarios

As discussed in Chapter 3, the total energy consumption for cooking in Pyuthan is dominated by fuelwood, followed by agricultural residues, LPG, electricity, and biogas.

According to the household survey conducted in the district in 2014, most (around 82.8%) of the cooking energy demand is met using TCS, which is followed by MICS[20], LPG, electricity, and biogas cookstoves (Figure 9.1).

Figure 9.1: Share of Cooking Energy Mix by Technology in Pyuthan in 2014



Note: The shares are calculated in final energy terms.
HICS = highly efficient cookstove, LPG = liquefied petroleum gas, MICS = moderately improved cookstove, TCS = traditional cookstove.
Source: Authors.

[20] The efficiency of MICS was set to be 20% in this study (considering improved mud cookstoves) (AEPC 2008).

The HICS was found to have a negligible share of about 0.09% in the total cooking energy mix in the district.[21] From the survey, around 53% of the households in the district were found to have two or more heads of cattle, with the total biogas potential of 8,158 tons of oil equivalent (toe) in 2014.

As such, around 67% of the demand for useful energy for cooking of the households in the district, who own at least two heads of cattle, could be met by biogas and the rest by other cleaner forms of energy.

Table 9.2 presents the energy mix in cooking by type of stove technology under the base case and different cleaner cooking access cases in the selected years. The base case represents the continuation of the present trend of technology and energy use in cooking in 2017, 2022, and 2030. The cooking stove technology and fuel mixes under the base case are assumed to remain the same as that in 2014. Thus, the share of biomass use in TCS in meeting the total cooking energy demand is assumed to remain at 82.8% till 2030 under the base case, while LPG's share is assumed to be 1.7% and electricity's is at 0.8%.

This study showed that biomass requirement in the base case would be around 50,171 toe in 2017, 55,148 toe in 2022, and 64,160 toe in 2030 (Table 9.2). Table 9.2 also shows that under the cleaner cooking access scenarios the total requirement of biomass for cooking (mainly fuelwood) would decrease by around 8% in CCA1, 21% in CCA2, 38% in CCA3, 50% in CCA4, 63% in CCA5, 72% in CCA6, and 63% in CCA7 with the replacement of TCS.

The total energy requirement for cooking would also decrease with the replacement of TCS: it would be reduced by 8.2% in CCA1, 20.0% in CCA2, 33.6% in CCA3, 42.2% in CCA4, 53.1% in CCA5, 60.0% in CCA6, and 56.9% in CCA7. The share of MICS in the total cooking energy mix would rise from 24.6% in CCA1 to 56.4% in CCA6.

Similarly, the share of HICS in the total cooking energy mix would increase to 12.3% in CCA6 as that compared to 0.2% in CCA1. The share of biomass briquette in the total cooking energy mix would increase to 9.4% under CCA6.

The shares of biogas, LPG and electric stoves would be 8.5%, 7.7%, and 5.8% in the total cooking energy mix under CCA6 scenario. CCA7 is a scenario in which 100% of the TCS are replaced by a combination of cleaner biomass technologies only such as MICS, HICS, biogas cookstoves, and biomass briquette cookstoves. When the traditional cookstoves are replaced completely by efficient biomass options, the share of MICS in the total energy requirement for cooking under CCA7 would rise to 57.1%, which is followed by HICS (14.1%), briquette stoves (11.6%), and biogas stoves (11.4%).

[21] In this study, the efficiency of HICS was considered to be 35% (considering rocket stoves) (AEPC 2008).

Table 9.2: Energy Requirements for Cooking under Different Cases,
(toe [in final energy terms])

Fuel and Technology Type	2014	2017	2022	2030
Base Case				
Biomass/TCS	40,401	42,760	47,002	54,683
Biomass/MICS	6,959	7,366	8,097	9,420
Biomass/ HICS	42	45	49	57
Biogas	189	200	220	255
Biomass Briquette	0	0	0	0
LPG	830	878	965	1,123
Electric	371	392	431	502
CCA1				
Biomass/TCS	32,321	34,208	37,602	43,746
Biomass/MICS	10,999	11,642	12,797	14,888
Biomass/ HICS	85	90	99	115
Biogas	189	200	220	255
Biomass Briquette	0	0	0	0
LPG	830	878	965	1,123
Electric	371	392	431	502
CCA2				
Biomass/TCS	24,240	25,656	28,201	32,810
Biomass/MICS	10,999	11,642	12,797	14,888
Biomass/ HICS	2,393	2,533	2,784	3,239
Biogas	189	200	220	255
Biomass Briquette	0	0	0	0
LPG	830	878	965	1123
Electric	371	392	431	502
CCA3				
Biomass/TCS	16,160	17,104	18,801	21,873
Biomass/MICS	10,999	11,642	12,797	14,888
Biomass/ HICS	2,393	2,533	2,784	3,239
Biogas	1,658	1,755	1,929	2,244
Biomass Briquette	0	0	0	0
LPG	830	878	965	1,123
Electric	371	392	431	502
CCA4				
Biomass/TCS	10,100	10,690	11,751	13,671
Biomass/MICS	10,999	11,642	12,797	14,888
Biomass/ HICS	2,393	2,533	2,784	3,239
Biogas	1,658	1,755	1,929	2,244
Biomass Briquette	1,836	1,944	2,136	2,486

continued on next page

Table 9.2 *continued*

Fuel and Technology Type	2014	2017	2022	2030
LPG	830	878	965	1,123
Electric	371	392	431	502
CCA5				
Biomass/TCS	4,040	4,276	4,700	5,468
Biomass/MICS	10,999	11642	12,797	14,888
Biomass/ HICS	2,393	2,533	2,784	3,239
Biogas	1,658	1,755	1,929	2,244
Biomass Briquette	1,836	1,944	2,136	2,486
LPG	830	878	965	1,123
Electric	1,128	1,194	1,313	1,527
CCA6				
Biomass/TCS	0	0	0	0
Biomass/MICS	10,999	11,642	12,797	14,888
Biomass/ HICS	2,393	2,533	2,784	3,239
Biogas	1,658	1,755	1,929	2,244
Biomass Briquette	1,836	1,944	2,136	2,486
LPG	1,503	1,591	1,749	2,034
Electric	1,128	1,194	1,313	1,527
CCA7				
Biomass/TCS	0	0	0	0
Biomass/MICS	12,010	12,711	13,972	16,255
Biomass/ HICS	2,971	3,144	3,456	4,021
Biogas	2,392	2,532	2,783	3,238
Biomass Briquette	2,449	2,592	2,849	3,314
LPG	830	878	965	1,123
Electric	371	392	431	502

CCA = cleaner cooking access case, HICS = highly efficient cookstove, LPG = liquefied petroleum gas, MICS = moderately improved cookstove, TCS = traditional cookstove.
Source: Authors.

9.3.2 Incremental Cost of Energy Access for Cleaner Cooking

As mentioned in Section 9.1, the incremental energy access cost (IEAC) of 100% replacement of traditional biomass cookstoves in this study is analyzed for two different cases: the first case estimates the IEAC for a combination of cleaner cooking options based only on biomass (including biogas) and the second case estimates IEAC considering the combination of both cleaner biomass and nonbiomass options.

Figures 9.2 and 9.3 show the IEAC curves for cooking in Pyuthan in 2017 and 2030 respectively under the cleaner cooking scenario CCA7, in which MICS and HICS each replaces 25% of TCS, while biogas stoves replace 30% of TCS and biomass briquette stoves replace 20%. In Figures 9.2 and 9.3, the horizontal width of a bar represents the reduction in biomass requirement associated with the use of a cleaner option as compared to that with the use of TCS, whereas the vertical axis represents the corresponding incremental costs.

The IEAC of the cleaner cooking options would range from –NRs8.1 to NRs4.5 per kgoe. As can be seen in the figures, the replacement of TCS with MICS and HICS involves a negative IEAC meaning that both of these cleaner options are in fact cost saving. The replacement of TCS with biogas and briquette stoves, would, on the other hand, involve a positive IEAC.

Note that since the study conducted the IEAC analysis for different years considering the fuel and device costs at constant prices of 2014 the IEAC values of different options would not change over the years; the absolute amount of biomass reduction potential would, however, be different in each year.

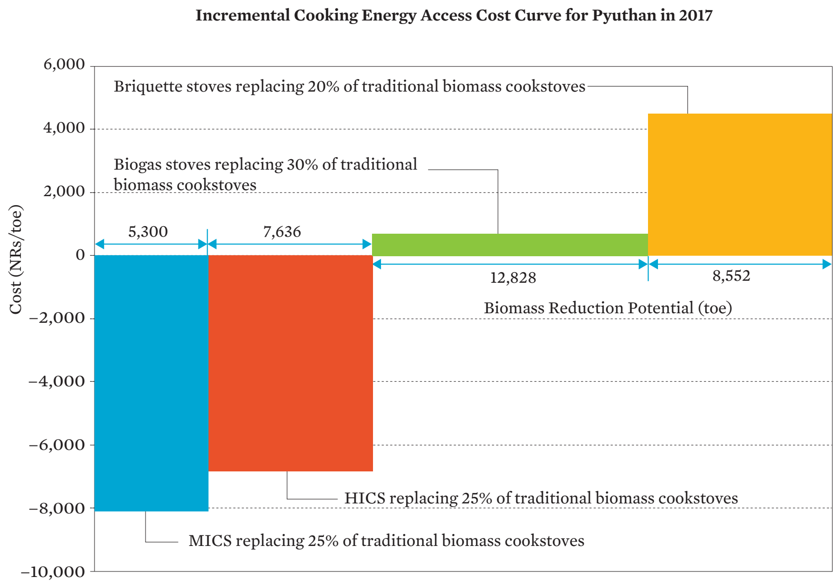
In CCA7 a 100% replacement of traditional biomass cookstoves by cleaner biomass options has a potential to reduce 34,316 toe of biomass in 2017. Of the total biomass saved, a 25% replacement of traditional biomass cookstoves by MICS could abate around 15.4% of biomass in 2017. A replacement of 25% of TCS by HICS would result in 22.3% reduction in the total biomass consumption in 2017 while a 30% replacement of TCS with biogas cookstoves would reduce the biomass consumption by 37.4%.

A 20% replacement of the traditional cookstoves with biomass briquette stoves would occupy a share of about 24.9% in the total biomass reduction under CCA7 scenario in 2017. Since the study considered same percentage replacements of traditional cookstoves by cleaner biomass cookstoves in 2022 and 2030 as that in 2017, the shares of cleaner technologies in the total biomass savings would remain the same in the selected years. It should also be noted that the reduction of biomass here refers to the reduction of solid biomass comprising of fuelwood and agricultural residues only.

If 100% of biomass-based cooking is not considered to be practical, a combination of more diversified cleaner options including the use of non-biomass-energy are to be considered to replace the use of biomass with TCS, e.g., CCA5 and CCA6. Figures 9.4 and 9.5 show the IEAC of different cleaner cooking options and the corresponding biomass reduction potential in the case of CCA6 in 2017 and 2030. The IEAC ranges from –NRs8.1 to NRs15.4 per kgoe if a combination of both biomass and non-biomass cooking options are considered. The figure shows that replacement of TCS with MICS and HICS would in fact be cost saving options (note the negative IEAC values), whereas the use of biogas to replace the biomass use in TCS would increase the cost slightly. The use of biomass briquette, electricity and LPG would increase the cost significantly. Note also that the IEAC of replacing biomass use in the TCS by biomass briquette stoves is higher (around NRs4.5 per kgoe) than the IEAC of replacing TCS by biogas cookstove (around NRs0.7 per kgoe). The IEAC of replacing the TCS by biomass briquette cookstove is almost the same as the IEAC of replacing the TCS by electric stoves. Note that although the absolute amount of biomass reduction potential of different options would change over the years, the IEAC values would remain the same as constant costs at 2014 prices are considered in the present analysis.

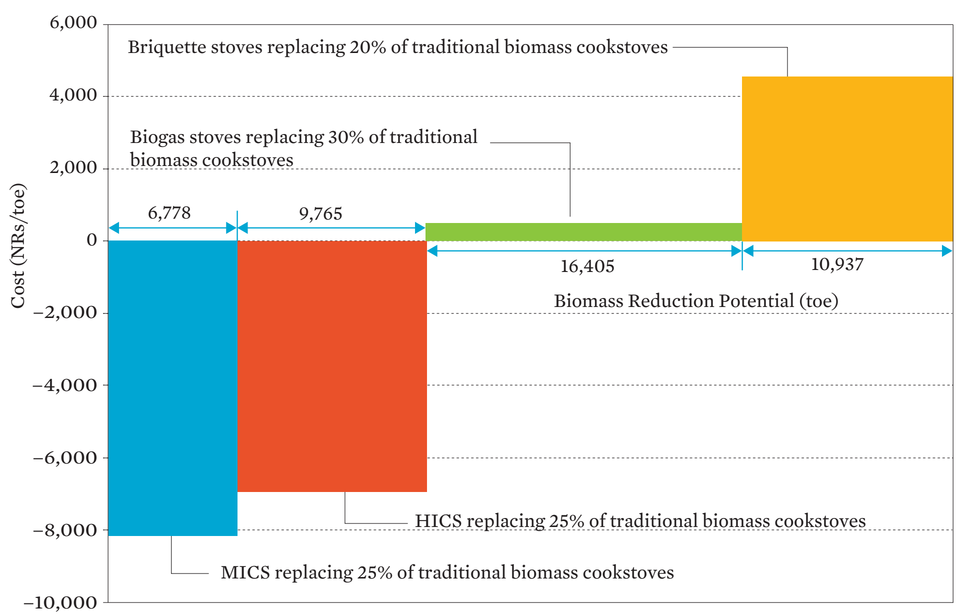
Of the total biomass saved in 2017, a 20% replacement of traditional biomass cookstoves by biogas stoves has the highest share of around 23.8% in the total biomass reduction under CCA6 case. This is followed by briquette and electric stoves which has a share of around 17.8% each

Figure 9.2: Incremental Energy Access Cost Curve for Cooking in Pyuthan with Cleaner Biomass Options Only, 2017



HICS = highly efficient improved cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient improved cookstove, NRs = Nepalese Rupees, toe = ton of oil equivalent.
Source: Authors.

Figure 9.3: Incremental Energy Access Cost Curve for Cooking in Pyuthan with Cleaner Biomass Options Only, 2030



HICS = highly efficient improved cookstove, MICS = moderately efficient improved cookstove, NRs = Nepalese Rupees, toe = ton of oil equivalent.
Source: Authors.

in the total biomass reduction in 2017. A 20% replacement of traditional biomass cookstoves by HICS has a share of 17.0% in the biomass reduction in 2017 while a 20% replacement by MICS has shares of about 11.8% and a 10% replacement by LPG has shares of about 11.9% in the same year under CCA6. It should be noted that as the study has considered the same percentage replacements of traditional cookstoves by cleaner biomass cookstoves, the share of cleaner technologies in the total biomass savings would remain the same in all the snapshot years (i.e., 2017, 2022, and 2030).

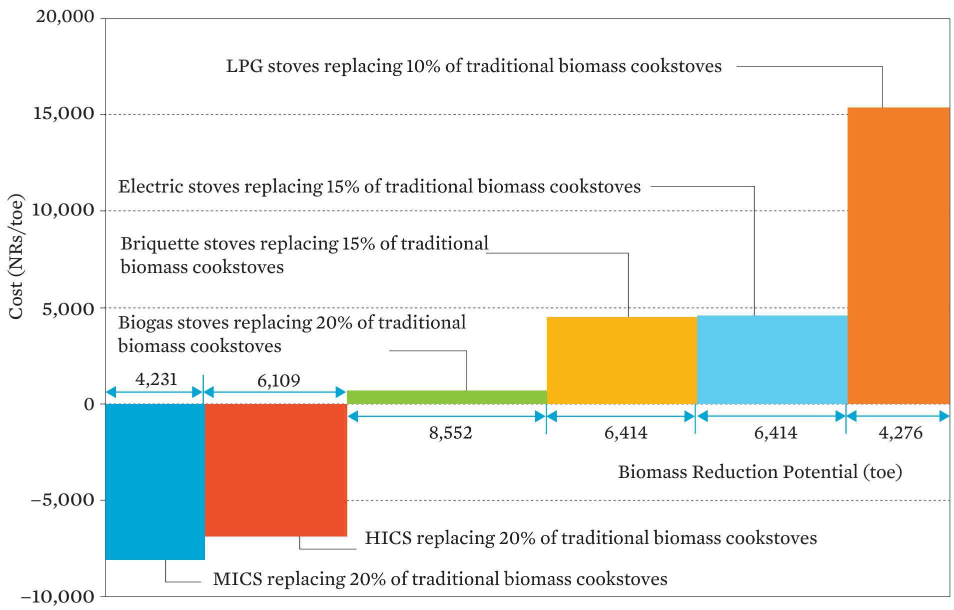
Table 9.3 shows the biomass reduction potential under each of the CCA scenarios. Note that under CCA7, i.e., replacement of 100% of the TCS with a combination of cleaner cooking options would avoid the total biomass requirement by around 34,316 toe in 2017; 37,720 toe in 2022; and 43,884 toe in 2030. These figures represent a 68.4% reduction from the total biomass requirement in the corresponding base case. In the case of CCA6 where both biomass and non-biomass options were considered, there would be a reduction in total biomass requirement for cooking of 35,996 toe in 2017; 39,567 toe in 2022; and 46,032 toe in 2030, or a reduction of about 72% of the biomass requirement in the corresponding base case.

Table 9.3: Biomass Reduction Potential with Clean Cooking Options in 2017, 2022, and 2030

Cases	Biomass Replacement Potential, toe		
	2017	2022	2030
CCA1: Replacing 20% of traditional biomass cookstoves by MICS	4,231	4,651	5,411
CCA2: Replacing 20% of traditional biomass cookstoves by MICS and 20% by HICS	10,340	11,366	13,223
CCA3: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS and 20% by biogas cookstoves	18,892	20,766	24,159
CCA4: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS, 20% by biogas and 15% by briquette cookstoves	25,306	27,816	32,362
CCA5: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS, 20% by biogas, 15% by briquette and 15% by electric cookstoves	31,720	34,867	40,564
CCA6: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS, 20% by biogas, 15% by briquette, 15% by electric and 10% by LPG cookstoves	35,996	39,567	46,032
CCA7: Replacing 25% of traditional biomass cookstoves by MICS, 25% by HICS, 30% by biogas and 20% by briquette cookstoves	34,316	37,720	43,884

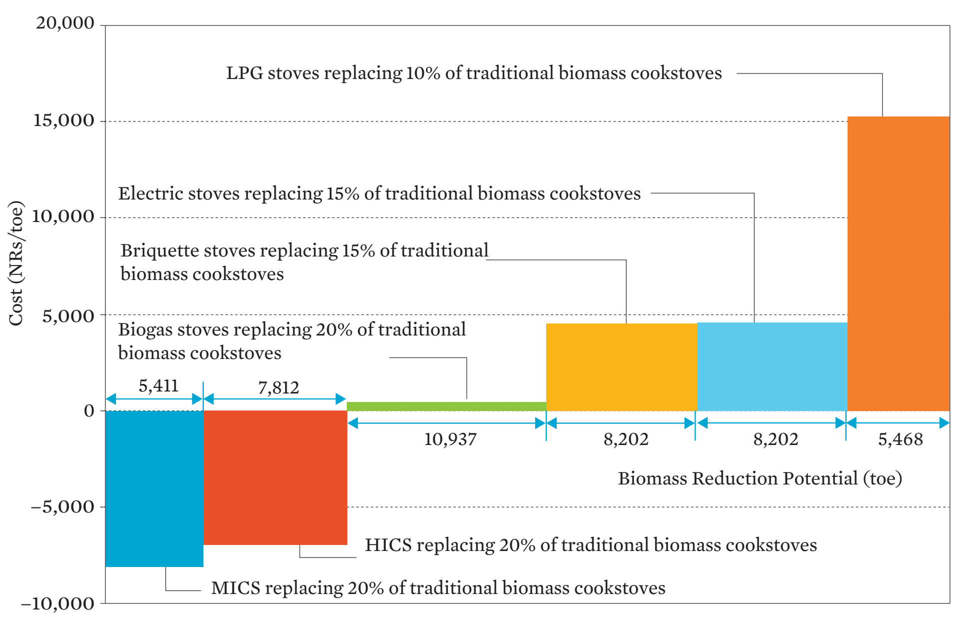
CCA = cleaner cooking access, HICS = highly efficient improved cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient improved cookstove, toe = ton of oil equivalent.
Source: Authors.

Figure 9.4: Incremental Energy Access Cost Curve for Cooking in Pyuthan in 2017 with Cleaner Biomass and Non-Biomass Options



HICS = highly efficient improved cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient improved cookstove, NRs = Nepalese Rupees, toe = ton of oil equivalent.
Source: Authors.

Figure 9.5: Incremental Energy Access Cost Curve for Cooking in Pyuthan in 2030 with Cleaner Biomass and Non-Biomass Options



HICS = highly efficient improved cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient improved cookstove, NRs = Nepalese Rupees, toe = ton of oil equivalent.
Source: Authors.

Table 9.4: Additional Investment Requirement with both Cleaner Biomass- and Non-Biomass-Cooking Technologies in 2017, 2022, and 2030

Cases	Additional Investment Requirement, million NRs		
	2017	2022	2030
CCA1: Replacing 20% of traditional biomass cookstoves by MICS	1.0	1.1	1.2
CCA2: Replacing 20% of traditional biomass cookstoves by MICS and 20% by HICS	9.5	10.4	11.9
CCA3: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS and 20% by biogas cookstoves	86.6	94.4	108.3
CCA4: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS, 20% by biogas and 15% by briquette cookstoves	86.9	94.7	108.7
CCA5: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS, 20% by biogas, 15% by briquette and 15% by electric cookstoves	89.3	97.4	111.7
CCA6: Replacing 20% of traditional biomass cookstoves by MICS, 20% by HICS, 20% by biogas, 15% by briquette, 15% by electric and 10% by LPG cookstoves	91.1	99.3	114.0
CCA7: Replacing 25% of traditional biomass cookstoves by MICS, 25% by HICS, 30% by biogas and 20% by briquette cookstoves	128.0	139.5	160.0

HICS = highly efficient improved cookstove, LPG = liquefied petroleum gas, MICS = moderately efficient improved cookstove.
Source: Authors.

Tables 9.4 presents the additional initial investment requirements for replacing TCS with cleaner options under different CCA scenarios. An initial investment in cooking devices of about NRs28 million in 2017, NRs30 million in 2022, and NRs35 million in 2030 would be required under the base case. The additional investment requirement under the CCA6 scenario would be NRs91.1 million in 2017 and NRs114.0 million in 2030. The additional investment requirement under the all cleaner biomass scenario (CCA7) would be NRs128 million in 2017 and it would increase to NRs160 million in 2030. Note that these figures are higher than the investment requirements under CCA6, which considers a combination of cleaner biomass and non-biomass options mainly because of the higher share in CCA7 of biogas, which requires a significantly higher investment.

9.4 Key Findings and Limitations

This chapter estimated the total biomass reduction potential and the additional investment requirements of various cleaner cooking options under seven different CCA scenarios. It has also estimated the incremental costs of different options for providing access to cleaner cooking energy. The cleaner cooking options considered in this analysis include MICS, HICS, briquette, biogas, LPG and electric cookstoves. According to the household survey conducted in the district in 2014, around 77% of the cooking energy demand is met by biomass using TCS (with 10% efficiency), this is followed by biomass using MICS (with 20% efficiency), LPG, electricity, and biogas. The survey showed insignificant share of HICS (with 30% efficiency) in the cooking technology-mix of the district.

The study found that if the present trend of using traditional biomass cookstoves is to continue in future, then its share would remain at 82.8% till 2030 under the base case. Under the CCA scenarios considered, the study has estimated that total biomas requirement could be reduced by 8% in CCA1, 21% in CCA2, 38% in CCA3, 50% in CCA4, 63% in CCA5, 72% in CCA6, and 68% in CCA7 as compared to the total biomass requirement in the base case.

The study calculated the IEAC of different cleaner cooking options and determined the potential for biomass reduction of the options under two different scenarios aimed at 100% replacement of the traditional biomass based cookstoves: (i) with cleaner biomass-based cooking options (CCA7) and (ii) with diversified cleaner options including both cleaner biomass- and non-biomass based options (CCA6). In CC7, the scenario with only the cleaner biomass options, IEACs are negative for replacing TCS with MICS (–NRs8.1 per kgoe) and HICS (–NRs6.8 per kgoe), meaning that these are in fact cost saving options. A positive IEAC is incurred when replacing TCS with biogas stoves (NRs0.7 per kgoe) and briquette stoves (NRs4.5 per kgoe). Under CCA6, a significant increase in IEAC is associated with replacing TCS with electric cookstoves (NRs4.5 per kgoe) and LPG cookstoves (NRs15.4 per kgoe), while the IEAC of biomass options are the same as stated in the case of CCA7.

An important point to note is that at the prices considered in this study, use of biomass briquette for cooking would be a more expensive option than biogas. It is estimated that replacing 100% of the traditional biomass cookstoves by a combination of MICS, HICS, biogas, briquette, electric and LPG cookstoves under the hybrid scenario of CCA6 would require additional investments of NRs91.1 million in 2017, NRs99.3 million in 2022 and NRs114.0 million in 2030. Similarly replacing 100% of the traditional biomass cookstoves by a combination of MICS, HICS, briquette and biogas cookstoves under the biomass-only scenario of CCA7 would require additional investments of NRs128.0 million in 2017, NRs139.5 million in 2022 and NRs160.0 million in 2030.

10

Benefits of Energy Access Programs

10.1 Introduction

Access to cleaner energy can generate different kinds of benefits, i.e., environmental, health, and social (i.e., education, employment, reduction of human drudgery, etc.) at the local level, energy security benefits at the national level, and greenhouse gas (GHG) reduction at the global level. The objective of benefit assessment in this study is to estimate the different benefits of increased access to modern energy services in the district. This chapter discusses the assessment of benefits of electricity and cleaner cooking energy access in terms of time savings, education, health, and reduction in the emissions of indoor air pollutants and GHGs. This chapter assesses the implications of electricity access on energy security, productive activities, and energy inequality.

10.2 Methodology

Potential benefits of energy access include improved lighting, educational benefits, better health, employment opportunities, less human drudgery, energy security benefits, reduced GHG emissions, reduced local pollutants, less energy inequality, and other economic benefits (Shrestha and Acharya 2015). Generally, the benefits associated with energy access should be quantified after providing access. As the survey conducted for this study purpose provides information for a given time (2014), the survey data cannot quantify both the present and future benefits. However, an attempt was made in this study to quantify benefits by comparing village development committees (VDCs) that are already electrified with the VDCs without cleaner energy access. The following describes the methodology used in this study to quantify benefits of cleaner energy access:

(i) **Time Savings.** Based on the sustainable energy access planning (SEAP) framework, this study considered the opportunity cost approach to value the amount of time saved. This study estimated the amount of time that would have been saved by using cleaner energy resource instead of using traditional resources and approximated the monetary benefits associated with the use of cleaner energy using the average monthly income and the amount of time spent on collecting and purchasing traditional fuels.

(ii) **Reduction in Indoor Air Pollution and GHG Emissions.** The reductions in indoor air pollution and GHG emissions due to improved lighting and cleaner cooking access were quantified in this study. For this, the study estimated the total emissions both with and without the energy access program. In cases of both with and without an energy access program, the emissions of GHGs and air pollutants were estimated as the product of the amount of fuel consumed by the type of end use and its associated emission factor. The local air pollutants considered in this study include: particulate matter 10 (PM_{10}), carbon monoxide (CO), oxides of nitrogen (NO_X), and black carbon

(BC) while the GHG emissions include carbon dioxide (CO_2) besides black carbon. Apart from this, sulfur dioxide (SO_2) is also estimated for residential cooking. The emission factors used for the estimation of pollutants for lighting and cooking are presented in Appendixes 27 and 28. For details, refer to Equations 7.5 to 7.9 in Chapter 7 of the SEAP framework.

(iii) **Greater Energy Security.** This study considered two different indicators for measuring energy access: by calculating the share of imported energy in total energy consumption and diversification in the mix of energy resources. Reduction in the share of imported energy in the total energy consumption indicates the degree of improvement of energy security with an energy access program. The effects of diversification of energy resources in this study were measured using the Shannon-Wiener Index (more details are in the SEAP framework and Grubb et al. 2006). This index indicates that the higher value implies higher diversification of energy supply mix.

(iv) **Increased Productive Activity.** The increase in the level of productivity could be estimated from the market value of the incremental output. However, in this study the increase in productive activities was quantified based on the increased volume of output with and without cleaner energy access, increased number of households running small home businesses with electricity access, and increased level of income from the productive activities with and without cleaner energy access.

(v) **Educational Benefit.** The educational benefits due to the electricity access program could be assessed in terms of the increased number of study hours with the access to electricity and the improvement in terms of income prospects expressed in terms of monetary value based on increase in earnings due to higher educational achievement from electricity access. However, in this study educational benefits in terms of increased number of study hours were quantified while the higher future earnings benefit was not assessed in this report. Refer to Equation 7.3 of Chapter 7 of the SEAP framework for more details.

(vi) **Health Benefit.** Health benefits due to an energy access program in this study were quantified based on the cost savings due to a lesser number of hospital visits attributable to the energy access program. Since the survey was conducted only for a particular year, it provided data for only a specific point in time; it would not be possible to quantify such benefits in the future. However, an attempt was made in this study to quantify such benefits by making a comparison between the VDCs with and without cleaner energy access (Refer to Equation 7.2 in Chapter 7 of the SEAP framework).

(vii) **Reduced Energy Inequality.** To evaluate the effects of electricity access programs on electricity inequality, a measure called electricity Gini coefficient was used (see Chapter 7 in the SEAP Framework). The Gini coefficient measures inequality of a distribution. The electricity Gini coefficient is a concept similar to the income Gini coefficient, which is used to measure income inequality of a population with the difference being that the electricity Gini coefficient deals with the cumulative distribution of energy consumption and cumulative distribution of population (note that the standard income Gini coefficient deals with the cumulative distribution of income and population). An energy Gini coefficient is defined similarly and used to measure the effect of an energy access program on energy inequality.[22]

[22] Appendix 6 of the SEAP Framework details the steps involved in the calculation of Gini-coefficient.

Gini coefficient of annual income, electricity, and total energy consumption are calculated for the whole Pyuthan district and for each of the 49 VDCs. Altogether, 2,330 sample households from the 49 VDCs were considered in the calculation.

10.3 Benefits of Electricity Access

This section presents the estimated benefits associated with increased electricity access in terms of time savings, reduction in indoor air pollution and GHG emissions, energy security, increase in productive activities, improved health and increased education benefits.

10.3.1 Time Saving in the Collection of Non-electric Fuels for Lighting

Kerosene, pinewood stick, candle, etc. are the traditional sources of lighting used in the district. Although there are batteries now that store electricity for later use, not many households prefer them due to their limited capacity and high price. The use of electricity for lighting leads to proper and efficient lighting in homes. With the use of electricity for lighting, time for collecting traditional sources of lighting will also be saved.

The potential time savings from the collection of kerosene and its estimated equivalent monetary benefit for each VDC of Pyuthan district are presented in Table 10.1. To obtain the average monthly hours saved in buying kerosene per household in this study, the average time spent per visit in buying kerosene per month is multiplied by the frequency of visits made by the household in a month for buying kerosene. The annual time saving is derived based on the information on average monthly hours saved. In the present study, the amount of time spent per visit in buying kerosene was estimated from the household survey data. However, the data on the frequency of a household's visit to the market to purchase kerosene for lighting are not generated by the survey. As such, this study estimates the potential time savings and the corresponding monetary benefit in a case of buying kerosene four times a month. As mentioned in Section 10.2 of this chapter, the monetary benefit associated with time savings due to increased electricity access was estimated using the opportunity cost approach.[23]

On average, if it is assumed that a household buys kerosene four times a month then the time savings for a household in the district by using electricity instead of other fuels like kerosene, battery, pinewood stick, candle, etc. was estimated to be 35 hours per year, the equivalent monetary value of which is NRs3,297 per year. However, across the VDCs the estimated time savings for purchasing kerosene was found to vary from as high as 97 hours in Dharampani to as low as 1 hour in Ligha.

[23] To estimate the benefit, the monthly average income per household per VDC has been estimated from the total average yearly income per VDC obtained from the household survey. From the estimated average monthly income, the daily and hourly average incomes per household are calculated by assuming the average working days per month as 25 and the average working hours per day as 7.

Table 10.1: Time Savings for the Collection of Kerosene

No.	Village Development Committee	Kerosene buying 4 times a month: Average yearly hours saved per Household	Kerosene buying 4 times a month: Benefit in NRs
1	Arkha	5	456
2	Badikot	17	1,442
3	Bangesal	2	157
4	Baraula	22	2,025
5	Barjiwang	31	2,555
6	Belbas	26	2,046
7	Bhingri	42	4,069
8	Bijayanagar	90	8,485
9	Bijuwar	70	6,471
10	Bijuli	65	6,512
11	Chuja	55	4,519
12	Dakhakwadi	11	860
13	Damri	14	986
14	Dangwang	90	7,945
15	Dharampani	97	10,010
16	Dharmawoti	36	3,379
17	Udayapurkot	14	668
18	Dhuwang	32	1,314
19	Dhungegadhi	5	453
20	Gothiwang	33	2,267
21	Hansapur	4	197
22	Jumrikanda	79	6,323
23	Khaira	72	6,866
24	Khawang	9	842
25	Khung	3	283
26	Kochiwang	10	612
27	Ligha	1	87
28	Liwang	48	4,131
29	Lung	30	2,005
30	Majhakot	51	3,569
31	Maranthana	76	7,144
32	Markawang	23	1,745
33	Narikot	30	2,731
34	Nayagaon	35	4,135
35	Okherkot	27	3,225
36	Pakala	22	2,239
37	Phopli	2	181

continued on next page

Table 10.1 *continued*

No.	Village Development Committee	Kerosene buying 4 times a month	
		Average yearly hours saved per Household	Benefit in NRs
38	Puja	3	353
39	Khalanga	49	5,322
40	Rajbara	2	311
41	Ramdi	44	3,904
42	Raspurkot	59	4,690
43	Saari	63	5,738
44	Swargadwari Khaal	5	421
45	Syauliwang	12	999
46	Tiram	13	679
47	Turwang	96	16,837
48	Tusara	74	7,142
49	Bangemarot	22	2,228
	Total Average	**35**	**3,297**

No. = number, NRs = Nepalese rupees.
Source: Authors.

10.3.2 Reduction in Indoor Air Pollution and Greenhouse Gas Emissions

The reduction in indoor air pollution and GHG emissions in this study were assessed based on the approach described in the SEAP Framework. The indoor air pollutants and GHG emissions due to non-electric sources of lighting (kerosene, pinewood stick, candle, biogas, and liquefied petroleum gas [LPG]) for each VDC in the years 2014, 2017, 2022 and 2030 are presented in Appendix 29. The emissions in 2017, 2022, and 2030 were estimated based on the projected level of consumption of non-electric energy sources used for lighting. The analysis found that replacement of kerosene, candle, and pinewood stick based lighting with electricity could result in emission abatements of around 41,275 kilograms (kg) of BC, 7,747 kg of CO, 4,844 kg of PM_{10}, 669 kg of NO_X, and 1,433 ton of CO_2 emissions in 2017. Similarly, it could abate around 47,357 kg of BC, 8,888 kg of CO, 5,558 kg of PM_{10}, 767 kg of NO_X and 1,644 tons of CO_2 emissions in 2022. In 2030, lighting with electricity could abate around 62,342 kg of BC, 11,701 kg of CO, 7,317 kg of PM_{10}, 1,010 kg of NO_X and 2,165 tons of CO_2 emissions in 2030.

10.3.3 Energy Security

Energy access programs can increase the energy security in two different ways, i.e., through diversification of the energy resource mix and reduction of the share of imported energy or fuels in total energy consumption. Each of these effects is described next.

a. Effect on Energy Diversification

Energy mix diversification in this study is measured through the Shannon-Wiener (SW) index (the SEAP Framework and Grubb, Butler, and Twomey 2006 has further details).

Table 10.2: Shannon-Wiener Index of Energy Resource Mix in Pyuthan District

Cases	2014	2017	2022	2030
Base	0.28	0.25	0.23	0.22
ELA 1	–	0.21	0.19	0.18
ELA 2	–	0.20	0.21	0.33
ELA 3	–	0.23	0.35	0.38

ELA = electricity access case.
Source: Authors.

With other things remaining the same, higher energy mix diversification means higher level of energy security. The level of energy mix diversification in this study is assessed for three different energy access cases (ELA), called ELA1, ELA2, and ELA3 (See Table 6.1) besides the base case. This study assumed that with access to electricity, kerosene, candle, and pinewood stick will not be used for lighting in the years 2017, 2022, and 2030. The SW Index is calculated for the Pyuthan district as a whole and also for a few selected VDCs of the district under the different electricity access cases. Table 10.2 presents the SW Index for the Pyuthan district and Table 10.3 shows the SW Index for the selected VDCs of the district.

Table 10.3: Shannon-Wiener Index of Selected Village Development Committees

Cases	2014	2017	2022	2030
Damri				
Base case	0.06	0.20	0.20	0.20
ELA1		0.20	0.20	0.20
ELA2		0.20	0.21	0.27
ELA3		0.21	0.28	0.30
Dakhakwadi				
Base case	0.20	0.40	0.41	0.41
ELA1		0.40	0.40	0.41
ELA2		0.40	0.41	0.52
ELA3		0.41	0.55	0.60
Arkha				
Base case	0.60	0.65	0.65	0.65
ELA1		0.65	0.66	0.68
ELA2		0.66	0.68	0.77
ELA3		0.68	0.77	0.81
Bijuwar				
Base case	0.24	0.35	0.36	0.37
ELA1		0.33	0.34	0.37
ELA2		0.33	0.35	0.46
ELA3		0.35	0.48	0.54

continued on next page

Table 10.3 *continued*

Cases	2014	2017	2022	2030
Tirram				
Base case	0.11	0.14	0.14	0.16
ELA1		0.13	0.14	0.17
ELA2		0.14	0.16	0.28
ELA3		0.15	0.28	0.35
Okherkot				
Base case	0.13	0.15	0.16	0.17
ELA1		0.14	0.15	0.16
ELA2		0.14	0.15	0.27
ELA3		0.15	0.28	0.34
Jumrikanda				
Base case	0.08	0.09	0.10	0.10
ELA1		0.05	0.06	0.10
ELA2		0.06	0.10	0.26
ELA3		0.10	0.27	0.34
Badikot				
Base case	0.48	0.64	0.65	0.66
ELA1		0.62	0.63	0.65
ELA2		0.62	0.64	0.75
ELA3		0.64	0.76	0.81
Khalanga				
Base case	0.18	0.20	0.21	0.23
ELA1		0.19	0.20	0.23
ELA2		0.19	0.21	0.29
ELA3		0.19	0.29	0.35

ELA = electricity access case.
Source: Authors.

As can be seen from Table 10.2, the value of the SW Index of the district in the base case varies from 0.28 in 2014 to 0.22 in 2030. With 100% electrification from 2017 onwards (i.e., replacement of kerosene, candle, or pinewood stick for lighting by electricity), the SW Index would be declining under the ELA1 case as that compared to the base case. The reason for the base case being more diversified is the usage of many types of fuels which includes kerosene, candle, as well as pinewood stick. As mentioned earlier, in the electrification cases these fuels have been replaced by electricity. As the level of electricity supplied under the ELA1 case is not significantly high as compared to the base case, the SW Index would be in the lower range. However, with the increased level of electricity access under ELA2 and ELA3 cases, the SW Index of the district would improve mostly from 2022 onward.

As Table 10.3 shows, the SW Index was found to vary widely across the selected VDCs, i.e., from as low as 0.09 in Jumrikanda VDC to as high as 0.65 in Arkha VDC in the base case in 2017. It should be noted that in the base case, the SW Index of electrified VDCs such as Dakhakwadi is higher (i.e., the VDC is more energy diversified) than that of partially off-grid electrified VDC (e.g., Damri VDC) and has a lower SW Index. With increased electricity consumption in the higher electricity access cases (such as ELA2 and ELA3), the value of the SW Index was found to increase (that is, there would be a greater energy diversification with the higher level of electricity access).

In 2014 the SW Index of grid electrified VDCs such as Arkha, Bijuwar, Tirram and Okherkot are higher than that of the partially off-grid electrified VDC Damri (Table 10.3). Although, the table presents the SW index of selected VDCs, it gives an indication of the difference between the fully electrified and partially electrified VDCs.

b. Reduction in Imported Energy or Fuel Use

The level of reduction in the share of imported energy shows the extent of energy security improvement with an energy access program. Kerosene and LPG are the two imported fuels in Pyuthan district. Fuelwood and agricultural residues are the major sources of energy in Pyuthan, and imported energy (both kerosene and LPG) has a share of around 1% only in the total energy consumption of the district in 2014 (Table 10.4). In 2014, kerosene had a share of around 0.6% in the total energy consumption of the district, and was used mainly for lighting. According to the household survey data, electricity had a share of around 1.2% in the total energy consumption in 2014. Under the base case, imported fossil fuels were found to occupy a share of 1.2% by 2030, among which 0.8% of the share was occupied by kerosene. The share of imported fossil fuels would reduce to 0.36% under ELA1, 0.35% under ELA2, and 0.34% under ELA3, by 2030 (since kerosene for lighting had been replaced with electricity, this share was only due to LPG consumption for cooking). Khalanga, the district headquarters of Pyuthan, has the highest share of imported fuel of 4% due to a relatively higher LPG consumption in the VDC.

Table 10.4: Share of Imported Fossil Fuels in Total Energy Consumption under Different Cases
(%)

Case	2014	2017	2022	2030
Base	0.92	0.96	1.03	1.17
ELA1	0.92	0.30	0.32	0.36
ELA2	0.92	0.30	0.32	0.35
ELA3	0.92	0.30	0.31	0.34

ELA = energy access case.
Source: Authors.

10.3.4 Increase in Productive Activities

The increase in productive activities is quantified based on the number of households running small home businesses and the average income of households with and without cleaner energy access. Among the 2,330 surveyed households in the district, around 60 households had family businesses. Out of the 60 households with family businesses, around 54 (4% of the total 1,377 electrified households) were electrified by grid connection, microhydro and/or solar home system. Only 1% of the unelectrified households owned family businesses in the district.

From the survey, it was found that around 90% of the households who owned family businesses had access to electricity. This indicates that increasing households' access to electricity may contribute to a rise in the number of family businesses. The survey showed that the average annual income of unelectrified households is less than those of the electrified households. Based on the survey, it was found that the average annual income of the unelectrified households was around NRs133,406 while that of the electrified households was around NRs199,384. While several factors could affect the average household income, a considerable difference in income is observed between electrified and unelectrified households.

Table 10.5 shows the average annual incomes of electrified and unelectrified households of selected VDCs of Pyuthan. Although it is difficult to draw a definitive conclusion based on the results of small number of VDCs, the table shows the possibility of significantly higher average income by electrified households.

Table 10.5: Average Annual Income of Electrified and Unelectrified Households of Different Village Development Committees
(in NRs)

Village Development Committees	Average Annual Income of Unelectrified Households	Average Annual Income of Electrified Households
Badikot	88,282	195,458
Dhuwang	81,609	90,116
Majhakot	120,784	161,688
Nayagaon	171,065	252,602
Turwang	113,588	400,193

Source: Authors.

10.3.5 Education Benefit

Education benefits due to the electricity access program in this study were assessed in terms of the increased number of study hours with electricity access (Table 10.6). Based on the household survey conducted for the study in 2014, it was found that, on the average, students in electrified households in the district spend about 1.38 hours per day for studies at home as compared to 0.83 hours in unelectrified households. This shows that there could be significant education benefits from electricity access.

Table 10.6 shows that the average study hours per student in electrified households are higher than those in unelectrified households.

Similarly it was observed that the average study hours of fully electrified VDCs are more compared to that of the partially electrified VDCs. For example, based on the information obtained from the survey, the average study hour of fully electrified VDCs like Dakhakwadi and Khaira is 1.42. The average study hours for partially electrified VDCs are lower, such as in Ligha (0.97) and Kochiwang (1.1).

Table 10.6: Average Study Hours in Selected Electrified and Unelectrified Households, 2014

Village Development Committees	Average Study Hour of Unelectrified Households	Average Study Hour of Electrified Households	Increase in Average Study Hours if Electrified, %
Arkha	0.38	0.65	42
Hansapur	0.93	1.07	13
Makarwang	0.45	1.47	69
Khalanga	0.77	1.40	45
Badikot	0.55	1.71	68

Source: Authors.

10.3.6 Health Benefits

Health benefits due to an electricity access program can be quantified based on the cost savings due to a reduced number of hospital visits with electricity access. Since the survey provides data for only a specific point in time, it is not possible to quantify such benefits before and after electrification. However, one way to quantify such benefit could be to compare between the relevant indicator in the areas with and without clean electricity access. The average number of annual absent days at the district level due to illness in unelectrified households was estimated to be 12 days, while the average for electrified households is 9 days. The estimated average number of hospital visits per year is obtained to be same (2.4) in both cases.

Table 10.7 compares the average numbers of absent days and hospital visits by households between a few fully electrified and partially off-grid electrified VDCs. Although various factors could affect the health status of the villagers, the survey reveals that the number of absent days in fully electrified VDCs is much less than those in partially off-grid electrified VDCs. No significant difference was observed between the fully electrified and partially electrified VDCs in terms of the average number of hospital visits per household. Even though it is difficult to draw a general conclusion from the results of the fewer number of VDCs, the table gives an indication that the electrified households have lower average annual absent days due to health problems than those of the unelectrified households.

Table 10.7: Comparison of Average Absent Days and Hospital Visits in Selected Fully Electrified and Partially Electrified Village Development Committees

Village Development Committees	Electrification Status	Average Annual Absent Days due to Health Problems	Average Hospital Visits per year
Dakhakwadi	Fully Electrified	12	2.4
Khaira	Fully Electrified	14	2.8
Damri	Partially off-grid electrified	32	3.3
Ligha	Partially off-grid electrified	19	2.3

Source: Authors.

10.4 Benefits of Access to Cleaner Cooking

10.4.1 Time Saving in the Collection of Fuelwood for Cooking

Fuelwood and agricultural residues are the traditional sources of energy mostly used for cooking in Pyuthan. Considerable time could be involved in collecting or purchasing these fuels for cooking. Collection and buying time, however, can be saved if households switch to modern fuels such as LPG and biogas.

Given the present trend in the country, it has been assumed in this study that the traditional sources of fuels for cooking will be replaced by LPG in the future. The potential time saved after switching from traditional fuels to LPG for each VDC of Pyuthan is tabulated in Table 10.8.

On the average, the annual time saved by a household by using LPG instead of fuelwood and agriculture residues for cooking was found to be 368 hours. In monetary terms, this is equivalent to NRs32,638 per year. If biogas is used instead of LPG then additional time and potential money can be saved as biogas is produced within the house and no time will be devoted to purchasing it from the market. It also reduces the problem of energy security as biogas is an indigenous energy resource whereas LPG is imported from abroad.

Table 10.8: Time Saved for Collection of Fuelwood for Cooking

Village Development Committee	Average annual hours saved by using LPG	Average annual household benefit by using LPG (in NRs)
Arkha	795	76,601
Badikot	382	32,263
Bangesal	429	31,422
Baraula	416	38,951
Barjiwang	243	19,767
Belbas	360	28,311
Bhingri	493	47,712
Bijayanagar	288	27,266
Bijuwar	148	13,693
Bijuli	444	44,426
Chuja	206	16,979
Dakhakwadi	245	19,753
Damri	394	27,412
Dangwang	518	45,627
Dharampani	161	16,645
Dharmawoti	163	15,444
Udayapurkot	531	25,412
Dhuwang	260	10,768

continued on next page

Table 10.8 *continued*

Village Development Committee	Average annual hours saved by using LPG	Average annual household benefit by using LPG (in NRs)
Dhungegadhi	403	38,620
Gothiwang	309	21,249
Hansapur	366	18,214
Jumrikanda	345	27,579
Khaira	87	8,320
Khawang	405	36,038
Khung	426	45,978
Kochiwang	572	34,814
Ligha	545	35,513
Liwang	348	29,990
Lung	359	24,345
Majhakot	243	16,952
Maranthana	209	19,669
Markawang	330	25,009
Narikot	311	28,287
Nayagaon	613	73,128
Okherkot	225	27,180
Pakala	967	100,264
Phopli	223	19,666
Puja	438	55,675
Khalanga	228	24,872
Rajbara	481	63,332
Ramdi	167	14,845
Raspurkot	413	33,081
Saari	239	21,883
Swargadwari Khaal	308	24,651
Syauliwang	577	48,821
Tiram	461	24,214
Turwang	283	49,866
Tusara	242	23,277
Bangemarot	444	45,462

LPG = liquefied petroleum gas.
Source: Authors.

10.4.2 Reduction in Indoor Air Pollution due to Cleaner Cooking

Table 10.9 presents the amount of indoor air pollution for selected pollutants due to residential cooking under different cleaner cooking scenarios. It can be seen that replacing only 20% of the traditional biomass cookstoves (TCS) by the moderately efficient improved cookstoves

(MICS) could abate around 9% of PM_{10}, BC, and CO emissions and 8% of SO_2 and NO_X emissions in 2017, 2022, and 2030 as compared to the base case (which assumes continuous use of TCS). It should be noted that since the study assumed the same percentage in all the selected years for the replacement of TCS by the combination of different cleaner cookstoves, the percentage of emissions reduction would be same in all the snapshot years. PM_{10} emissions would reduce by around 22% under CCA2, 39% under CCA3, 52% under CCA4, 65% under CCA5, and 73% under CCA6 from the base case values. Similarly, BC emissions would be abated by around 21% under CCA2, 38% under CCA3, 51% under CCA4, 63% under CCA5, and 72% under CCA6.

Table 10.9: Reduction in Indoor Air Pollution due to Cleaner Residential Cooking (thousand kg)

Cases/Emission Type	2014	2017	2022	2030
PM_{10} emission				
Base	523.6	554.2	609.2	708.7
CCA1	523.6	506.9	557.2	648.2
CCA2	523.6	431.8	474.6	552.1
CCA3	523.6	338	371.5	432.2
CCA4	523.6	267	293.5	341.5
CCA5	523.6	196.1	215.5	250.8
CCA6	523.6	148.9	163.7	190.5
BC emission				
Base	94.7	100.2	110.1	128.1
CCA1	94.7	91.7	100.8	117.2
CCA2	94.7	79.3	87.2	101.5
CCA3	94.7	62.3	68.5	79.7
CCA4	94.7	49.5	54.4	63.3
CCA5	94.7	36.7	40.4	47
CCA6	94.7	28.2	31	36.1
SO_2 emission				
Base	5.1	5.4	6	6.9
CCA1	5.1	5	5.5	6.4
CCA2	5.1	4.2	4.6	5.3
CCA3	5.1	4.4	4.8	5.6
CCA4	5.1	3.7	4.1	4.8
CCA5	5.1	3.1	3.4	3.9
CCA6	5.1	2.9	3.1	3.6
NO_X emission				
Base	28.1	29.7	32.7	38
CCA1	28.1	27.4	30.1	35
CCA2	28.1	23.3	25.6	29.8

continued on next page

Table 10.9 *continued*

Cases/Emission Type	2014	2017	2022	2030
CCA3	28.1	24.3	26.7	31.1
CCA4	28.1	20.8	22.8	26.6
CCA5	28.1	17.2	18.9	22
CCA6	28.1	15.9	17.5	20.4
CO emission				
Base	9,736.1	10,304.7	11,327.0	13,177.9
CCA1	9,736.1	9,426.5	10,361.7	12,054.9
CCA2	9,736.1	8,101.7	8,905.4	10,360.7
CCA3	9,736.1	6,357.4	6,988.1	8,130.0
CCA4	9,736.1	5,040.1	5,540.1	6,445.4
CCA5	9,736.1	3,722.8	4,092.1	4,760.8
CCA6	9,736.1	2,846.9	3,129.4	3,640.7

BC = black carbon, CCA = cleaner cooking access case, CO = carbon monoxide, HICS = highly efficient improved cookstoves, MICS = moderately efficient improved cookstoves, NO_x = nitrous oxide, PM = particulate matter, SO_2 = sulfur dioxide, TCS = traditional cookstoves.
Note: CCA1: Replacing 20% of TCS by MICS; CCA2: Replacing 20% of TCS by MICS and another 20% by HICS; CCA3: Replacing 20% of TCS by MICS, 20% by HICS and another 20% by biogas cookstoves; CCA4: Replacing 20% of TCS by MICS, 20% by HICS, 20% by biogas and another 15% by briquette cookstoves; CCA5: Replacing 20% of TCS by MICS, 20% by HICS, 20% by biogas, 15% by briquette and another 15% by electric cookstoves; CCA6: Replacing 20% of TCS by MICS, 20% by HICS, 20% by biogas, 15% by briquette, 15% by electric and another 10% by LPG cookstoves.
Source: Authors.

10.5 Effects on Energy- and Electricity-Inequality

Energy access, be it access to electricity or access to cleaner energy for cooking and other services, is expected to reduce the inequality in energy use in the area where an energy access program is introduced. To assess the effect of electricity access programs on electricity inequality, a measure called electricity Gini coefficient is used (Chapter 7 in the SEAP Framework has more details). The electricity Gini coefficient is a concept similar to the income Gini coefficient, which is used as a measure of income inequality of a population with the difference being that the electricity Gini coefficient deals with the cumulative distribution of electricity consumption and cumulative distribution of population (the standard income Gini coefficient deals with the cumulative distribution of income and cumulative distribution of population). An energy Gini coefficient is defined similarly and used to measure the effect of an energy access program on energy inequality. Table 10.10 shows the income, electricity consumption, and total energy consumption Gini coefficients of Pyuthan district under the base case in 2014. Similarly, the VDC-wise Gini coefficients in 2014 are presented in Table 10.11. As can be seen from Table 10.10, there was a relatively higher level of inequality in electricity consumption in the district than the income inequality. On the contrary, the population in the district appears to face smaller inequality in terms of energy consumption than that in income distribution.

There is a larger level of inequality in electricity consumption than in the distribution of income in all but four VDCs: Bijuli, Khawang, Ramdi and Raspurkot (Table 10.11). The opposite is mostly the case in terms of the inequality in total energy consumption: there is smaller inequality in terms of total energy consumption than that in income distribution in all but eight VDCs: Bangesal, Bhingri, Dakhakwadi, Khaira, Nayagaon, Phopli, Khalanga, and Tusara.

The table also shows that the inequality in terms of electricity consumption is larger than the inequality in terms of total energy consumption in all but six VDCs: Bhingri, Bijuli, Dakhakwadi, Khaira, Nayagaon, and Pakala. It should be noted from the table that 16 out of 49 VDCs were found to have an electricity Gini coefficient above 0.60.

Table 10.10: Electricity, Total Energy, and Income Gini Coefficients of Pyuthan District under the Base Case, 2014

Type (yearly)	Gini Coefficient
Income	0.421
Electricity consumption	0.663
Total energy consumption	0.393

Source: Authors

Table 10.11: Income, Electricity, and Total Energy Gini Coefficients in the Village Development Committees of Pyuthan District in the Base Case (without an Electricity Access Program), 2014

Village Development Committee	Income Gini Coefficient	Electricity Gini Coefficient	Total Energy Gini Coefficient
Arkha	0.383	0.455	0.317
Badikot	0.393	0.620	0.358
Bangesal	0.456	0.706	0.497
Baraula	0.543	0.634	0.366
Barjiwang	0.257	0.391	0.157
Belbas	0.351	0.688	0.238
Bhingri	0.423	0.453	0.454
Bijayanagar	0.385	0.514	0.212
Bijuwar	0.395	0.498	0.241
Bijuli	0.570	0.418	0.442
Chuja	0.428	0.811	0.326
Dakhakwadi	0.283	0.395	0.420
Damri	0.404	0.598	0.408
Dangwang	0.490	0.679	0.266
Dharampani	0.429	0.524	0.280
Dharmawoti	0.386	0.476	0.241
Udayapurkot	0.313	0.693	0.251
Dhuwang	0.420	0.582	0.236
Dhungegadhi	0.419	0.760	0.344
Gothiwang	0.327	0.543	0.158

continued on next page

Table 10.11 *continued*

Village Development Committee	Income Gini Coefficient	Electricity Gini Coefficient	Total Energy Gini Coefficient
Hansapur	0.428	0.651	0.292
Jumrikanda	0.358	0.747	0.202
Khaira	0.394	0.414	0.445
Khawang	0.474	0.398	0.210
Khung	0.338	0.452	0.161
Kochiwang	0.284	0.520	0.334
Ligha	0.380	0.417	0.237
Liwang	0.445	0.524	0.341
Lung	0.387	0.574	0.175
Majhakot	0.403	0.571	0.216
Maranthana	0.413	0.599	0.375
Markawang	0.396	0.502	0.309
Narikot	0.375	0.575	0.330
Nayagaon	0.390	0.484	0.509
Okherkot	0.380	0.415	0.349
Pakala	0.535	0.330	0.410
Phopli	0.342	0.730	0.430
Puja	0.342	0.683	0.179
Khalanga	0.335	0.507	0.361
Rajbara	0.331	0.650	0.176
Ramdi	0.375	0.349	0.193
Raspurkot	0.456	0.428	0.257
Saari	0.348	0.490	0.222
Swargadwari Khaal	0.290	0.767	0.254
Syauliwang	0.461	0.575	0.168
Tiram	0.306	0.604	0.287
Turwang	0.431	0.540	0.295
Tusara	0.388	0.528	0.407
Bangemarot	0.486	0.611	0.395

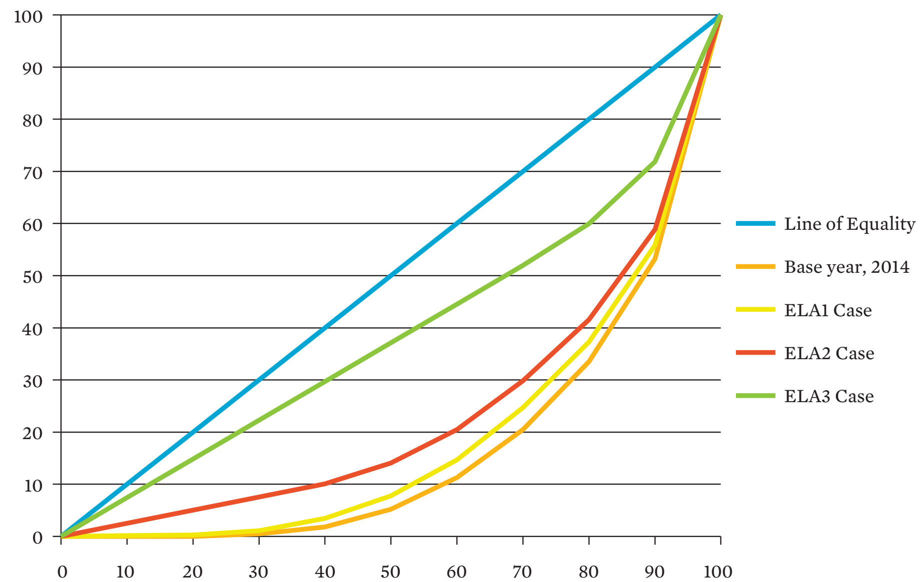
Source: Authors.

The effects of electricity access programs on electricity inequality can be observed from the comparison of the change in the shapes of electricity Lorenz curves with and without the electricity access programs[24] under different scenarios in the years 2017, 2022, and 2030. As an illustration, the effects of three electricity access cases: Tier 1 level of electricity access in ELA1, Tier 2 level in ELA2, and Tier 3 level in ELA3 (as described in Chapter 6) were

[24] The Lorenz curve for electricity consumption represents a ranked distribution of the cumulative percentage of the population on the x-axis versus the distribution of cumulative percentage of residential energy consumption along the y-axis (Shrestha and Acharya 2015).

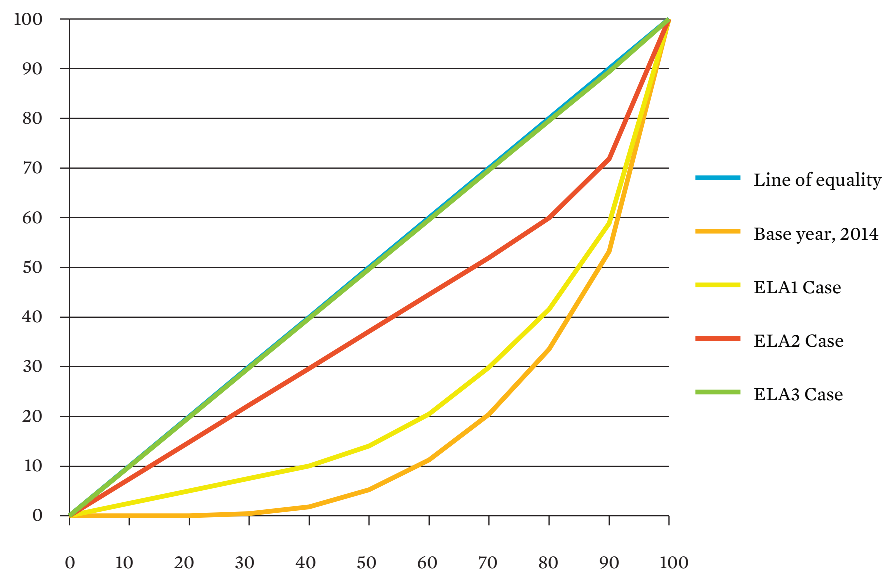
analyzed in this study for the year 2017. Figure 10.1 shows the Lorenz curves for electricity consumption in 2017 under ELA1, ELA2 and ELA3 cases. Figure 10.2 shows the similar curves for electricity consumption in 2022 while Figure 10.3 shows the curves for 2030.

Figure 10.1: Lorenz Curves for Electricity Consumption, 2017



Source: Authors.

Figure 10.2: Lorenz Curve for Electricity Consumption, 2022



ELA = electricity access case.
Source: Authors.

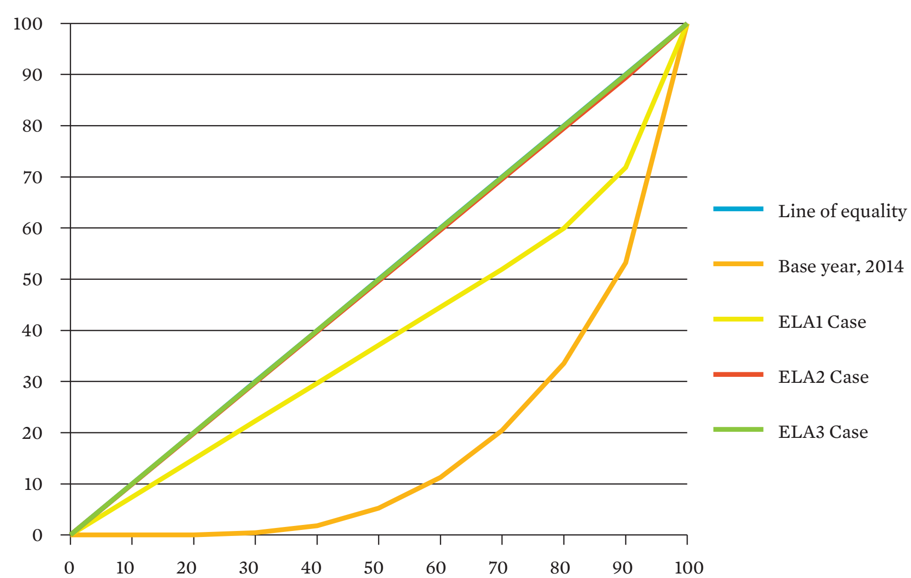
Although not much change will take place in terms of electricity inequality under ELA1 in the nearer term till 2022, there will be a significant reduction in electricity inequality by 2030.

With the improvement in electricity access case, the Lorenz curve moves upward showing a reduction in electricity inequality (Figure 10.1).

Note that in 2017, the three alternative electricity access (ELA) cases consider providing electricity access to households at the minimum level of Tier 1 in ELA1, Tier 2 level in ELA2, and Tier 3 in ELA3. Considerable reductions in electricity inequality would be achieved at the district level with electricity access programs in different cases (Figures 10.2 and 10.3). The electricity Gini coefficient would decrease by 15% to 63% in 2017, 57% to 99% in 2022, and 97% to 100% in 2030 under the electricity access cases considered in this study.

There will be a significant reduction in electricity inequality at higher levels of electricity access in 2017 (Figure 10.1). In 2022, electricity inequality would almost disappear under ELA3, and it would reduce only moderately under ELA1 and significantly under ELA2 (Figure 10.2). In 2030, electricity inequality would be almost non-existent under both ELA2 and ELA3 as the corresponding Lorenz curves almost coincide with the line of equality, while it would reduce significantly under ELA1 (Figure 10.3). These are also reflected by the values of electricity Gini coefficients under different electricity access cases in the selected years in Table 10.12. Interestingly, the table also reveals that the inequality in total energy consumption would not be affected significantly by the levels of electricity access considered in the three cases here.

Figure 10.3: Lorenz Curve for Electricity Consumption, 2030



Source: Authors.

Table 10.12: Electricity and Total Energy Gini Coefficients for Different Electricity Access Cases

Cases	Electricity Gini coefficient	Total Energy Gini coefficient
2017		
ELA1	0.624	0.393
ELA2	0.533	0.393
ELA3	0.229	0.391
2022		
ELA1	0.533	0.393
ELA2	0.229	0.391
ELA3	0.007	0.374
2030		
ELA1	0.229	0.391
ELA2	0.007	0.374
ELA3	0	0.362

ELA = electricity access case.
Source: Authors.

10.6 Key Findings and Limitations

The benefits of access to cleaner energy was assessed in terms of environmental, health, and social benefits at the local level, energy security benefits at the national level, and GHG reduction at the global level. The study found that on average, the time savings for a household by using electricity instead of other fuels like kerosene, battery, pinewood stick, candle, etc. is 35 hours per year and its equivalent monetary value is NRs3,297 per year. Similarly, the study found that on average, the time saved in a household by using LPG instead of fuelwood and agricultural residue for cooking is 368 hours per year, equivalent to NRs32,638 per year. The analysis found that replacement of kerosene-, candle- and pinewood stick-based lighting with electricity could abate around 7,747 kg of CO, 669 kg of NO_X, 4,844 kg of PM_{10}, 41,275 kg of BC and 1,433 ton of CO_2 emissions in 2017. The study found that significant reductions of about 73% of PM_{10} and 72% of BC emissions could be attained under CCA6 by using a combination of different energy efficient cleaner cookstoves as that compared to the base case.

The study found that among the surveyed households, around 60 households had family businesses, among which 90% had electricity access, and only 10% had no access to electricity. This showed that productive uses increases with an energy access program. The study also found that with energy access, up to 48 hours of time saving per month per household could be attained (from time saved from purchasing kerosene for lighting). Around 113 tons of oil equivalent (toe) kerosene could be replaced in 2017, 130 toe in 2022, and 171 toe in 2030 with increased electricity access. The survey revealed that students in VDCs with electricity access studied longer hours at home. The study found that the average study hour of students among unelectrified households of Pyuthan district was 0.83 hours, while the average for students in electrified households of Pyuthan was 1.38 hours. Residents of households in fully electrified VDCs were absent from work fewer times and visited the hospital on fewer occasions than those in partially electrified VDCs. For example, Dakhakwadi, one of the fully electrified VDCs, has, on average, 12 number of average annual absent days from work due to health related problems and the average hospital visits per year was 2.4. However, in the case of Damri, a partially electrified VDC, the average number of annual absent days due to health problem was found to be 32 and the average hospital visits per year was found to be 3.3. The study also found that there would be a substantial reduction in energy inequality with a higher level of electricity tiers. The electricity Gini coefficient obtained was 0.663. In 2017, the electricity Gini coefficient would improve from 0.624 in ELA1 to 0.229 in ELA3. Similarly, the electricity Gini coefficient in 2022 would improve from 0.533 in ELA1 to 0.007 in ELA3 and would improve from 0.229 in ELA1 to 0 in ELA3 in 2030.

This study has estimated some impacts of energy access programs in the Pyuthan district, such as reduction in local pollution and GHG emissions based on the amount of energy consumption and emission factors of the fuels and technologies used. However, in the absence of emission factors specific to Pyuthan district or Nepal in general, the level of estimation may not be very accurate.

Since the field survey provided energy access information for 2014 only, it is difficult to quantify benefits associated with energy access in the future. To address the longer-term benefits such as education, health, productive activities, and time savings associated with an energy access program, the study compared the various effects in VDCs without electricity or clean cooking energy access with those in a similar VDC with such access. Thus the estimations so derived present an order of magnitude of only the benefits. Better estimates of benefits could be obtained when information specific to the study areas become available. Also, it should be noted that this study was not able to obtain the monetary benefits in terms of increased future earnings from a higher level of education achieved with an improved access to electricity since the field survey was conducted only at one specific point in time.

11 Affordability of Energy Access Programs and Policy Implications

11.1 Introduction

The affordability assessment aims to determine whether or not the cost associated with using the acceptable minimum level of basic energy services such as cooking and lighting is affordable to households; it also determines the size of the household population that cannot afford to pay for such costs. As explained in the sustainable energy access planning (SEAP) framework, affordability can be assessed using two alternative approaches, the energy burden approach and the residual income approach (Chapter 9 in the SEAP Framework). This study used the energy burden approach to assess the affordability of households to use cleaner energy in the Pyuthan district.

This chapter examined the energy burden of the households in 2014 in the base case (considering the actual energy consumption and energy devices used in cooking and lighting services in that year) in two different cases: (i) considering only the supply side costs and (ii) considering both supply and demand side costs.

The study then estimated the basic minimum level of cooking and lighting energy services needed by a household. It then assesses the energy burden associated with meeting the basic minimum levels of energy that is needed for cooking and lighting services in that year.

Assessments of the energy burden of households were carried out for three future snapshot years (2017, 2022, and 2030) in the base case (assuming the levels of energy consumption and energy devices used in cooking and lighting services to be the same as those in the base case in 2014) and three different energy access cases.

The study then focused on the levels of the financial support that would be required to make energy services affordable in different energy access cases.

11.2 Methodology and Data

As mentioned in Section 11.1, the affordability to energy services in this study was analyzed using the energy burden approach. In the energy burden approach, the term "energy burden" refers to the ratio of energy expenditure of a household to the household's income. This section describes the methodology and details of the data used in this study.

Methodology

The energy burden of each household was calculated as the percentage of the annual household income used to pay for energy bills as well as the annual (i.e., annuitized) costs of energy-using devices and their operation.

In the energy burden approach, a household is considered to have affordability problem if the household's energy burden exceeds a threshold value of energy burden, which represents the maximum acceptable level of the burden from the public policy perspective. As such, this approach requires information on the minimum acceptable level of energy burden.

In this assessment, the level of energy burden in 2014 was calculated based on the actual expenditure and income provided by each household during the survey. The calculation of household energy expenditures in future years was based on constant prices of 2014. Cooking and lighting were considered the basic energy services in this study.

Therefore, the energy burden was assessed considering these services both individually and jointly in this study, i.e., considering cooking only, lighting only, as well as considering a combination of both cooking and lighting.

To estimate the level of energy burden, one has to find information on the annual expenditure for the particular energy service and the total income of the household. In this study, the cooking expenditure includes fuel cost and annuitized costs of devices and their operation and maintenance (O&M). The expenditure for lighting energy service includes electricity cost (or fuel cost in the case of lighting based on other fuels such as kerosene, candles and others), and annuitized device cost.

The annuitized device cost includes annuitized costs of electrical connection (for grid connected households), solar home systems (for households electrified using solar photovoltaic system), wiring and bulbs; and annuitized costs of kerosene lamps (for unelectrified households).

The cost of lighting was calculated using the household survey data on the average cost of electricity (based on the monthly electrical bill), average daily number of hours of operation and wattage of lamps. In the case of the households that used kerosene for lighting, the annual lighting expenditure was estimated as the sum of the amount they spent on kerosene and the annuitized cost of kerosene lamps.

This study also analyzed the changes in the level of energy burden if the households are provided with the energy required to use the basic minimum level of energy services. For this present assessment, the basic minimum level of energy required per household for cooking was obtained from the household survey conducted in each village development committee (VDC) in the Pyuthan district. The useful energy consumption for cooking was calculated by type of fuel and stoves used by each household in the district in the sample survey.[25] The useful energy per capita was then calculated for each household using the household size data.

The sample households were ranked based on the income and were divided into 10 income groups. The average useful energy per capita was calculated for each income decile. In this study, the lowest level of useful energy consumption per capita among the income deciles in the district was considered as the threshold value for the minimum energy requirement for cooking.

[25] Useful energy is calculated as the product of input energy of the fuel and the efficiency of the cookstove used.

This study estimated the level of energy burden for basic cooking and lighting services for two different cases: (i) considering only the supply side related costs and (ii) considering both the supply side as well as the demand side costs. In case of cooking services, the supply side cost includes fuel and cylinder costs for liquefied petroleum gas (LPG), only fuel costs for biomass based cooking, and biogas digester and its O&M cost for biogas based cooking. Demand side cost for cooking activity includes the cost of stove and its O&M cost.

In case of electricity use, the supply side cost includes the initial electrical connection cost and electricity cost for grid based electricity use, while it consists of solar home system cost for nongrid based electricity. In addition to this, it also includes the cost of wiring in both the cases. The demand side cost in this case includes the cost of the bulb. It should be noted that in Tiers 2 and 3, the cost of electrical appliances other than lamps was not considered.

The financial support required by each household was calculated as the amount needed to keep the energy burden within the energy burden threshold. The households having energy burden above the energy burden threshold was considered as households with an energy affordability problem. The average financial support required by such households at each tier was calculated as the mean of the financial support needed by the households at corresponding tiers. The percentage of households that would require financial support at each tier was estimated as the ratio of number of households with affordability problem to the total number of households.

Energy Access Cases

In this study, the energy burden of the households was assessed in the year 2017, 2022, and 2030 for four different cases: one base case and three different energy access cases, Tier 1, Tier 2, and Tier 3. The "base case" represents the scenario in which the average household energy consumption pattern and energy devices used would be the same as that in 2014. The energy access cases or tiers differ in terms of the types of electricity end uses; they also differ in terms of the type of fuel and stoves used for cooking (Table 11.1). Tier 3 has two variants: "Tier 3-LPG" and "Tier 3-Biogas" differentiated based on the type of cooking fuel considered while keeping the electricity end uses and level of electricity consumption unchanged.

The minimum level of energy required for cooking was considered as 27.2 kilograms of oil equivalent (kgoe) per capita per year; this is the minimum level of per capita useful cooking energy consumption among the income deciles in the district based on the household survey (Table 5.6). Following the minimum lighting standard of 300 lumens for at least 4 hours every night per household as stated in the "Total Energy Access Minimum Standards" of Practical Action, this study has considered the basic annual energy requirement for lighting as 4.4 kilowatt hours (kWh) per household in energy access Tier 1 (Practical Action 2012) and the use of light-emitting diode (LED) lamps with a luminous efficacy of 100 lumens per watt. Electricity consumption in Tiers 2 and 3 include electricity use for lighting as well as other electrical devices based on the Global Tracking Framework (GTF) of World Bank/ESMAP and IEA (2013). Table 11.2 presents the minimum level of electricity consumption considered in this assessment under different energy access tiers. As can be seen, electricity consumption per household considered in Tier 2 is 66 kWh, while it is 321 kWh in Tier 3.

Table 11.1: Definition of Energy Access Tiers: Types of End Uses, Fuels, and Cookstoves

Name of Energy Access Tier	End Uses of Electricity	Types of Fuel and Stove used in Cooking	
		Fuel Type	Stove Type
Tier 1	Lighting only	Fuelwood	ICS
Tier 2	Lighting, radio, phone charging, fan and television	Biomass briquette	Briquette stove
Tier 3-LPG	Lighting, radio, phone charging, fan, television, food processor and refrigerator	LPG	LPG Stove
Tier 3-Biogas	Lighting, radio, phone charging, fan, television, food processor and refrigerator	Biogas	Biogas Stove

ICS = improved cookstove, LPG = liquefied petroleum gas.
Source: Authors, Adapted from Practical Action (2012) and World Bank/ESMAP and IEA (2013).

Table 11.2: Electricity Consumption for Different Energy Access Tiers (kWh)

Electrical devices	Level of Energy Access		
	Tier 1	Tier 2	Tier 3
Lighting	4.4	27.8	27.8
Radio		0.7	0.7
Phone charger		0.7	0.7
Fan		21.9	21.9
Television		14.6	14.6
Food processors			73
Washing machine			182.5

kWh = kilowatt hour.
Source: Adapted from Practical Action (2012) and World Bank/ESMAP and IEA (2013).

It is important to note here that the definitions of energy access tiers considered in this chapter are different from the definitions of tiers in earlier chapters.

Data

To assess the existing level of energy burden of the households, the energy expenditures were estimated using the data obtained from the household survey. The estimation used the data used on fuelwood consumption, initial electrical connection cost, wiring cost, level of electricity consumption, type of device (i.e., cookstove, lamp), number of hours used for each end use services (e.g., cooking, lighting, space heating, animal feed preparation, etc.) and wattage of electrical devices. The data on efficiency of cookstoves used for the estimation were based on available national sources as discussed in Chapter 9. The data on household income were based on the household survey.

To assess the energy burden of households under different energy access tiers, the fuelwood price considered was the average price of fuelwood in the VDC paid by the households. The price of briquette was based on local market survey. LPG is currently subsidized in Nepal. However, this study considered the unsubsidized price of LPG based on information available from the Nepal Oil Corporation to estimate the energy burden of the households (NOC 2014). This was done to reflect the real cost of LPG to the economy in assessing the energy affordability of households and also to have a more accurate estimate of the population that needs direct or indirect support as well as the level of such support. The costs of biogas digester and ICS are based on Joshi (2014). The operation cost of biogas digester which includes the regular feeding of the animal dung were estimated based on wage rate and annual labor input. The wage rate per hour is considerd to be NRs314 based on DUTCIDC (2014) and labor input is considered to be 20 labor days per year based on Zuzhang (2013). The cost of briquette stove and LPG stove (including LPG cylidner) are based on market survey.

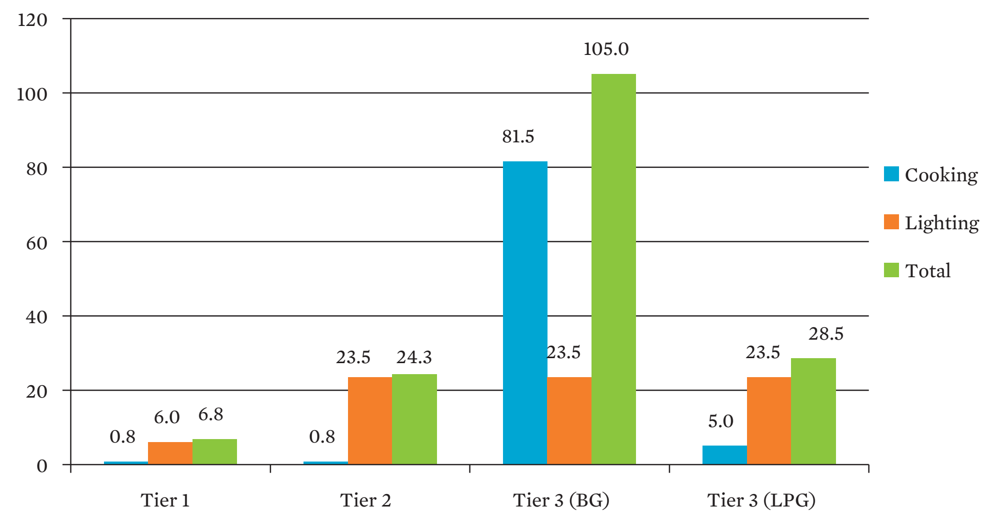
In the case of electricity use based on solar home systems, the costs of solar home systems, wiring and lamps considered are based on the local market survey. In the case of households with electricity supply from the local distribution network, the electrical connection cost is based on the amount paid to the Nepal Electricity Authority (NEA) by the households who participated in the survey. The electricity cost considered in this study were the VDC-wise estimated price of electricity obtained through the cost assessment module of this study (Chapter 8). The income of the households were assumed to increase at 3.56% per year following MoF (2014).

The energy burden approach requires information on the minimum acceptable energy expenditure as a percentage of household income to determine whether or not a household has an affordability problem. There is, however, no such universally accepted value. Also, no such threshold has been officially defined in the context of Nepal. Therefore, the chapter assesed affordability of households for three different energy threshold values, i.e., 10%, 15%, and 20%.

Upfront Cost of Devices

Figure 11.1 shows the upfront cost associated with different energy access tiers considered in this chapter. The upfront cost for lighting includes bulb cost, wiring cost, initial electrical connection cost for connecting to the national grid or solar home system cost. In the case of Tier 1, the minimum electricity requirement would be met by the solar home system as the grid connection would not be cost-effective for the level of electricity use in Tier 1. In the cases of Tiers 2 and 3, electricity is supplied from the grid. The upfront cost in Tier 2 and Tier 3 (i.e., in the case of both LPG and biogas cooking options) for electricity use would be the same. In case of cooking, the upfront cost is the cost of the cooking devices. In Tier 3-LPG case, the cost of the LPG cylinder is also included whereas in Tier 3-Biogas case, the cost of the biogas digester is also included. Total upfront cost is lowest in Tier 1 and highest for the biogas option in Tier 3-Biogas case.

Figure 11.1: Upfront Cost of Cooking and Lighting in Different Energy Access Tiers (thousand NRs)



BG =biogas, LPG = liquefied petroleum gas.
Source: Authors.

11.3 Assessment of Present and Future Levels of Energy Burden

This section discusses the status of the energy burden of the households and their affordability to use the basic minimum energy services in 2014. It also discusses the affordability of households to different tiers of energy access in 2017, 2022, and 2030.

11.3.1 Status of Energy Burden in 2014

The average energy burden of cooking and lighting on households in Pyuthan district was found to be 5.56%. Table 11.3 presents the percentage of households whose energy burden was below the selected threshold energy burden levels in 2014 when only the energy supply side costs were considered. Similarly, Table 11.4 shows the same when both energy supply and demand side costs were considered.[26] Note that these tables present the percentage of the households with energy burden of lighting and cooking individually as well as of both lighting and cooking combined below a threshold energy burden level in 2014.

Considering only the supply side costs in both lighting and cooking (Table 11.3), nearly 62% of the households were found to have overall energy burden up to 5%. This means around 38% of the households were spending more than 5% of their income on the energy services in cooking and lighting. The table also shows that 23.3% of the households spent more than

[26] Supply side costs include fuel costs while the demand side costs includes device and operation and maintenance costs.

5% of their income on cooking energy service only, while the corresponding figure was 8.5% in the case of lighting only. Around 15.6% of households have the energy burden of more than 10% for cooking and lighting energy services. 8.2% of the households spent above 10% of their income on cooking energy only, while only 1.8% of the households spent above 10% of their income on lighting energy only.

Table 11.3: Cumulative Distribution of Households in Pyuthan District by Level of Energy Burden by Type of End Use in 2014 Considering only the Supply Side Costs

	Percentage of Households with Energy Burden (%)				
Type of Energy Service	**up to 5%**	**up to 10%**	**up to 15%**	**up to 20%**	**above 20%**
Cooking only	76.7	91.8	97.3	99.1	0.9
Lighting only	91.5	98.2	99.5	99.7	0.3
Both cooking and lighting	61.9	84.4	93.3	97.2	2.8

Source: Authors.

Similarly, when both supply and demand side costs are considered (Table 11.4), almost 59.5% of the households are found to spend less than or equal to 5% of their income on the overall energy; 24.4% of the households spent more than 5% for cooking only while only 10.2% households spent more than 5% of their income on lighting services. Similarly, 8.5% of the households spent more than 10% of their income in cooking and 2.1% of the households spent more than 10% for lighting only, while 17.1% of the households spent more than 10% on cooking and lighting combined.

Table 11.4: Cumulative Distribution of Households in Pyuthan District by Level of Energy Burden by Type of End Use in 2014 Considering both Supply and Demand Side Costs

	Percentage of Households with Energy Burden (%)				
Type of Energy Service	**up to 5%**	**up to 10%**	**up to 15%**	**up to 20%**	**above 20%**
Cooking only	75.6	91.5	97.2	99.1	0.9
Lighting only	89.8	97.9	99.4	99.7	0.3
Both cooking and lighting	59.5	82.9	92.5	96.7	3.3

Source: Authors.

11.3.2 Affordability for Meeting Basic Minimum Energy Services in 2014

As discussed earlier, the minimum level of cooking energy service required is 27.2 kgoe per capita per year and electricity level is 4.4 kWh per year based on the minimum lighting standard of 300 lumens for at least 4 hours every night per household. The device used for cooking is fuelwood improved cookstove (ICS) and lighting is solar home system. Table 11.5 presents the distribution of households with different levels of energy burden under the existing pattern of energy consumption for cooking and lighting (i.e., without an energy access program); similarly it presents the distribution with the level of cleaner energy use for cooking and lighting (as defined earlier) under an energy access program. If only the supply side costs are considered, at the existing patterns of energy consumption (i.e., without an energy access program), 84.4% of the households are found to have the energy burden up to 10%. This means that 15.6% of the households have an energy burden above 10%. The study finds that under an energy access program, 23.5% of the households would have an energy burden of more than 10% if they use the basic minimum level of cleaner energy services. The present study shows that only 2.8% of households would have to spend more than 20% of their income with the existing pattern of energy consumption; this figure would increase to 4.5% with the basic minimum level of energy services considered in this chapter.

When both supply and demand side costs are considered, 82.9% of the households are found to have their energy burden up to 10% at their existing level of energy consumption; the percentage of such households would decrease to 74.7% if they were to use the basic minimum level of services. This means 17.1% of the households would have to spend more than 10% of their income under the existing energy consumption pattern, whereas 25.3% of the households would have to spend above 10% of their income for the basic minimum energy services considered. This study also shows that only 3.3% of the households spend more than 20% of their income under the existing pattern of energy consumption, whereas 4.9% of the households would have to spend more than 20% using the basic minimum energy services considered.

Table 11.5: Cumulative Distribution of Households by Level of Energy Burden, 2014

	Percentage of Households with Energy Burden (%)				
	up to 5%	up to 10%	up to 15%	up to 20%	more than 20%
(i) Considering only Supply Side Costs					
With existing cooking and lighting practices	61.9	84.4	93.3	97.2	2.8
With basic minimum energy services	45.5	76.5	89.7	95.5	4.5
(ii) Considering both Supply and Demand Side Costs					
With existing cooking and lighting practices	59.5	82.9	92.5	96.7	3.3
With basic minimum energy services	43.1	74.7	88.6	95.1	4.9

Source: Authors.

11.3.3 Assessment of Affordability to Different Tiers of Energy Access in Selected Years

The energy burden of the households would increase with the level of energy access considered. Furthermore, for a particular level of energy access, the energy burden when both supply and demand side costs of energy access are considered would be higher than when only the supply side costs are considered. Affordability of households to use cleaner energy services depends on the total cost of using such services, which includes both supply and demand side costs. Consideration of only the supply side costs would obviously underestimate the actual level of energy burden faced by households. This section discusses the affordability of households to different levels of cleaner energy services under the selected energy access cases.

Table 11.6 shows the distribution of households by the level of energy burden under the base case and different energy access cases in 2017 considering only the supply side costs, while Table 11.7 presents similarly the distributions considering both the supply and demand side related costs.

If only the supply side costs are considered, 86.6% of the households would spend up to 10% of their income on cooking and lighting energy services in the base case in 2017 (Table 11.6); this means 13.4% of the households would have their energy burden above 10%. For any given threshold level of energy burden, the size of the population exceeding such a threshold increases with the level of minimum energy usage per household considered under a universal energy access program. As can be seen in Table 11.6, more than 19% of the households would have an energy burden above 10% under energy access Tier 1, whereas 65.6% of the households would have an energy burden above 10% under energy access Tier 2 (Section 11.2 for the definition of different cases). Likewise, the households that would have an energy burden above 10% under energy access Tier 3-LPG would increase to 84.5%. If all the households could make use of the biogas option for cooking under Tier 3-Biogas, 31.1% of the households would have an energy burden up to 10%.[27] Similarly, the table shows that only 2.1% of the households would spend more than 20% of their income on cooking and lighting energy services in the base case. The percentage of the households having their energy burden above 20% would be 3.7% under Tier 1, whereas the percentage of such households would increase to 33.0% under Tier 2. About 57% of the households would have their energy burden above 20% under Tier 3-LPG case, whereas only 35.7% households would have such energy burden under Tier 3-Biogas case.

Table 11.6: Distribution of Households by Level of Energy Burden in 2017 (Considering only Supply Side Costs)

	Percentage of Households with Energy Burden (%)			
Case	**up to 10%**	**up to 15%**	**up to 20%**	**above 20%**
Base	86.6	95.1	97.9	2.1
Tier 1	80.9	92.1	96.3	3.7
Tier 2	34.4	53.7	67.0	33.0
Tier 3-LPG	15.5	29.7	42.6	57.4
Tier 3-Biogas	31.1	50.3	64.3	35.7

LPG = liquefied petroleum gas.
Source: Authors.

If both supply and demand side options are considered, the percentage of households with energy burden up to 10% would be 85.9% in the base case as shown in Table 11.7.[28] Under

[27] Note that not all households can have access to biogas as ownership of at least two cattle is required for this option. Biogas options are found feasible only for 52.3% of total households in Pyuthan district.

[28] The demand side cost includes the costs of electric light bulbs and cookstoves. However, it does not include the costs of electrical appliances other than lamps.

energy access cases, the corresponding percentage would decrease to 79.1% under Tier 1, and 33.1% under Tier 2, and 14.1% under Tier 3-LPG. It shows that at any given threshold energy burden, the size of the population having the energy burden below such a threshold decreases with the level of minimum energy usage per household. Only 2.4% of the households spend more than 20% of their income on cooking and lighting energy services in the base case. The percentage of households having energy burden more than 20% would be 4.1% under Tier 1. The corresponding figures would increase to 34.3% in Tier 2 and 60.1% under Tier 3-LPG. The energy burden of households would be the highest under Tier 3-LPG. It should be noted that the unsubsidized cost of LPG was considered in the present analysis (If the subsidized cost was used, the energy burden of households would be lower and accordingly the percentage of the households having energy burden below a threshold energy burden would be higher). If biogas option in Tier-3 is considered, the percentage of households having energy burden up to 10% would be 28.8%, while 37.9% of the households would have energy burden above 20%.

Table 11.7: Distribution of Households by Level of Energy Burden in 2017 (Considering both Supply and Demand Side Costs)

	Percentage of Households with Energy Burden (%)			
Case	up to 10%	up to 15%	up to 20%	above 20%
Base	85.9	94.5	97.6	2.4
Tier 1	79.1	91.2	95.9	4.1
Tier 2	33.1	51.5	65.7	34.3
Tier 3-LPG	14.1	27.6	39.9	60.1
Tier 3-Biogas	28.8	48.6	62.1	37.9

LPG = liquefied petroleum gas.
Source: Authors.

Table 11.8 shows the percentage of households with energy burden below or equal to a threshold level in 2022, when only the supply side costs are considered. In 2022, the percentage of households with an energy burden above 10% in all the energy access tiers would be less than in the corresponding tiers in 2017. This is because the level of energy burden of the households is lower in 2022 than that in 2017 due to the growth in the household income over time. In the base case, only 8.8% of the households would have energy burden above 10%. Similarly, less than 15% of the households would spend more than 10% of their income under Tier 1, while 57.9% of the households would spend more than 10% under Tier 2. Eighty percent of households would have energy burden above 10% under Tier 3-LPG. The percentage of biogas-using households having energy burden more than 10% would be 61.5% in Tier 3-Biogas case. Less than 1% of the households would spend more than 20% of their income on energy services in the base case. Similarly, 2.1% of the households would have energy burden above 20% under Tier 1, whereas 25.9% would have energy burden above 20% under Tier 2. In the Tier 3-LPG case, almost 50% of the households would have energy burden above 20%. Nearly 30% of the households would have an energy burden more than 20% in Tier 3-Biogas case.

As can be seen from Table 11.9, if both the supply and demand side costs are considered, 9.8% of the households would have energy burden above 10% in the base case, whereas

Table 11.8: Distribution of Households by Level of Energy Burden in 2022 (Considering only Supply Side Costs)

	Percentage of Households with Energy Burden (%)			
Case	up to 10%	up to 15%	up to 20%	above 20%
Base	91.2	97.2	99.1	0.9
Tier 1	85.8	95.4	97.9	2.1
Tier 2	42.1	62.2	74.1	25.9
Tier 3-LPG	20.0	37.1	50.6	49.4
Tier 3-Biogas	38.5	58.9	70.2	29.8

LPG = liquefied petroleum gas.
Source: Authors.

Table 11.9: Distribution of Households by Level of Energy Burden in 2022 (Considering both Supply and Demand Side Costs)

	Percentage of Households with Energy Burden (%)			
Case	up to 10%	up to 15%	up to 20%	above 20%
Base	90.2	96.7	98.9	1.1
Tier 1	84.9	95.0	97.7	2.3
Tier 2	40.3	60.7	72.7	27.3
Tier 3-LPG	18.8	35.2	48.4	51.6
Tier 3-Biogas	36.6	56.2	69.0	31.0

LPG = liquefied petroleum gas.
Source: Authors.

the percentage of such population would be 15.1% under Tier 1, nearly 60% under Tier 2, 80.2% under Tier 3-LPG and 63.4% under the Tier 3-Biogas case. In the base case, 1.1% of the households would have energy burden above 20%. Similarly, the percentage of households having energy burden above 20% would be 2.3% in Tier 1, 27.3% in Tier 2, 51.6% in Tier 3-LPG, and 31.0% in Tier 3-Biogas.

The percentages of households at different levels of energy burden in 2030, considering only the supply side costs are shown in Table 11.10. Less than 5% of the households would spend more than 10% of their income on energy services in the base case. The percentage of households having energy burden more than 10% would be 6.7% in Tier 1, 43.3% in Tier 2, 67.9% in Tier 3-LPG and 47.4% in Tier 3-Biogas case. Similarly, the households with energy burden above 20% in 2030 would be 0.3% only in the base case, 0.8% in Tier 1, 15.6% in Tier 2, 18.2% in Tier 3-Biogas and 34.9% in Tier 3-LPG case.

If both the supply and demand side costs are considered in 2030, around 5% of the households would have an energy burden above 10% (Table 11.11). The percentage of households with energy burden above 10% would be 7.5% in Tier 1, 45.7% in Tier 2. Similarly, the percentage of households would be 70.4% in Tier 3-LPG and 49.6% in Tier 3-Biogas. Less than 1% of the

Table 11.10: Distribution of Households by Level of Energy Burden in 2030 (Considering only Supply Side Costs)

	Percentage of Households with Energy Burden (%)			
Case	up to 10%	up to 15%	up to 20%	above 20%
Base	95.5	99.1	99.7	0.3
Tier 1	93.3	97.9	99.2	0.8
Tier 2	56.7	73.6	84.4	15.6
Tier 3-LPG	32.1	50.3	65.1	34.9
Tier 3-Biogas	52.6	69.9	81.8	18.2

LPG = liquefied petroleum gas.
Source: Authors.

Table 11.11: Distribution of Households by Level of Energy Burden in 2030 (Considering both Supply and Demand Side Costs)

	Percentage of Households with Energy Burden (%)			
Case	up to 10%	up to 15%	up to 20%	above 20%
Base	95.1	98.9	99.7	0.3
Tier 1	92.5	97.7	99.2	0.8
Tier 2	54.3	72.5	83.1	16.9
Tier 3-LPG	29.6	48.2	62.6	37.4
Tier 3-Biogas	50.4	68.9	79.9	20.1

LPG = liquefied petroleum gas.
Source: Authors.

households would be having energy burden above 20% in the base and Tier 1 cases in 2030, whereas the percentage of such a population would be 16.9% in Tier 2, 20.1% in Tier -3-Biogas and 37.4% in Tier 3-LPG case.

11.4 Level of Support Needed for Energy Access Affordability

The size of the household population that would need some kind of financial support to be able to afford the use of cleaner energy services would depend upon the energy burden threshold level. The population size would also depend upon the definition of the types of basic energy services considered and their minimum usage levels considered under a universal energy access program. Clearly, the energy burden threshold and basic energy services have to be defined in the context of a particular country or area, and as such, they form a part of the energy access policy.

The energy burden assessment provides information on the size of households having energy affordability problem, i.e., the household population that would need some kind of financial support so that the actual energy burden faced by the household lies within the threshold limit once the financial support is provided. The financial support can be in the form of subsidy or soft loan or some other financial incentives that should make the access to cleaner energy affordable to the households.

The estimated size of such population and the level of support to be provided would also depend upon the types of the costs to be considered under a support scheme; i.e., whether the support schemes are intended to consider the supply side costs only or both supply and demand side costs. Furthermore, the level of financial support to be provided to households would depend upon the threshold energy burden considered.

The higher the value of the threshold energy burden, the smaller would be the financial support needed for predefined minimum cleaner energy consumption per household. This section discusses the percentage of households that would have energy burden above 10%, 15% and 20% in 2017, 2022, and 2030. In addition, it also discusses the level of support required per household and the total financial support required in the Pyuthan district as a whole under different energy access cases considered in order to make the energy services affordable.

Table 11.12 presents the percentage of households having an energy burden above 10%, 15% and 20% under different energy access cases or tiers in 2017, 2022, and 2030, considering only the supply side costs. In 2017, the percentage of households with an energy burden above 10% would be in the range of 19.1% in Tier 1 to 84.5% in Tier 3-LPG case. In case of Tier 3-Biogas, only 70.0% of households would have an energy burden above 10%. The percentage of households with an energy burden above 10% is less in Tier 3 with biogas option than with LPG option due to higher supply side cost (mainly fuel cost) of LPG.

Table 11.12: Percentage of Households with Energy Burden above Selected Levels under Different Energy Access Cases (Considering Supply Side Costs Only)

		Energy Access Case (%)			
Energy Burden	Year	Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
Above 10%	2017	19.1	65.6	84.5	70.0
	2022	14.2	57.9	80.0	62.5
	2030	6.7	43.3	67.9	49.3
Above 15%	2017	7.9	46.3	70.3	51.6
	2022	4.6	37.8	62.9	42.1
	2030	2.1	26.4	49.7	30.4
Above 20%	2017	3.7	33.0	57.4	37.1
	2022	2.1	25.9	49.4	30.2
	2030	0.8	15.6	34.9	18.7

LPG = liquefied petroleum gas
Source: Authors.

In 2030, the percentage of the households with an energy burden above 10% would be 6.7% in Tier 1 and 67.9% in Tier 3-LPG case. Note that the corresponding percentage of households at each selected energy burden level is smaller in 2030 due to the increase in the households' income over time. The percentage of households with an energy burden above 20% would be 3.7% in Tier 1 and 33.0% in Tier 2, and 57.4% in Tier 3-LPG case in 2017. Likewise, in 2030, the percentage of households with an energy burden above 20% would be 0.8% in Tier 1, 15.6% in Tier 2, 34.9% in Tier 3-LPG and 18.7% in Tier 3-Biogas.

Unlike Table 11.12, Table 11.13 presents the percentage of households having energy burden above 10%, 15%, and 20% if both supply and demand side costs are considered.

The percentage of households having an energy burden above 10% in 2017 would be in the range of 20.9% in Tier 1 and 85.9% in Tier 3-LPG case. In the same way, the percentage of households having energy burden above 10% in 2030 would range from 7.5% in Tier 1 to 70.4% in Tier 3-LPG case. In 2017, the percentage of households with the energy burden above 20% would range from 4.1% in Tier 1 to 60.1% in Tier 3-LPG. Similarly, the percentage of households with an energy burden above 20% in 2030 would be in the range of 0.8% in Tier 1 to 37.4% in Tier 3-LPG case.

Table 11.13: Percentage of Households with Energy Burden above Selected Levels under Different Energy Access Cases (Considering both Supply and Demand Side Costs)

Energy Burden	Year	Energy Access Case (%)			
		Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
Above 10%	2017	20.9	66.9	85.9	72.1
	2022	15.1	59.7	81.2	64.4
	2030	7.5	45.7	70.4	51.5
Above 15%	2017	8.8	48.5	72.4	53.3
	2022	5.0	39.3	64.8	45.0
	2030	2.3	27.5	51.8	32.0
Above 20%	2017	4.1	34.3	60.1	39.2
	2022	2.3	27.3	51.6	31.6
	2030	0.8	16.9	37.4	20.4

Source: Authors.

The households facing affordability problem would need some kind of support in order to reduce their actual energy burden below a threshold level. Table 11.14 presents the amounts of average financial support required per household to reduce the energy burden of the households to the selected threshold values of 10%, 15%, and 20% when only the supply side costs are considered.

The level of support required decreases with the higher level of threshold energy burden considered and increases with the higher level of energy access considered. In 2017, the average support required per household at the threshold energy burden of 10% would range from NRs2,308 in Tier 1 to NRs20,649 in Tier 3-LPG case. If biogas option is considered in Tier-3, then the average support required would be NRs11,579 at the threshold energy burden of 10%. The support needed in Tier 3-Biogas would be less than in Tier 3-LPG case. Although the initial investment cost of biogas system is very high compared to LPG based cooking, the higher fuel cost of LPG makes it more expensive cooking option than biogas based system.

At energy burden threshold of 15%, the level of support required in 2017 would be in the range of NRs1,859 in Tier 1 to NRs17,542 in Tier 3-LPG. Similarly, in 2030, the support needed per household would be in the range of NRs1,893 in Tier 1 to NRs17,263 in Tier 3-LPG if the threshold energy burden of 10% is considered, whereas it would range from NRs1,253 in Tier 1 to NRs13,074 in Tier 3-LPG if the threshold energy burden is set at 20%.

Table 11.14: Average Financial Support Required per Household at Different Tiers (Considering Supply Side Costs only)

Energy Burden Threshold	Year	Energy Access Case (NRs)			
		Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
10%	2017	2,308	10,079	20,649	11,579
	2022	2,010	9,303	19,065	10,740
	2030	1,893	8,419	17,263	9,488
15%	2017	1,859	8,494	17,542	9,727
	2022	1,882	7,922	16,259	9,214
	2030	1,535	6,751	14,343	7,945
20%	2017	1,612	7,492	15,539	8,744
	2022	1,488	6,772	14,291	7,881
	2030	1,253	5,921	13,074	6,933

Source: Authors.

As shown in Table 11.15, if both supply and demand side costs are considered, the average support required per household (having affordability problem) at the energy burden threshold of 10% would be in the range of NRs2,384 in Tier 1 to NRs22,101 in Tier 3-LPG in 2017. At the threshold energy burden of 20%, the average support required per household would lie between NRs1,964 in Tier 1 and NRs18,440 in Tier 3-LPG. At the higher energy burden threshold of 20%, the average financial support needed per household would vary between NRs1,756 in Tier 1 and NRs16,607 in Tier 3-LPG in 2017, whereas it would vary from NRs1,545 in Tier 1 to NRs13,945 in Tier 3-LPG in 2030.

Overall, with the energy burden threshold of 10%, the average support needed per household when both supply and demand side costs are considered under different energy access cases in the selected years would be 3% to 8% higher than that when only supply side costs are considered; similarly, the average support needed would increase by 6% to 23% when the higher energy burden threshold of 20% is considered.

Table 11.16 presents the total amount of the financial support required at the maximum in the Pyuthan district in order to reduce the energy burden to the threshold energy burden level in 2014, 2022, and 2030 under different energy access cases when only supply side costs are considered.

If the energy burden threshold of 10% is considered, the total financial support required in 2017 at the district level under different energy access cases would lay in the range of NRs22 million in Tier 1 to NRs876 million in Tier 3-LPG. Similarly, with the energy burden threshold of 10%, the total support required would be between NRs8 million (in Tier 1) and NRs737 million (in Tier 3-LPG) in 2030.

Table 11.15: Average Financial Support Required per Household at Different Tiers (Considering both Supply and Demand Side Costs)

Energy Burden Threshold	Year	Energy Access Case (NRs)			
		Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
10%	2017	2,384	10,665	22,101	12,385
	2022	2,173	9,796	20,576	11,570
	2030	1,964	8,746	18,440	10,206
15%	2017	1,946	8,872	18,816	10,547
	2022	2,016	8,392	17,556	9,747
	2030	1,701	7,251	15,545	8,677
20%	2017	1,756	7,957	16,607	9,408
	2022	1,685	7,193	15,455	8,648
	2030	1,545	6,204	13,945	7,462

Source: Authors.

Table 11.16: Total Financial Support Required at Different Tiers in Pyuthan District (Considering Only Supply Side Costs)

Energy Burden Threshold	Year	Energy Access Case (million NRs)			
		Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
10%	2017	22	332	876	212
	2022	16	295	835	191
	2030	8	229	737	150
15%	2017	7	197	620	129
	2022	5	164	560	110
	2030	2.1	112	448	79
20%	2017	3	124	448	83
	2022	1.7	96	386	68
	2030	0.6	58	287	42

Source: Authors.

As expected, the level of total support required would decrease when a higher energy burden threshold is considered. It should be noted here that the total financial support needed for Tier 3-Biogas represents only the households that can have biogas options for cooking. If the energy burden threshold is increased to 15%, the level of total financial support needed at the district level would decrease by 68% to 74% in energy access Tier 1, by 41% to 51% in Tier 2, by 29% to 39% in Tier 3-LPG, and by 39% to 47% in Tier 3-Biogas.

Similarly, if the energy burden threshold is increased to 20%, the level of total financial support needed would be reduced by 86% to 93% in energy access Tier 1, by 63% to 75% in Tier 2, by 49% to 61% in Tier 3-LPG, and by 61% to 72% in Tier 3-Biogas.

As shown in Table 11.17, if both the supply and demand side costs are considered, the total amount of support required at the district level in different energy access tiers in 2017 would be in the range of NRs25 million in Tier 1 to NRs954 million in Tier 3-LPG at energy burden threshold of 10%. The total amount would decrease in 2022 and 2030 at energy burden threshold of 10%.

Similarly, at the energy burden threshold of 20%, the amount of support required would vary between NRs4 million in Tier 1 and NRs502 million in Tier 3-LPG in 2017.

The support needed in 2030 at the same energy burden threshold would be lower than that in 2017. If the energy burden threshold is increased to 15%, the level of total financial support needed at the district level would decrease by 64% to 73% in energy access Tier 1, by 40% to 50% in Tier 2, by 28% to 38% in Tier 3-LPG and by 38% to 46% in Tier 3-Biogas. Similarly, if the energy burden threshold is increased to 20%, the level of total financial support needed would be reduced by 84% to 92% in energy access Tier 1, by 62% to 74% in Tier 2, by 47% to 60% in Tier 3-LPG, and by 59% to 70% in Tier 3-Biogas.

Table 11.17: Total Financial Support Required at Different Tiers in Pyuthan District (Considering Both Supply and Demand Side Costs)

Energy Burden Threshold	Year	Energy Access Case (million NRs)			
		Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
10%	2017	25	358	954	234
	2022	18	320	915	213
	2030	9.2	251	816	168
15%	2017	9	216	685	144
	2022	6	180	623	124
	2030	2.5	125	506	90
20%	2017	4	137	502	95
	2022	2.1	107	436	78
	2030	0.7	66	328	50

Source: Authors.

11.5 Role of Upfront Cost in Affordability

Upfront cost represents the initial investment required by the households to access energy services. Upfront cost can become an initial barrier while switching to cleaner energy services.

This can be a serious problem especially in the case of low income households. For example, use of biogas for cooking services would incur an initial cost of owning a biogas digester and a biogas stove. Table 11.18 shows the upfront cost as a percentage of income (or "upfront cost burden") under different energy access cases ("Tiers") for each of the income deciles.

In Tier 1, households in the lowest two income deciles have upfront costs above 10% of their average annual income. The burden of the upfront costs on these two categories of households would increase to as high as 64% and 40% under energy access Tier 2, whereas the burden would be 75% and 47% under energy access Tier 3 (if LPG is used for cooking).

Under energy access Tier 2, only the three highest deciles have upfront costs equal to or below 10% of the annual average income. Under Tier 3-Biogas, the upfront cost burden is much above 10% of the average income in all income deciles. In Tier 3-LPG, the upfront cost burden is below 10% only in the highest two income deciles.

It can be seen that upfront cost represents a significant portion of the household annual income. As such, it indicates the need for some kind of financing support mechanisms (such as soft loans) to make cleaner energy services (in particular, cleaner cooking) affordable to the households. It should be noted here that the present study has considered unsubsidized costs of devices and fuels although there are in fact a number of subsidy schemes on improved cookstoves, solar home systems, and biogas digesters at the household level (MOPE 2016).

Table 11.18: Upfront Cost as the Percentage of Income in Different Income Deciles for Selected Levels of Energy Access in 2017

Income Decile	Average Income Per Household (NRs)	Upfront Cost Burden (%)			
		Tier 1	Tier 2	Tier 3-LPG	Tier 3-Biogas
1	38,159	17.7	63.6	74.7	275.3
2	61,053	11.1	39.7	46.7	172.1
3	80,789	8.4	30.0	35.3	130.0
4	103,309	6.5	23.5	27.6	101.7
5	127,295	5.3	19.1	22.4	82.5
6	155,744	4.3	15.6	18.3	67.4
7	193,435	3.5	12.5	14.7	54.3
8	243,243	2.8	10.0	11.7	43.2
9	330,784	2.0	7.3	8.6	31.8
10	581,748	1.2	4.2	4.9	18.1

Source: Authors.

11.6 Key Findings and Final Remarks

The study assessed the affordability of households using energy burden. At their present income level, if the households were to use basic minimum energy services (i.e., cooking and lighting), considering only the supply side costs, it was found that 23.3% of the households would not be able to afford the use of basic minimum energy services if the energy burden threshold of 10% was used as the criterion to identify the households facing affordability problem.

If both supply and demand side costs of energy access were considered, the size of the population unable to afford the basic energy services would be higher. The present assessment showed that the size of such a population would increase to 25.3% when both the supply and demand side costs are considered with the same energy burden threshold.

This study showed that if both the supply and demand side costs are considered, about 21% of households would face an energy burden above 10% under the energy access Tier 1 in 2017; the corresponding figure would be much higher (i.e., 66.9%) in Tier 2. Under energy access Tier 3-LPG, 85.9% of the households would have their energy burden above 10%. A smaller percentage of households is deemed to face the affordability problem at a higher threshold levels of energy burden.

For example, when the energy burden threshold is increased to 20%, the percentage of households facing the energy affordability problem would decrease to 4.1% in energy access case Tier 1, to 34.3% in Tier 2, and to 60.1% in Tier 3-LPG.

It should be noted that the number of households facing an energy affordability problem and the level of financial support needed would depend upon the definition of basic energy services and their usage levels.

In addition, it depends upon the value of the energy burden threshold to be used if the use of the energy burden approach is considered. More importantly, the determination of a target for the minimum level of energy use by households in a universal energy access program in itself involves several policy issues and implications.

This study assessed the average level of financial support needed by the households when the energy burden threshold is set at 10%. Similarly, it also carried out affordability assessments at alternative energy burden thresholds of 15% and 20%. At the energy burden threshold of 10%, the average financial support required per household considering both supply and demand side costs in 2017 was found to be NRs2,384 in Tier 1 and NRs10,665 in Tier 2. In the case of Tier 3, the average level of support needed was estimated to be NRs22,101 if LPG is considered for cooking and NRs12,385 if the biogas option is considered for cooking. In the same year, if energy burden threshold of 15% is considered, the financial support required varies between NRs1,946 in Tier 1 to NRs18,816 in Tier 3-LPG.

Similarly, at a higher energy burden threshold of 20%, the financial support required per household varies between NRs1,756 in Tier 1 and NRs16,607 in Tier 3-LPG. If a support scheme for an energy access program is to be sustainable, it is important to determine the basic minimum level of energy services that a household would need irrespective of the income level and also to set the threshold energy burden high enough so that nonpoor households could be excluded from any financial and other support scheme under an energy access support policy.

The total financial support at the district level in 2017 considering both supply and demand side costs would be in the range of NRs25 million to NRs954 million. At an energy burden threshold of 15%, the total financial support would be NRs9 million in Tier 1 and NRs685 million in Tier 3-LPG.

Similarly, at a higher energy burden threshold of 20%, the financial support required would be about NRs4 million in Tier 1 and NRs502 million in Tier 3-LPG in the same year.

This study also discussed the role of the upfront cost in assessing the energy affordability of households. In particular, the upfront cost could present a major barrier to energy affordability in the case of low-income households.

The present analysis showed that in the case of lowest-income decile households, the upfront cost would account for about one-sixth of the income of the households in energy access Tier 1, whereas it would be about 64% in Tier 2.

In the case of Tier-3, the upfront cost represents about 75% of the household income in the lowest decile when the LPG option is considered for cooking; the corresponding figure would be 275% when the biogas based cooking is considered. Although the burden of upfront cost for other low-income deciles would be lower but it would still be quite significant.

In some situations, the financial resources to alleviate the energy affordability problem could be limiting. Energy access policy makers may then find it convenient to choose the energy burden threshold such that it could balance the level of financial support to be provided with the resources available.

There are some limitations of the present analysis. This study assessed the affordability for only two energy services i.e., nonelectric cooking and electric lighting in Tier 1. In addition, Tier 2 includes fans and television, while Tier 3 also includes food processor and washing machine; however, the costs of electric appliances other than lamps are not included in the calculation of demand side costs in the present analysis.

Obviously, the demand side costs are underestimated in the analysis. The study also did not consider space heating as an energy service in the energy access cases considered. If space heating is also considered, the energy burden of the household is expected to be significantly higher than that estimated in this study.

12

Key Insights and Implications for Energy Access Program Development and Implementation

This study was carried out to determine the cost-effective cleaner and climate friendly energy options to provide sustainable universal access to cleaner energy services in the Pyuthan district of Nepal, their investment requirements and other costs. It also assessed various kinds of benefits by providing cleaner energy services to households. The study carried out an assessment of households' affordability to use basic minimum levels of cleaner energy services and the sustainability of cleaner energy options. As an intermediate step, the study conducted assessments of energy poverty and energy demand besides reviewing the energy resources potential in the district.

This chapter highlights key insights generated on the basis of the findings of this study from the perspective of a universal energy access program development. It also discusses policy and program implementation implications as well as it states some limitations of the study.

12.1 Key Findings and Insights

Status of Electricity and Energy Consumption

Based on the sample survey conducted under this study, it is estimated that about 80% of the households in the Pyuthan district were found to be using electricity in 2014. The survey exhibited a wide variation across the village development committee (VDCs) in terms of average electricity consumption at the household level: It varied from 11.3 kilowatt hours (kWh) to as high as 685.5 kWh. Around 20% of the households in the district were found to consume less than 3 kWh of electricity in that year.

The survey also revealed that biomass energy, particularly fuelwood, accounted for 94% of the total household energy consumption and 98% of the total cooking energy needs in the district.

Out of the total, 64% of the households in the district were found using traditional biomass cookstoves. This clearly highlights the level of energy poverty in the district and therefore the importance of universal energy access programs to enable households to use electricity and cleaner energy options for cooking in the district.

The sample survey showed that the minimum level of useful energy consumed by a household in the district was 27.2 kilograms of oil equivalent (kgoe) per capita. Considering this amount as the minimum amount of useful cooking energy required, the share of energy-poor households (i.e., the households using less than this minimum threshold value of cooking energy) across the 49 VDCs of the district is found to vary from 17.4% to 93.9%.

Table 12.1: Minimum Annual Electricity Consumption Per Household under Universal Electricity Access Cases (kWh)

Electricity Access Case	Universal Access Program Commencement Year 2017	2022	2030
ELA1	3	66	285
ELA2	66	285	1,464
ELA3	285	1,464	2,267

ELA = electricity access case, kWh = kilowatt hour.
Source: Adapted from World Bank/ESMAP and IEA (2013).

Implications of Electricity Access Programs on Total Electricity Demand

This study estimated the increases in total electricity demand for each VDC of the district from that under the base case (i.e., without universal electricity access) when three different alternative levels of minimum electricity consumption for households are considered under a universal electricity access program in each of the three alternative commencement years, i.e., 2017, 2022, and 2030.[29]

With some modifications, the study adopted the types of electricity applications and the minimum annual electricity consumption per household under different tiers of universal access as defined in the Global Tracking Framework (GTF). The minimum levels of electricity consumption per household considered in three alternative universal electricity access program cases in different years of program commencement are shown in Table 12.1.

As the total electricity demand in the district under a universal electricity access program would be higher than that under the base case (i.e., without universal access), this study has estimated the amount by which the total demand would increase under each electricity access case. It shows that the additional demand imposed by universal electricity access programs that aim at providing up to at least 66 kWh per household in the district would not exceed 10% of the demand in the base case.

The total demand would increase much more, by about 51% in 2017 and 41% in 2022, if the level of minimum electricity consumption per household under an electricity access program is raised to 285 kWh. The total electricity demand would increase by several folds compared to the demand in the base case. It would increase by 367.2% in 2022 and 273.4% in 2030 if the households are to use at least 1,464 kWh, whereas it would increase by 469.4% if they use at least 2,267 kWh in 2030.

Sustainability of Energy Access Options

The sustainability of four alternative electricity supply options i.e., grid (or large hydro) based supply, solar home system (SHS), biomass power generation and microhydro were assessed

[29] Note that in the base case some households may have no access to electricity at all and some of those using electricity may be consuming it below the minimum level targeted by an electricity access program, while the rest of the households would be using electricity above the minimum level targeted by the electricity access program.

in the context of Pyuthan district by estimating the energy sustainability index of each option using two different approaches (i.e., the multiattribute utility approach and multiattribute average scoring approach).

Both these approaches ranked grid extension (which is based on hydropower in the case of Nepal) highest and biomass power generation lowest in terms of sustainability. The approaches generated different rankings in the SHS and microhydro options.

Similarly, the study assessed the sustainability of the following six different cooking options: moderately efficient biomass improved cookstoves (MICS), highly efficient biomass improved cookstoves (HICS), LPG, biogas, electric, and solar.

The assessment ranked the electric cooking highest in terms of sustainability, which was followed by solar cooking, HICS, MICS, LPG, and biogas based cooking in a descending order.

The identification of the grid based hydroelectricity as the most sustainable electricity supply option and electric cooking as the most sustainable cooking option in the context of Nepal are in fact both consistent with the hydroelectric energy endowment of the country. This finding was also found to be consistent with the result of the cost assessments in this study.

Levels of Universal Electricity Access and Cost Implications

This study assessed the costs of electricity supply under the base case and three alternative universal electricity access cases (or programs) in 2017 (similarly in 2022 and 2030) each targeting a minimum level of electricity consumption per household as stated in Table 12.1.

In doing so, the study estimated the least-cost technology and energy resource options to meet the annual demand in each VDC of the district and the corresponding total life time costs under each of the alternative universal access cases (or programs) if the programs are to start operating in the selected years. The total district level costs are obtained as the sum of all VDC-level costs.

The study showed that the total electricity supply system cost and investment requirement in the district would not increase significantly if a universal electricity access program sets the level of the minimum annual electricity consumption per household up to 66 kWh. In 2017, the total supply system cost would increase by only 7% and 13% respectively compared to the base case if the values of the minimum annual electricity use per household are set 3 kWh under ELA1 and 66 kWh under ELA2; the total investment requirement would increase by 6% under ELA1 and 12% under ELA2.

This is because the total electricity generation requirement in 2017 would increase by 4% under ELA1 and by 11% under ELA2 compared to that in the base case.[30] If, however, the minimum consumption level per household is increased to 285 kWh, the total supply cost in 2017 would be 54% higher than that in the base case while the investment requirement would be 52% higher. With the same level of minimum consumption per household, the total electricity supply cost would increase by 44% and 30% in 2022 and 2030 respectively.

[30] Note that the generation requirement here corresponds to the case when LED lamps are considered for lighting.

When the minimum electricity consumption of a household is set at the levels of 1,464 kWh under ELA2 and 2,267 kWh under ELA3 in 2030, the supply system cost would be several folds higher, i.e., 251% more in ELA2 and 431% more in ELA3. The investment requirement would be 254% higher in ELA2 and 436% higher in ELA3 in the district in 2030 (this is because the total electricity generation requirement would be 273% higher in ELA2 and 469% higher in ELA3 than that in the base case level).

Thus the present study showed that a universal electricity access program that allows each household to consume at least up to 66 kWh per year could be implemented at a relatively modest additional cost. Implementation of a universal access program with the minimum household electricity consumption of 285 kWh could be implemented with an additional supply system expansion cost of about 50%, whereas universal access programs with the minimum consumption per household at 1,464 kWh and 2,267 kWh would incur much higher increase in total cost and require a very large increase in investment for their implementation.

The study found that the incremental cost of electricity access (or supply) in per unit terms would decrease with an increase in minimum electricity consumption per household under the universal access programs considered. This suggests that a higher level of universal access could benefit from some kind of economy of scale in access.

However, a higher level of minimum electricity consumption per household would also impose higher energy burden, which means the targeted minimum level of electricity use is likely to be affordable to a smaller percentage of households; and in such a case a larger volume of financial support may have to be mobilized to help make electricity access affordable to all.

Clearly, the volume of financial support required to make electricity use affordable to energy-poor households and the financial and other resources available to the government would play a role in setting the minimum level of electricity use that a universal electricity access program could aim at and the timing of introducing such a program. Besides, the sustainability of such programs in the long run would be a consideration in deciding on the minimum electricity consumption level.

In the case of access to cleaner cooking options, the study revealed that replacing traditional biomass cookstoves with moderately efficient improved cookstoves would generate savings of NRs8.10 per kgoe while transitioning to highly efficient improved cookstoves would generate NRs6.80 per kgoe (as their incremental energy access costs [IEAC] are negative).

The replacement of traditional biomass cookstoves with biogas stoves would incur positive IEAC of NRs0.70 per kgoe while briquette stoves woud add IEAC of NRs4.50 per kgoe. At the prices considered in this study, the usage of biomass briquette for cooking is more expensive than biogas.

Energy Access Technology Implications

Role of decentralized vs. grid based supply options. The study showed that the decentralized electrification options based on solar photovoltaic (PV), microhydropower, and biomass would play a relatively small role in the total electricity supply of Pyuthan district and that the extension of power grid would be the predominant and cost-effective option for providing electricity access in the district from a long-term perspective.

Cost assessment in this study, which was conducted to find the least cost electricity supply options and the corresponding levels of electricity generation, revealed that the combined share of decentralized renewable energy options (consisting of solar PV, microhydro, and biomass) would be mostly below 5.5% under universal electricity access programs ELA1 to ELA3 in 2017.

Grid based supply seems to be the dominant option that would meet over 90% of the total demand even under universal access programs with low levels of universal electricity consumption per household. The study also showed that it would be cost-effective to meet the entire electricity demand through the grid when higher levels of electricity consumption per household are targeted (e.g., under ELA2 and ELA3 in 2030).

Thus, at the present level of technology and resource costs, decentralized supply options, especially solar PV and biomass, seem to have a much smaller role than the grid extension (based on medium and large hydropower generation). Nevertheless, the role of decentralized options cannot be underestimated in VDCs that are sparsely populated and are remotely located especially when the electricity consumption level per household targeted by a universal access program is not high. It should also be noted that the role of the micro- and minihydro options in this study was restricted due to the relatively insignificant potential of microhydro power generation reported by the available sources. It is possible for the micro- and minihydro options to have a bigger role in providing electricity access in the district in case larger micro- and minihydro potential would be applicable in the district.

Significance of demand side options. This study demonstrated that the cost of using electricity by households under an electricity access program could vary significantly depending upon the technologies used in the demand side. For example, this study showed that if universal electricity access of at least 66 kWh is provided per household in 2022, the electricity supply system cost would increase by 21.3% whereas the total supply and demand side costs would increase by 21.5%, when incandescent lamps are used instead of light-emitting diode (LED) lamps.

The electricity supply system (i.e., the supply side) would cost about 4.5% higher whereas the total supply and demand side cost would be 4.8% higher when compact fluorescent lamps (CFLs) are used instead of LED lamps. Thus, other things remaining the same, electricity supply system with the use of LED lighting was clearly shown to be the least costly. This highlighted the need for considering both supply and demand side options for developing cost efficient electricity access programs and to identify the least cost combination of both types of options.

Note, however that efficient and less costly demand side options may not necessarily be adopted by all households because of their high initial costs and other barriers. Therefore, supportive policies and mechanisms will have to be in place for an effective implementation of such options while developing energy access programs.

Benefits of Cleaner Energy Access

Provision of universal access to cleaner energy forms a part of sustainable development objectives.

However, the magnitude of benefits from an energy access program is not invariant with the level of use of cleaner energy services, and this signifies the assessment of the levels of benefits from an energy access program.

Cleaner energy access includes both tangibles and intangibles benefits. Some benefits are private or internal to the households while others are external. However, all these benefits provide a rationale for the provision of access to cleaner energy options to households.

This study assessed *ex ante* different kinds of benefits associated with cleaner energy access programs based on the information gathered from the sample household survey. Different kinds of benefits estimated by the study can be highlighted as follows:

- **Time savings and reduction of drudgery.** Households who purchased kerosene at least 4 times a month for lighting were estimated to save, on an average, up to 35 man-hours annually if they would have electricity access. Similarly, households using LPG for cooking instead of fuelwood and agricultural residues are found to save up to 368 man-hours per year and reduce the drudgery associated with the collection of fuelwood and agricultural residues.
- **Reduction of GHGs and local pollutant emissions.** There would be a significant reduction in the GHGs and local pollutants emissions with the use of electricity for lighting and energy efficient stoves instead of traditional stoves for biomass based cooking. For example, this study estimated that the use of diversified cleaner cooking options including improved biomass cookstoves, biogas, biomass briquettes, electricity, and LPG to replace cooking with traditional biomass stoves,[31] could reduce particulate matter 10 emissions by about 73% and black carbon emissions by about 72%. Similarly, displacement of nonelectric energy used in lighting through electric lighting alone could avoid around 1,433 tons of carbon dioxide emissions in 2017.
- **Productive Activities.** Of the total number of households who owned a family business, about 90% were those who had access to electricity, whereas that do not have access to electricity owned only 10%. This shows that more people are likely to get engaged in productive activities and be self-employed in households with electricity supply than those without it.
- **Education.** Students in the electrified households are found to spend 66% more time studying than those in the unelectrified households in the district.
- **Health.** People in grid electrified VDCs are found to have fewer annual absent days than their counterparts in the off-grid electrified VDCs of the district.
- **Energy Inequality.** The study estimated electricity Gini coefficient as an index of electricity inequality in the district. In 2014, about one-third of the VDCs in the district were found to have a relatively high value of electricity Gini coefficient, i.e., above 0.6. If all households in the district were to use a minimum of 3 kWh of electricity under a universal electricity access program, the value of the electricity inequality index was estimated to improve only nominally (by 5.9%) in 2017. The electricity inequality index would improve much more, by about 20% and 66% with universal electricity

[31] In this case the shares of inefficient traditional biomass stoves are replaced by cleaner or more efficient cooking options as follows: 20% each by MICS and HICS, 20% by biogas and 15% by biomass briquette stoves, 15% by electric, and 10% by LPG cookstoves. Biomass stoves, share is 75% while nonbiomass stoves, share is 25%.

access programs allowing households at least 66 kWh and 285 kWh of electricity use per annum respectively.

The Issue of Affordability

The households' capacity to afford electricity is an important issue even in areas where grid based electricity supply is available.

The size of the household population facing an energy affordability problem and the level of financial support needed to make a desired (or targeted) minimum level of cleaner energy services affordable under a universal energy access program would depend upon the definition of the types of basic energy services considered and their usage levels.

The level of support to be provided would also depend upon the coverage of the costs involved, i.e., whether or not the policy maker or planner intends to cover only the supply side costs or both supply and demand side costs. More importantly, the determination of a target for the minimum level of energy use by households in a universal energy access program in itself involves several policy issues and implications.

This study carried out an assessment of the households' capacity to afford cleaner energy usage for three different cases (or "tiers") of access to electricity and cleaner cooking options with the minimum level of annual electricity consumption per household set at 4.4 kWh in energy access Tier 1, increases to 66 kWh in Tier 2, and further increases to 321 kWh in Tier 3 and considering the annual useful cooking energy requirement per household of 27.2 kgoe in each of these cases (or Tiers).[32]

Choice of minimum energy consumption level per household and affordability. For any given threshold level of energy burden, the size of the population exceeding the threshold increases with the level of minimum energy usage per household considered under a universal energy access program.

In other words, the higher the minimum level of energy consumption per household, the higher would be the size of the population exceeding the threshold energy burden. For example, this study showed that in 2017, 20.9% of the households would have their energy burden above 10% under energy access Tier 1, whereas the corresponding figures would be 66.9% under energy access Tier 2 and 85.9% under energy access Tier 3 (when both supply and demand side costs are considered).

Similarly, in 2030, only 7.5% of households would have their energy burden higher than 10% under energy access Tier 1, while 45.7% of households would have a higher level of energy burden under Tier 2 and 70.4% of households under Tier 3.

[32] In the case of Tier 1, improved cookstove (ICS) with firewood is used for cooking and electricity is used for lighting only. In Tier 2, biomass briquette and an ICS are used for cooking, while electricity is used for lighting, phone charging, and powering fans, radios, and televisions. In Tier 3, two alternative gaseous fuel options, LPG and biogas, were considered separately, whereas electricity end uses include food processor and refrigerator in addition to what has been considered in Tier 2.

Threshold energy burden and size of population having energy affordability problem. A larger percentage of households are likely to face the affordability problem if a lower threshold is set for the energy burden and vice versa.

For example, as discussed in Chapter 11, in 2022 this study found that under energy access Tier 1, about 2.3% of the households would have their energy burden above 20%, whereas 15.1% would have their energy burden above 10%.

Similarly, under energy access Tier 2, 59.7% of the households would have their energy burden above 10%, whereas 27.3% of the households would have energy burden above 20%. Likewise, in 2030, 37.4% of households would face an energy burden of above 20% under energy access Tier 3 as compared to 70.4% of the households, whose energy burden would exceed 10%. This clearly implies that the threshold energy burden is an important parameter in developing an energy access policy.

Role of supply and demand side costs in energy access affordability. The capacity of households to afford to use cleaner energy services depends on the total cost of using such services, which includes both supply and demand side costs. Consideration of only the supply side costs would obviously underestimate the actual level of energy burden faced by households.

As an example, this study estimated that in 2022, 14.2% of the households in the district would have an energy burden above 10% under energy access Tiers 1 when only the supply side costs are considered as compared to 15.1% when both supply and demand side costs are considered.

Similarly, in 2030, 6.7% of households would have their energy burden above 10% under Tier 1 when only supply side costs are considered, whereas a larger percentage of households (i.e., 7.5%) would face such an energy burden when both supply and demand side costs are included.

Upfront costs and affordability. Upfront costs present an initial barrier while switching to the use of electricity and other forms of cleaner energy; this is especially a serious problem in the case of low-income households. This study found that even to access a low level of energy use (i.e., for cooking and electricity use only in lighting) under Tier 1, households in the lowest two income deciles would have to spend more than 10% of their annual income on the initial costs of devices.

The burden of the upfront costs on the annual income of these two categories of households would increase to as high as 64% and 40% under Tier 2 level of energy access, whereas the corresponding figures would be 75% and 47% under Tier 3 level of energy access (if LPG is used for cooking).

This showed the need for some kind of financing or other mechanisms (such as device subsidy and/or long-term soft loans) to support the low-income households on initial costs of cooking devices as well as home electrification and lamps. It should be noted that the government has subsidy schemes on improved cookstoves, SHS, and biogas digesters at the household level (MOPE 2016). However, the study calculated the upfront costs and energy burden of the households at the real cost, i.e., at market prices (without any subsidy).

Choice of a threshold energy burden and financial support implications. The level of financial support to be provided to households would depend upon the threshold energy burden set by the policy makers. The higher the value of the threshold energy burden, the smaller the financial support needed for the predefined minimum cleaner energy consumption per household.

This study assessed the average level of financial support that would be needed by the households, whose energy expenditure would exceed threshold energy burden. The study has done this for three different levels of energy burden thresholds, i.e., 10%, 15%, and 20% for each of the three alternative tiers of energy access considered in 2017, 2022, and 2030.

As an example, at the threshold burden of 10%, it shows that the average annual financial assistance required per household in 2022 would be NRs2,173 under energy access Tier 1; NRs9,796 under Tier 2; and NRs20,576 under Tiers 3 if both supply and demand sides are considered.[33]

If, however, only the supply side costs are considered, the corresponding level of the support per household would be reduced to NRs2,010 under Tier 1; NRs9,303 under Tier 2; and NRs19,065 under Tier 3. Similarly, at the same threshold energy burden, the level of the support needed in 2030 would decrease to NRs1,964 under Tier 1; NRs8,746 under Tier 2; and NRs18,440 under Tier 3 (LPG option) when both supply and demand side costs are considered.

However, if, only the supply side costs are considered, the average level of the financial support needed per household would be somewhat lower, i.e., NRs1,893 under Tier 1; NRs8,419 under Tier 2; and NRs17,263 under Tier 3.

If the energy burden threshold was set at a higher level of 20%, the level of support required per household in 2022 would be NRs1,685 under Tier 1; NRs7,193 under Tier 2; and NRs15,455 under Tier 3 (when both supply and demand side costs are considered). Similarly, the level of support required per household in 2030 would be NRs1,545 under Tier 1; NRs6,204 under Tier 2; and NRs13,945 under Tier 3.[34] It should be noted here that only the lighting and cooking device costs are considered in the demand side costs and that the supply side costs dominate the total energy access cost per household. Therefore most of the financial support would be needed to cover the supply side costs.

Note that the energy burden faced by a household would depend on the level of energy services households use. On the other hand, the choice of the threshold value for the energy burden by energy access policy makers would itself imply allowing households to use certain level of energy services without any support from the state. With the given income and energy prices, more households would be eligible for any financial support (if provided by a government policy) if the threshold burden is set at a lower level. The opposite would be the case when the threshold energy burden is set at a higher level.

On the other hand, for the given income and prices, a lower level of minimum energy services to be provided under an energy access program would impose a lower level of energy burden

[33] Energy access Tier 3 here considers LPG as an option for cooking.

[34] It should be noted here that costs of electrical appliances other than for lighting are not included in the demand side costs.

and this means a smaller household population would be eligible for financial support or other incentives at a given threshold energy burden.

If the support schemes for an energy access program is to be sustainable, it is important to determine the basic minimum level of energy services that a household would need irrespective of the income level and to set the threshold energy burden high enough so that nonpoor households could be excluded from any financial and other scheme under an energy access support policy.

12.2 Some Policy and Program Implementation Implications

(i) This study estimated the multidimensional energy poverty index (MEPI) to assess the level of energy poverty for each VDC of the district. Based on estimated values of MEPI the study has identified 5 VDCs facing low level of energy poverty, 17 VDCs being under moderately high energy poverty, and 27 VDCs with high level of energy poverty. This finding provided an interesting insight to the energy access planners and policy makers as to the identification of the VDCs which deserve priority intervention in terms of the implementation of cleaner energy access programs.

(ii) The study identified VDCs with different levels of disparity in terms of electricity usage by estimating electricity Gini-coefficients at the VDC level. It has revealed that households in 16 VDCs (i.e., about one-third of the VDCs) in the district suffer from a "very high" level of electricity inequality, another 16 VDCs have a "high" level of electricity inequality and 17 VDCs have "low to moderately high" level of inequality. If reducing electricity inequality is one of the key considerations of electricity access programs of the government policy makers, these indicators provide a basis for prioritizing the implementation of such programs.

(iii) The Renewable Energy Subsidy Policy, 2073 BS (RESP) of the government declared a number of subsidy schemes to promote different kinds of renewable energy technologies in the country (MOPE, 2016). The subsidy amount under RESP varies according to technology and geographical region (based mainly on the remoteness of an area) and generally covers 40% of the total initial costs. RESP also discusses about "mobilizing" credit to over 30% of the initial costs. However, unless the subsidy amount and credit for meeting the upfront costs is easily accessible at the local level, poor households may still find it difficult to use electricity and other cleaner energy options; in this case, it would be hard to achieve the goal of universal access to cleaner energy. It should be noted that subsidies under the RESP focuses on the upfront costs of distributed and decentralized renewable energy technologies. Besides the upfront costs, the high price of electricity could also be a barrier for low-income households to use electricity for cooking, for which grid supply is found to be the predominant option. If electric cooking is to be a part of a universal energy access program, additional support policies and mechanisms would be necessary. A proactive policy would be required to introduce an electricity tariff that would make electric cooking affordable even to poor households. However, introduction of such a policy would also have to take into consideration the long-term sustainability of electricity price subsidies and their economy wide effects.

(iv) A reform in electricity tariff would be desirable to make electricity more affordable to poor households. At present, electricity pricing of the Nepal Electricity Authority is based on an increasing block tariff with the lowest block allowing a monthly consumption of up to 20 kWh; the households in this category are liable to pay a fixed monthly service charge of NRs30 and an energy charge of NRs3 per kWh. This is also the tariff structure for the lowest consumption block in the case of Butwal Power Company—a private power supply company which is partly involved in electricity supply in Pyuthan district. Note that a household consuming 20 kWh per month would have their annual consumption of 240 kWh and this level of consumption is several times higher than the minimum annual consumption levels per household in the lower levels of energy access (e.g., 4.4 kWh and 66 kWh considered under energy access Tiers 1 and 2) in the affordability assessment. This shows that electricity tariff at present does not sufficiently consider the issue of electricity access to the poor and the associated affordability problem. An innovative reform and restructuring of electricity tariff would be needed to address the poor households' electricity access and affordability problems.

(v) This study showed that there would be significant cost savings when traditional biomass cookstoves (with an energy efficiency of 10%) are replaced by moderately efficient improved cookstoves (MICS) and highly efficient improved cookstoves (HICS). However, traditional biomass in its natural form may pose some inconvenience in using MICS and HICS due to its irregular size; as such it may need additional time and effort for preparation or processing for its efficient use in MICS and HICS. Thus it is important for the design and production of improved cookstoves (ICS) to closely match with the type and size of biomass typically used by the households. Besides, the ICS design should also carefully consider the cooking patterns of the households. In any case, programs to promote ICS would be more effective when households are oriented to the efficient operation and maintenance of the ICS.

Electricity is considered as a major source of energy in Nepal as the country is endowed with a large hydropower potential. As the economy grows and the purchasing power of people increases, it is expected that households will move upward along the energy ladder. That means, over the longer run, households in both urban and rural areas are likely to opt for modern fuels like LPG and electricity for cooking. This study showed that the use of electricity supplied from the grid would be a cheaper option than LPG to replace biomass in cooking. Furthermore, electricity use would improve the energy security status of the country. Thus from a long-term perspective, electricity as a source of cooking energy would not only be a more sustainable option for cleaner cooking but it would also improve the national energy security. From this standpoint, the development of a coordinated policy for the promotion of energy access and enhancement of energy security appears highly important.

12.3 Some Limitations of the Study

The following are some of the key limitations of the present study:

(i) Inadequate hydropower resource assessment: The presently available information on the small hydropower generation potential (including that of micro- and minihydro) in the case of Pyuthan district seems to be inadequate as the total microhydro potential in the district is reported to be 14 kW, which is considered as such in this study. This value of the micro- and minihydro potential seems to be too low for the geographical area of the district. It is therefore likely that the role of decentralized electrification is underestimated in the study and accordingly, that of grid based electrification is likely to have been overestimated at least for cases with lower tiers of electricity access. It shows the need for a more comprehensive assessment of micro- and minihydro power potential in different VDCs of the district.

(ii) This study considered only the demand for consumptive use of electricity; it did not include the demand for electricity used by households for productive uses nor did it consider electricity demand associated with the production sector and community services. As such, the total electricity demand and the corresponding capacity of the electricity supply system estimated in this study are expected to be smaller than that when the productive uses of electricity by the households and the demand of the nonhousehold sectors are considered. Thus, it is likely that the study might not have fully captured any economy of scale in electricity supply that could exist with a larger scale electricity supply.

(iii) The increase in the total electricity demand (and hence the electricity supply requirement) associated with a universal electricity access program would crucially depend on the minimum level of electricity consumption per household targeted by the program. The desired level of minimum electricity consumption per household figure specific to Nepal is, however, not available at present. This study considered three alternative levels of minimum electricity consumption per household for universal access in 2017, 2022, and 2030 and determined the least cost electricity generation mix and associated costs in each of these cases. Obviously, the estimated costs and generation mix would vary if a different value for the minimum level of household electricity consumption is considered under a universal electricity access program.

(iv) This study considered only the costs associated with lighting and cooking services and excluded energy services like space heating in assessing households' affordability to cleaner services. Thus the total energy burden faced by households would in fact be higher than what was estimated. As such, at any threshold energy burden, there would be a larger percentage of households whose energy expenditure would exceed the threshold burden than what was estimated in this study.

(v) This study borrowed emission factors for the estimation of both local and GHG emissions from several sources (national as well as international) for quantifying the emissions reduction benefit due to improved energy access. However, the estimates on the level of emissions could be different when more information on emission factors specific to Nepal (if not Pyuthan district) become available.

References

N. H. Afgan, M. G. Carvalho, and N. V. Hovanov. 2000. *Energy System Assessment with Sustainability Indicators*. Energy Policy 28 (9): 603–612.

Alternative Energy Promotion Center (AEPC). 2008. *Solar and Wind Energy Resource Assessment in Nepal, Kathmandu*.

AEPC. 2014. *District Climate and Energy Plan, Pyuthan District, National Rural and Renewable Energy Programme*. http://aepc.gov.np/docs/resource/subreport/20150811061738_District%20Climate%20and%20Energy%20Plan-%20Pyuthan.pdf (accessed 21 September 2014).

AEPC. 2016. *Terms of Reference*. http://aepc.gov.np/docs/workwithus/tor/20140730014639_02%20Mini-%20Micro%20Hydropower%20Expert%20 (SASEC-PSEP)%20_ToR.pdf (accessed 25 April 2016).

Asian Development Bank (ADB). 2017. *Poverty in Nepal*. https://www.adb.org/countries/nepal/poverty (accessed 25 August 2017).

Australian Bureau of Statistics (ABS), 2017, Appendix 5: Income Deciles, Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/4363.0Appendix52014-15?opendocument&tabname=Notes&prodno=4363.0&issue=2014-15&num=&view=. Accessed on December 28, 2017.

S. Bahramara, F. Jafari, A. Rahimi-Kian, and H. Lesani. 2012. *Planning of a Grid-connected Smart Micro-power System*. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6303190 (accessed February 2016)

S. C. Bhattacharyya. 2012. Energy Access Programmes and Sustainable Development: A Critical Review and Analysis. *Energy for Sustainable Development*. 16. pp. 260–271.

Biogas Support Program (BSP). 2012. *Year Book 2011/12*. Lalitpur, Nepal.

Government of Nepal. 2014. Central Bureau of Statistics. *National Population and Housing Census 2011 (Village Development Committee/Municipality)*. Pyuthan. Volume 06, NPHC2011. Kathmandu.

O. Demirtas. 2013. Evaluating the Best Renewable Energy Technology for Sustainable Energy Planning. *International Journal of Energy Economics and Policy*. 3. pp. 23–33.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GTZ) and AEPC. 2004. *Micro Hydropower Project Model. Version 1.0. Small Hydropower Promotion Project /GTZ, Mini-grid Support Programme*. Kathmandu, Nepal.

H. Doukas, et al. 2012. Assessing Energy Access Sustainability of Rural Communities using Principal Component Analysis. *Renewable and Sustainable Energy Reviews*. 16. pp. 1949–1957.

District Development Committee. 2012. District Energy Situation Report-Pyuthan, District Energy Efficiency Unit, Nepal.

Government of Nepal. 2008. *Micro-Enterprise Development Programme*. http://www.medep.org.np/index.php?page=page2&id=4 (accessed 10 September 2015).

Government of Nepal. Department of Hydrology and Meteorology. 2014. *Hydrology and Meteorology Data*. Kathmandu.

Government of Nepal. Ministry of Population and Environment. 2016. *Renewable Energy Subsidy Policy. 2073.* Kathmandu.

Government of Nepal. National Planning Commission, 2014. *An Approach to the Graduation from the Least Developed Country by 2022*. Kathmandu, Nepal.

Hamro Pyuthan. 2014. http://www.hamropyuthan.com/index.php?page=cms&id=7 (accessed 23 June 2014).

HOMER Energy and National Renewable Energy Laboratory. 2011. *Getting Started Guide for HOMER Legacy (Version 2.68)*. Colorado, USA.

International Energy Agency (IEA). 2016. *World Energy Outlook 2016*. Paris.

_____. 2011. *World Energy Outlook 2011*. Paris.

P. Lilienthal. 2005. The HOMER Micropower Optimization Model. *National Renewable Energy Laboratory*. Conference Paper. NREL/CP-710-37606.

B. Mainali, et al. 2014. Assessing Rural Energy Sustainability in Developing Countries. *Energy for Sustainable Development*. 19. pp. 15–28.

A. Maxim. 2014. Sustainability Assessment of Electricity Generation Technologies Using Weighted Multi-criteria Decision Analysis. *Energy Policy*. 65. pp.284–297.

Micro-Enterprise Development Programme (MEDP). 2008. Map of MEDEP Implementation Districts. UNDP, Government of Nepal. http://www.medep.org.np/index.php?page=page2&id=4 (accessed 28 December 2017).

National Renewable Energy Laboratory. 2016. *Distributed Generation Renewable Energy Estimate of Costs*. http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html (accessed 22 May 2016).

Nepal Oil Corporation (NOC). 2014. Fortnightly Profit & Loss. http://www.nepaloil.com.np/monthly-profit-and-loss-details/ (accessed 23 June 2014).

P. Nussbaumer, M. Bazilian, and V. Modi. 2012. Measuring Energy Poverty: Focusing on What Matters. *Renewable and Sustainable Energy Reviews*. 16. pp. 231–243.

M. Ongwandee, and W. Pipithakul. 2010. Air Pollutant Emissions from the Burning of Incense, Mosquite Coils, and Candles in a Small Experimental Chamber. *Applied Environmental Research*. 32 (1).

S. Pachauri, et al. 2013. *Pathways to Achieve Universal Household Access to Modern Energy by 2030*.

Practical Action. 2012. *Poor People's Energy Outlook 2012: Energy for Earning a Living, Technology Challenging Poverty*. Rugby, UK: Practical Action Publishing.

Practical Action. 2013. *Poor People's Energy Outlook 2013: Energy for Community Services*. Rugby, UK: Practical Action Publishing.

Rural Integrated Development Service–Nepal. 2013 Light. http://www.rids-nepal.org/index.php/Light.html (accessed 15 July 2015).

Sanima Hydropower. 2012. *Synopsis for Investment in Hydropower*. Kathmandu, Nepal.

R. M. Shrestha, et al. 2013. *Atmospheric Brown Clouds (ABC) Emission Inventory Manual*. Nairobi, Kenya: United Nations Environment Programme.

R. M. Shrestha, and J. Acharya. 2015. *Sustainable Energy Access Planning: A Framework*. Manila: Asian Development Bank.

Sipradi Energy Private Limited (SEPL). 2014. *Solar Data*. Kathmandu, Nepal.

E. Tedsen. 2013. *Black Carbon Emissions from Kerosene Lamps*. Berlin: Ecologic Institute.

United Nations Development Programme (UNDP). 2016. *Human Development Report 2016: Human Development for Everyone*. New York. http://hdr.undp.org/en/countries/profiles/NPL (accessed 25 August 2017).

J. J. Wang, et al. 2009. Review on Multi-Criteria Decision Analysis Aid in Sustainable Energy Decision-Making. *Renewable and Sustainable Energy Reviews*. 13 (9). pp. 2263–2278.

Water and Energy Commission Secretariat. 2010. *Energy Sector Synopsis Report 2010*. Kathmandu, Nepal.

Water and Energy Commission Secretariat (WECS). 2014. *Energy Consumption Situation in Nepal (Year 2011/12)*. Energy Data Sheet. Kathmandu.

World Bank. 2017a. *The World Bank Data*. http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD (accessed 28 August 2017)

World Bank. 2017b. *The World Bank Data*. http://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=NP (accessed 25 August 2017)

World Bank/ESMAP and International Energy Agency. 2013. *Sustainable Energy for All (SE4ALL)*. Global Tracking Framework. 3, 77889.

A. Zahnd. 2013. *The Role of Renewable Energy Technology in Holistic Community Development*. Switzerland: Springer International Publishing.

Appendixes

Appendix 1

Table A1: Questionnaire on Energy Poverty: Multidimensional Energy Poverty Index

There are six indicators considered in measuring energy poverty as shown in Table A1. How would you rate each indicators on a scale of 0 to 10 considering the relative importance of each indicator in contributing to energy poverty?

- 0 indicates that the indicator "does not contribute at all" to energy poverty
- 10 indicate that the indicator "contributes very strongly" in energy poverty.

S.No.	Indicators	Score
1	Cooking using traditional biomass fuels	
2	Cooking without chimney/hood in case of using solid biomass	
3	No access to electricity for lighting	
4	Use of traditional fuels for space heating	
5	No access to Radio	
6	No access to landline phone or mobile	

S.No. = serial number.
Source: Authors.

Appendix 2

Table A2: Estimated Number of Electricity Poor Households in Pyuthan

Village Development Committee	Total Number of Households	Estimated Number of Energy-Poor Households[a]
Arkha	900	220
Badikot	1,140	194
Bangesal	1,004	413
Baraulaa	883	134
Barjiwang	596	46
Belbas	1,318	54
Bhingri	1,301	116
Bijayanagar	937	141
Bijuwar	1,851	463
Bijuli	923	0
Chuja	1,232	812
Dakhakwadi	1,434	0
Damri	882	409
Dangwang	838	408
Dharampani	710	231
Dharmawoti	1,132	283
Udayapurkot	604	250
Dhuwang	708	260
Dhungeygadhi	763	234
Gothiwang	1,190	198
Hansapur	724	369
Jumrikanda	898	352
Khaira	914	0
Khawang	1,147	0
Khung	655	49
Kochiwang	706	41
Ligha	588	47
Liwang	933	35
Lung	1,019	220
Majhakot	697	263
Maranthana	1,455	509
Markawang	606	152
Narikot	706	221
Nayagaun	760	20
Okherkot	1,202	0
Pakala	936	0

continued on next page

Table *continued*

Village Development Committee	Total Number of Households	Estimated Number of Energy-Poor Households[a]
Phopli	1,537	671
Puja	1,087	298
Khalanga	1,536	261
Rajbara	845	384
Ramdi	525	0
Raspurkot	778	17
Saari	850	34
Swargadwari Khaal	636	130
Syauliwang	1,058	92
Tiram	1,122	247
Turwang	937	99
Tusara	1,193	222
Bangemaroth	1,320	225
Total	**47,716**	**9,824**

[a] Tier 0 level of households whose energy consumption is below Tier 1 level.
Source: CBS (2014) and Authors.

Appendix 3

Table A3: Estimated Number of Households in each Village Development Committee

Village Development Committee	2014[a]	2017	2022	2030
Arkha	900	948	1,033	1,185
Badikot	1,140	1,200	1,308	1,501
Bangesal	1,004	1,057	1,152	1,322
Bangeymaroth	1,320	1,390	1,515	1,738
Baraulaa	883	930	1,013	1,162
Barjibang	596	628	684	785
Belbas	1,318	1,388	1,512	1,735
Bhingri	1,301	1,370	1,493	1,713
Bijayanagar	937	987	1,075	1,233
Bijuli	923	972	1,059	1,215
Bijuwar	1,851	1,949	2,124	2,437
Chuja	1,232	1,297	1,414	1,622
Dakhawadi	1,434	1,510	1,645	1,888
Damri	882	929	1,012	1,161
Dangwang	838	882	961	1,103
Dharampani	710	748	815	935
Dharmawoti	1,132	1,192	1,299	1,490
Dhungeygadi	763	803	875	1,004
Dhuwang	708	745	812	932
Gothibang	1,190	1,253	1,365	1,567
Hansapur	724	762	831	953
Jumri Kada	898	946	1,030	1,182
Khaira	914	962	1,049	1,203
Khalanga	1,536	1,617	1,762	2,022
Khawang	1,147	1,208	1,316	1,510
Khochiwang	706	743	810	929
Khung	655	690	752	862
Ligha	588	619	675	774
Liwang	933	982	1,070	1,228
Lung	1,019	1,073	1,169	1,341
Maajhkot	697	734	800	918
Maranthana	1,455	1,532	1,669	1,915
Markawang	606	638	695	798
Narikot	706	743	810	929
Nayagaun	760	800	872	1,000

continued on next page

Table *continued*

Village Development Committee	2014[a]	2017	2022	2030
Okharkot	1,202	1,266	1,379	1,582
Pakala	936	986	1,074	1,232
Phopli	1537	1,618	1,763	2,023
Puja	1,087	1,145	1,247	1,431
Rajbara	845	890	970	1,112
Ramdi	525	553	602	691
Raspurkot	778	819	893	1,024
Saari	850	895	975	1,119
Sayuliwang	1,058	1,114	1,214	1,393
Sorgadwori	636	670	730	837
Tiram	1,122	1,181	1,287	1,477
Torbang	937	987	1,075	1,233
Tusara	1,193	1,256	1,369	1,570
Udayepurkot	604	636	693	795
Total	**47,716**	**50,240**	**54,747**	**62,814**

[a] CBS (2014).
Source: CBS (2014) and Authors.

Appendix 4

Table A4: Estimated Number of Population in each Village Development Committee

Village Development Committee	Growth Rates, 2001–2011, (%)	2014	2017	2022	2030
Arkha	2.34	5,783	6,200	6,962	8,380
Badikot	–0.65	5,327	5,223	5,055	4,797
Bangesal	1.80	6,726	7,097	7,761	8,955
Bangeymaroth	0.72	4,693	4,795	4,970	5,264
Baraulaa	–0.30	4,192	4,154	4,091	3,993
Barjibang	0.04	2,424	2,427	2,431	2,438
Belbas	0.95	5,802	5,968	6,256	6,745
Bhingri	0.82	5,433	5,568	5,799	6,190
Bijayanagar	0.37	4,008	4,052	4,127	4,250
Bijuli	–0.04	3,974	3,969	3,962	3,951
Bijuwar	1.30	7,446	7,740	8,255	9,152
Chuja	0.38	5,835	5,903	6,016	6,203
Dakhawadi	0.09	6,082	6,098	6,124	6,166
Damri	1.07	4,808	4,965	5,237	5,704
Dangwang	–0.23	4,524	4,493	4,442	4,363
Dharampani	–0.48	3,068	3,024	2,951	2,839
Dharmawoti	–0.02	4,882	4,880	4,876	4,869
Dhungeygadi	0.81	4,298	4,404	4,585	4,890
Dhuwang	–0.72	3,597	3,520	3,395	3,205
Gothibang	1.14	5,522	5,712	6,044	6,615
Hansapur	0.80	4,002	4,098	4,264	4,544
Jumri Kada	1.21	4,353	4,512	4,791	5,273
Khaira	–1.24	4,036	3,887	3,652	3,304
Khalanga	0.39	5,883	5,952	6,068	6,260
Khawang	1.59	6,072	6,365	6,886	7,809
Khochiwang	0.81	3,467	3,552	3,698	3,945
Khung	1.71	3,312	3,485	3,793	4,344
Ligha	5.37	3,735	4,369	5,674	8,620
Liwang	1.58	5,093	5,338	5,772	6,541
Lung	1.30	4,730	4,916	5,244	5,814
Maajhkot	0.70	3,253	3,321	3,439	3,635
Maranthana	0.69	6,328	6,460	6,686	7,063
Markawang	0.34	3,129	3,161	3,216	3,305
Narikot	0.58	3,375	3,434	3,535	3,702

continued on next page

Table *continued*

Village Development Committee	Growth Rates, 2001–2011, (%)	2014	2017	2022	2030
Nayagaun	0.57	3,482	3,541	3,643	3,813
Okharkot	0.40	5,755	5,825	5,942	6,136
Pakala	0.49	4,645	4,714	4,831	5,025
Phopli	1.81	7,900	8,337	9,119	10,526
Puja	1.12	5,192	5,368	5,674	6,200
Rajbara	2.11	5,200	5,536	6,144	7,258
Ramdi	−0.08	2,432	2,426	2,416	2,400
Raspurkot	−1.17	3,334	3,218	3,035	2,763
Saari	0.48	3,611	3,663	3,752	3,899
Sayuliwang	1.15	3,625	3,751	3,971	4,350
Sorgadwori	1.18	4,945	5,122	5,431	5,966
Tiram	−0.37	5,885	5,819	5,711	5,542
Torbang	−0.26	4,312	4,277	4,221	4,133
Tusara	0.04	5,773	5,780	5,791	5,809
Udayepurkot	1.36	3,198	3,330	3,563	3,970
Total		**228,481**	**233,750**	**243,304**	**260,919**

Source: CBS (2014) and Authors.

Appendix 5

Table A5: Distribution of Households based on their Electricity Consumption Level in Different Tiers in 2014

S.No.	Village Development Committee	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Arkha	24.4	70.7	4.9	0.0	0.0	0.0
2	Badikot	17.0	19.1	23.4	38.3	0.0	2.1
3	Bangesal	41.2	11.8	39.2	7.8	0.0	0.0
4	Baraulaa	15.2	6.5	50.0	21.7	2.2	4.3
5	Barjiwang	7.7	3.8	48.1	40.4	0.0	0.0
6	Belbas	4.1	49.0	28.6	14.3	4.1	0.0
7	Bhingri	8.9	2.2	37.8	48.9	2.2	0.0
8	Bijayanagar	15.1	11.3	37.7	35.8	0.0	0.0
9	Bijuwar	25.0	0.0	17.3	55.8	1.9	0.0
10	Bijuli	0.0	0.0	57.1	40.0	2.9	0.0
11	Chuja	65.9	11.4	20.5	2.3	0.0	0.0
12	Dakhakwadi	0.0	3.7	40.7	55.6	0.0	0.0
13	Damri	46.3	53.7	0.0	0.0	0.0	0.0
14	Dangwang	48.6	2.7	32.4	16.2	0.0	0.0
15	Dharampani	32.5	2.5	30.0	35.0	0.0	0.0
16	Dharmawoti	25.0	0.0	5.8	57.7	11.5	0.0
17	Udayapurkot	41.5	22.0	17.1	19.5	0.0	0.0
18	Dhuwang	36.7	18.4	42.9	2.0	0.0	0.0
19	Dhungeygadhi	30.6	20.4	24.5	20.4	2.0	2.0
20	Gothiwang	16.7	29.2	37.5	16.7	0.0	0.0
21	Hansapur	51.0	20.4	28.6	0.0	0.0	0.0
22	Jumrikanda	39.2	23.5	27.5	9.8	0.0	0.0
23	Khaira	0.0	0.0	62.7	35.3	2.0	0.0
24	Khawang	0.0	19.1	29.8	51.1	0.0	0.0
25	Khung	7.5	15.1	13.2	64.2	0.0	0.0
26	Kochiwang	5.8	15.4	53.8	25.0	0.0	0.0
27	Ligha	8.0	14.0	46.0	32.0	0.0	0.0
28	Liwang	3.8	45.3	41.5	9.4	0.0	0.0
29	Lung	21.6	21.6	31.4	25.5	0.0	0.0
30	Majhakot	37.7	0.0	22.6	39.6	0.0	0.0
31	Maranthana	35.0	0.0	32.5	32.5	0.0	0.0
32	Markawang	25.0	0.0	20.5	52.3	2.3	0.0
33	Narikot	31.4	9.8	39.2	19.6	0.0	0.0
34	Nayagaun	2.6	2.6	23.7	55.3	13.2	2.6
35	Okherkot	0.0	3.8	38.5	53.8	3.8	0.0

continued on next page

Table *continued*

S.No.	Village Development Committee	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
36	Pakala	0.0	0.0	64.1	35.9	0.0	0.0
37	Phopli	43.6	9.1	21.8	23.6	1.8	0.0
38	Puja	27.5	49.0	11.8	11.8	0.0	0.0
39	Khalanga	17.0	1.9	13.2	56.6	7.5	3.8
40	Rajbara	45.5	40.9	13.6	0.0	0.0	0.0
41	Ramdi	0.0	3.8	79.2	17.0	0.0	0.0
42	Raspurkot	2.2	2.2	50.0	43.5	2.2	0.0
43	Saari	4.0	26.0	34.0	36.0	0.0	0.0
44	Swargadwari Khaal	20.4	64.8	7.4	7.4	0.0	0.0
45	Syauliwang	8.7	43.5	39.1	8.7	0.0	0.0
46	Tiram	22.0	2.0	38.0	32.0	6.0	0.0
47	Turwang	10.5	7.9	31.6	44.7	5.3	0.0
48	Tusara	18.6	2.3	41.9	34.9	2.3	0.0
49	Bangemaroth	17.0	19.1	46.8	14.9	2.1	0.0
	Total Pyuthan	**20.3**	**16.5**	**32.7**	**28.7**	**1.5**	**0.3**

S.No. = serial number.
Source: Authors.

Appendix 6

Table A6 : Estimated Village Development Community-Wise Electricity Demand under the Base Case
(MWh)

S.No.	Village Development Committee	Household Type	Years 2014	2017	2022	2030
1	Arkha	**All (total)**	**26**	**30**	**38**	**56**
		EP	0	0	0	0
		ENP	26	30	38	56
2	Badikot	**All (total)**	**327**	**376**	**474**	**688**
		EP	0	0	0	0
		ENP	327	376	474	688
3	Bangesal	**All (total)**	**118**	**135**	**171**	**248**
		EP	0	0	0	0
		ENP	118	135	171	248
4	Baraula	**All (total)**	**312**	**359**	**453**	**657**
		EP	0	0	0	0
		ENP	312	359	453	657
5	Barjiwang	**All (total)**	**175**	**201**	**254**	**368**
		EP	0	0	0	0
		ENP	175	201	254	368
6	Belbas	**All (total)**	**271**	**311**	**393**	**570**
		EP	0	0	0	0
		ENP	271	311	393	570
7	Bhingri	**All (total)**	**529**	**608**	**767**	**1,114**
		EP	0	0	0	0
		ENP	529	608	767	1,114
8	Bijayanagar	**All (total)**	**255**	**294**	**371**	**538**
		EP	0	0	0	0
		ENP	255	294	371	538
9	Bijuwar	**All (total)**	**848**	**976**	**1,231**	**1,787**
		EP	0	0	0	0
		ENP	848	976	1,231	1,787
10	Bijuli	**All (total)**	**338**	**389**	**491**	**713**
		EP	0	0	0	0
		ENP	338	389	491	713
11	Chuja	**All (total)**	**61**	**70**	**89**	**129**
		EP	0	0	0	0
		ENP	61	70	89	129

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Years			
			2014	2017	2022	2030
12	Dakhakwadi	**All (total)**	**604**	**694**	**876**	**1,272**
		EP	0	0	0	0
		ENP	604	694	876	1,272
13	Damri	**All (total)**	**10**	**12**	**15**	**21**
		EP	0	0	0	0
		ENP	10	12	15	21
14	Dangwang	**All (total)**	**119**	**137**	**173**	**251**
		EP	0	0	0	0
		ENP	119	137	173	251
15	Dharampani	**All (total)**	**152**	**174**	**220**	**320**
		EP	0	0	0	0
		ENP	152	174	220	320
16	Dharmawoti	**All (total)**	**776**	**892**	**1,126**	**1,634**
		EP	0	0	0	0
		ENP	776	892	1,126	1,634
17	Udayapurkot	**All (total)**	**67**	**77**	**97**	**141**
		EP	0	0	0	0
		ENP	67	77	97	141
18	Dhuwang	**All (total)**	**56**	**64**	**81**	**117**
		EP	0	0	0	0
		ENP	56	64	81	117
19	Dhungegadhi	**All (total)**	**215**	**247**	**311**	**452**
		EP	0.14	0.14	0.16	0.18
		ENP	214	247	311	452
20	Gothiwang	**All (total)**	**160**	**184**	**232**	**337**
		EP	0	0	0	0
		ENP	160	184	232	337
21	Hansapur	**All (total)**	**35**	**40**	**50**	**73**
		EP	0	0	0	0
		ENP	35	40	50	73
22	Jumrikanda	**All (total)**	**78**	**90**	**114**	**165**
		EP	0	0	0	0
		ENP	78	90	114	165
23	Khaira	**All (total)**	**293**	**337**	**425**	**617**
		EP	0	0	0	0
		ENP	293	337	425	617

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Years 2014	2017	2022	2030
24	Khawang	**All (total)**	**24**	**27**	**34**	**50**
		EP	0	0	0	0
		ENP	24	27	34	50
25	Khung	**All (total)**	**14**	**16**	**20**	**30**
		EP	0	0	0	0
		ENP	14	16	20	30
26	Kochiwang	**All (total)**	**11**	**13**	**16**	**23**
		EP	0	0	0	0
		ENP	11	13	16	23
27	Ligha	**All (total)**	**10**	**12**	**15**	**22**
		EP	0	0	0	0
		ENP	10	12	15	22
28	Liwang	**All (total)**	**104**	**119**	**150**	**218**
		EP	0	0	0	0
		ENP	104	119	150	218
29	Lung	**All (total)**	**165**	**190**	**240**	**348**
		EP	0	0	0	0
		ENP	165	190	240	348
30	Majhakot	**All (total)**	**165**	**190**	**240**	**348**
		EP	0	0	0	0
		ENP	165	190	240	348
31	Maranthana	**All (total)**	**398**	**458**	**578**	**839**
		EP	0	0	0	0
		ENP	398	458	578	839
32	Markawang	**All (total)**	**229**	**263**	**332**	**481**
		EP	0	0	0	0
		ENP	229	263	332	481
33	Narikot	**All (total)**	**100**	**115**	**145**	**211**
		EP	0	0	0	0
		ENP	100	115	145	211
34	Nayagaon	**All (total)**	**545**	**627**	**792**	**1,149**
		EP	0	0	0	0
		ENP	545	627	792	1,149
35	Okherkot	**All (total)**	**469**	**539**	**680**	**987**
		EP	0	0	0	0
		ENP	469	539	680	987

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Years 2014	2017	2022	2030
36	Pakala	**All (total)**	**242**	**278**	**351**	**510**
		EP	0	0	0	0
		ENP	242	278	351	510
37	Phopli	**All (total)**	**364**	**419**	**529**	**767**
		EP	0.01	0.01	0.01	0.01
		ENP	364	419	529	767
38	Puja	**All (total)**	**87**	**100**	**126**	**183**
		EP	0	0	0	0
		ENP	87	100	126	183
39	Khalanga	**All (total)**	**1,011**	**1,163**	**1,468**	**2,130**
		EP	0	0	0	0
		ENP	1,011	1,163	1,468	2,130
40	Rajbara	**All (total)**	**24**	**28**	**35**	**51**
		EP	0	0	0	0
		ENP	24	28	35	51
41	Ramdi	**All (total)**	**111**	**128**	**162**	**235**
		EP	0	0	0	0
		ENP	111	128	162	235
42	Raspurkot	**All (total)**	**255**	**293**	**369**	**536**
		EP	0	0	0	0
		ENP	255	293	369	536
43	Saari	**All (total)**	**205**	**236**	**297**	**432**
		EP	0	0	0	0
		ENP	205	236	297	432
44	Swargadwari Khaal	**All (total)**	**53**	**61**	**77**	**112**
		EP	0	0	0	0
		ENP	53	61	77	112
45	Syauliwang	**All (total)**	**95**	**109**	**137**	**199**
		EP	0	0	0	0
		ENP	95	109	137	199
46	Tiram	**All (total)**	**408**	**469**	**592**	**859**
		EP	0	0	0	0
		ENP	408	469	592	859
47	Turwang	**All (total)**	**422**	**485**	**612**	**888**
		EP	0	0	0	0
		ENP	422	485	612	888

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Years 2014	2017	2022	2030
48	Tusara	**All (total)**	**352**	**405**	**511**	**742**
		EP	0	0	0	0
		ENP	352	405	511	742
49	Bangemaroth	**All (total)**	**270**	**310**	**391**	**568**
		EP	0	0	0	0
		ENP	270	310	391	568
	Total Pyuthan	**All (total)**	**11,957**	**13,750**	**17,351**	**25,186**
		EP	0	0	0	0
		ENP	11,957	13,750	17,351	25,186

EP = electricity poor households, ENP = electricity non-poor households, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Appendix 7

Table A7: Village Development Committee-Wise Estimated Electricity Demand under Different Scenarios in 2017

(MWh)

S.No.	Village Development Committee	Household type	Cases			
			Base	ELA1	ELA2	ELA3
1	Arkha	**All (total)**	**30.0**	**31.0**	**63.5**	**269.8**
		EP	30.0	30.4	48.3	204.0
		ENP	0.0	0.7	15.2	65.8
2	Badikot	**All (total)**	**376.0**	**376.3**	**392.1**	**521.8**
		EP	0.0	0.6	13.4	58.2
		ENP	376.0	375.8	378.7	463.7
3	Bangesal	**All (total)**	**135.0**	**136.7**	**166.7**	**345.5**
		EP	0.0	1.3	28.6	123.9
		ENP	135.0	135.4	138.1	221.6
4	Baraula	**All (total)**	**359.0**	**359.3**	**370.3**	**454.6**
		EP	0.0	0.4	9.3	40.3
		ENP	359.0	358.9	361.0	414.3
5	Barjiwang	**All (total)**	**201.0**	**201.0**	**204.7**	**242.9**
		EP	0.0	0.1	3.2	13.7
		ENP	201.0	200.9	201.6	229.1
6	Belbas	**All (total)**	**311.0**	**311.5**	**343.2**	**533.8**
		EP	0.0	0.2	3.7	16.1
		ENP	311.0	311.3	339.5	517.7
7	Bhingri	**All (total)**	**608.0**	**608.4**	**617.1**	**683.8**
		EP	0.0	0.4	8.0	34.7
		ENP	608.0	608.0	609.1	649.1
8	Bijayanagar	**All (total)**	**294.0**	**294.1**	**307.6**	**396.6**
		EP	0.0	0.4	9.8	42.4
		ENP	294.0	293.6	297.8	354.2
9	Bijuwar	**All (total)**	**976.0**	**977.0**	**1,007.6**	**1,137.2**
		EP	0.0	1.4	32.0	138.7
		ENP	976.0	975.6	975.6	998.5
10	Bijuli	**All (total)**	**389.0**	**389.1**	**389.1**	**438.6**
		EP	0.0	0.0	0.0	0.0
		ENP	389.0	389.1	389.1	438.6
11	Chuja	**All (total)**	**70.0**	**72.8**	**129.1**	**379.7**
		EP	0.0	2.5	56.2	243.4
		ENP	70.0	70.4	73.0	136.3

continued on next page

Table *continued*

S.No.	Village Development Committee	Household type	Cases			
			Base	ELA1	ELA2	ELA3
12	Dakhakwadi	**All (total)**	**694.0**	**694.1**	**695.3**	**760.5**
		EP	0.0	0.0	0.0	0.0
		ENP	694.0	694.1	695.3	760.5
13	Damri	**All (total)**	**12.0**	**12.8**	**61.0**	**264.4**
		EP	0.0	1.2	28.3	122.5
		ENP	12.0	11.5	32.7	141.9
14	Dangwang	**All (total)**	**137.0**	**138.2**	**165.5**	**290.2**
		EP	0.0	1.2	28.2	122.2
		ENP	137.0	137.0	137.3	167.9
15	Dharampani	**All (total)**	**174.0**	**175.2**	**190.5**	**262.7**
		EP	0.0	0.7	16.0	69.2
		ENP	174.0	174.5	174.5	193.5
16	Dharmawoti	**All (total)**	**892.0**	**892.8**	**911.5**	**980.4**
		EP	0.0	0.9	19.6	84.8
		ENP	892.0	891.9	891.9	895.6
17	Udayapurkot	**All (total)**	**77.0**	**77.9**	**101.0**	**196.1**
		EP	0.0	0.8	17.3	75.1
		ENP	77.0	77.1	83.6	121.1
18	Dhuwang	**All (total)**	**64.0**	**64.7**	**83.7**	**215.1**
		EP	0.0	0.8	18.0	78.0
		ENP	64.0	63.9	65.7	137.1
19	Dhungegadhi	**All (total)**	**247.0**	**247.3**	**272.1**	**378.5**
		EP	0.1	0.7	16.2	70.0
		ENP	247.0	246.6	256.0	308.5
20	Gothiwang	**All (total)**	**184.0**	**184.6**	**204.9**	**386.1**
		EP	0.0	0.6	13.7	59.5
		ENP	184.0	184.0	191.1	326.6
21	Hansapur	**All (total)**	**40.0**	**40.9**	**66.1**	**217.0**
		EP	0.0	1.1	25.6	110.7
		ENP	40.0	39.8	40.6	106.3
22	Jumrikanda	**All (total)**	**90.0**	**91.2**	**125.1**	**292.5**
		EP	0.0	1.1	24.4	105.6
		ENP	90.0	90.1	100.8	186.9
23	Khaira	**All (total)**	**337.0**	**337.1**	**337.1**	**399.5**
		EP	0.0	0.0	0.0	0.0
		ENP	337.0	337.1	337.1	399.5
24	Khawang	**All (total)**	**27.0**	**203.3**	**214.4**	**343.8**
		EP	0.0	0.0	0.0	0.0
		ENP	27.0	203.3	214.4	343.8

continued on next page

Table *continued*

S.No.	Village Development Committee	Household type	Cases			
			Base	ELA1	ELA2	ELA3
25	Khung	**All (total)**	**16.0**	**135.4**	**142.2**	**196.3**
		EP	0.0	0.2	3.4	14.8
		ENP	16.0	135.3	138.8	181.5
26	Kochiwang	**All (total)**	**13.0**	**82.6**	**89.5**	**211.6**
		EP	0.0	0.1	2.8	12.2
		ENP	13.0	82.5	86.7	199.4
27	Ligha	**All (total)**	**12.0**	**77.0**	**84.1**	**176.3**
		EP	0.0	0.1	3.3	14.1
		ENP	12.0	76.8	80.8	162.2
28	Liwang	**All (total)**	**119.0**	**119.1**	**137.3**	**291.8**
		EP	0.0	0.1	2.4	10.6
		ENP	119.0	119.0	134.8	281.2
29	Lung	**All (total)**	**190.0**	**190.7**	**214.6**	**353.1**
		EP	0.0	0.7	15.2	65.9
		ENP	190.0	190.0	199.4	287.2
30	Majhakot	**All (total)**	**190.0**	**191.0**	**208.4**	**284.9**
		EP	0.0	0.8	18.2	78.8
		ENP	190.0	190.2	190.2	206.1
31	Maranthana	**All (total)**	**458.0**	**459.6**	**493.2**	**647.6**
		EP	0.0	1.6	35.2	152.7
		ENP	458.0	458.0	458.0	495.0
32	Markawang	**All (total)**	**263.0**	**263.3**	**273.3**	**314.3**
		EP	0.0	0.5	10.5	45.4
		ENP	263.0	262.8	262.8	268.9
33	Narikot	**All (total)**	**115.0**	**115.7**	**131.5**	**233.0**
		EP	0.0	0.7	15.3	66.4
		ENP	115.0	115.0	116.2	166.6
34	Nayagaon	**All (total)**	**627.0**	**627.2**	**629.7**	**652.8**
		EP	0.0	0.1	1.4	6.0
		ENP	627.0	627.1	628.3	646.8
35	Okherkot	**All (total)**	**539.0**	**538.8**	**539.8**	**601.7**
		EP	0.0	0.0	0.0	0.0
		ENP	539.0	538.8	539.8	601.7
36	Pakala	**All (total)**	**278.0**	**278.4**	**278.4**	**344.9**
		EP	0.0	0.0	0.0	0.0
		ENP	278.0	278.4	278.4	344.9

continued on next page

Table *continued*

S.No.	Village Development Committee	Household type	Cases			
			Base	ELA1	ELA2	ELA3
37	Phopli	**All (total)**	**419.0**	**420.9**	**470.7**	**688.2**
		EP	0.0	2.0	46.4	201.0
		ENP	419.0	418.9	424.3	487.2
38	Puja	**All (total)**	**100.0**	**100.7**	**141.8**	**335.0**
		EP	0.0	0.9	20.6	89.4
		ENP	100.0	99.8	121.2	245.6
39	Khalanga	**All (total)**	**1,163.0**	**1,163.7**	**1,181.7**	**12,57.4**
		EP	0.0	0.8	18.0	78.2
		ENP	1,163.0	1,162.9	1,163.6	1,179.2
40	Rajbara	**All (total)**	**28.0**	**29.2**	**65.0**	**253.3**
		EP	0.0	1.2	26.6	115.1
		ENP	28.0	28.1	38.5	138.2
41	Ramdi	**All (total)**	**128.0**	**128.2**	**128.2**	**182.5**
		EP	0.0	0.0	0.0	0.0
		ENP	128.0	128.2	128.2	182.5
42	Raspurkot	**All (total)**	**293.0**	**292.8**	**293.9**	**341.9**
		EP	0.0	0.1	1.2	5.1
		ENP	293.0	292.7	292.7	336.8
43	Saari	**All (total)**	**236.0**	**235.7**	**245.9**	**330.2**
		EP	0.0	0.1	2.4	10.2
		ENP	236.0	235.6	243.6	320.0
44	Swargadwari Khaal	**All (total)**	**61.0**	**61.3**	**84.6**	**218.9**
		EP	0.0	0.4	9.0	38.8
		ENP	61.0	60.9	75.7	180.0
45	Syauliwang	**All (total)**	**109.0**	**109.0**	**134.5**	**328.6**
		EP	0.0	0.3	6.4	27.6
		ENP	109.0	108.7	128.2	301.0
46	Tiram	**All (total)**	**469.0**	**469.7**	**486.7**	**593.6**
		EP	0.0	0.8	17.1	74.0
		ENP	469.0	468.9	469.7	519.6
47	Turwang	**All (total)**	**485.0**	**485.3**	**492.8**	**558.9**
		EP	0.0	0.3	6.8	29.6
		ENP	485.0	485.0	486.0	529.3
48	Tusara	**All (total)**	**405.0**	**405.5**	**420.2**	**527.6**
		EP	0.0	0.7	15.4	66.5
		ENP	405.0	404.8	404.8	461.0

continued on next page

Table *continued*

S.No.	Village Development Committee	Household type	Cases			
			Base	ELA1	ELA2	ELA3
49	Bangemaroth	**All (total)**	**310.0**	**310.7**	**326.4**	**519.8**
		EP	0.0	0.7	15.5	67.4
		ENP	310.0	310.0	310.9	452.4
	Total Pyuthan	**All (total)**	**13,750.2**	**14,208.8**	**15,113.7**	**20,835.4**
		EP	0.2	30.0	679.5	2,944.5
		ENP	13,750.0	14,178.8	14,434.2	17,890.8

ELA = electricity access case, ENP = electricity non-poor households, EP = electricity poor households, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Appendix 8

Table A8: Village Development Committee-Wise Estimated Electricity Demand under Different Scenarios in 2022
(MWh)

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
1	Arkha	**All (total)**	**38.0**	**69.9**	**294.0**	**1,511.4**
		EP	0.0	16.5	71.7	368.6
		ENP	38.0	53.4	222.3	1,142.8
2	Badikot	**All (total)**	**474.0**	**490.0**	**623.5**	**1,993.6**
		EP	0.0	14.6	63.4	325.9
		ENP	474.0	475.4	560.1	1,667.7
3	Bangesal	**All (total)**	**171.0**	**204.0**	**388.3**	**1,686.1**
		EP	0.0	31.2	135.0	694.3
		ENP	171.0	172.9	253.2	991.8
4	Baraula	**All (total)**	**453.0**	**465.1**	**541.0**	**1,601.7**
		EP	0.0	10.1	43.9	225.7
		ENP	453.0	454.9	497.1	1,376.0
5	Barjiwang	**All (total)**	**254.0**	**257.6**	**288.2**	**1,000.9**
		EP	0.0	3.5	15.0	77.0
		ENP	254.0	254.1	273.2	923.9
6	Belbas	**All (total)**	**393.0**	**424.8**	**618.2**	**2,251.6**
		EP	0.0	4.1	17.6	90.3
		ENP	393.0	420.8	600.6	2,161.2
7	Bhingri	**All (total)**	**767.0**	**777.1**	**830.2**	**2,213.2**
		EP	0.0	8.7	37.8	194.2
		ENP	767.0	768.4	792.4	2,019.0
8	Bijayanagar	**All (total)**	**371.0**	**385.3**	**469.5**	**1,573.6**
		EP	0.0	10.7	46.2	237.5
		ENP	371.0	374.6	423.3	1,336.1
9	Bijuwar	**All (total)**	**1,231.0**	**1,266.3**	**1,394.9**	**3,138.2**
		EP	0.0	34.9	151.2	777.1
		ENP	1,231.0	1,231.4	1,243.7	2,361.0
10	Bijuli	**All (total)**	**491.0**	**491.1**	**526.3**	**1,576.8**
		EP	0.0	0.0	0.0	0.0
		ENP	491.0	491.1	526.3	1,576.8
11	Chuja	**All (total)**	**89.0**	**151.6**	**417.0**	**2,069.0**
		EP	0.0	61.2	265.2	1,363.7
		ENP	89.0	90.4	151.8	705.3

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
12	Dakhakwadi	**All (total)**	**876.0**	**877.0**	**926.9**	**2,408.2**
		EP	0.0	0.0	0.0	0.0
		ENP	876.0	877.0	926.9	2,408.2
13	Damri	**All (total)**	**15.0**	**66.5**	**288.1**	**1,481.2**
		EP	0.0	30.8	133.5	686.4
		ENP	15.0	35.7	154.6	794.8
14	Dangwang	**All (total)**	**173.0**	**203.8**	**329.9**	**1,407.3**
		EP	0.0	30.7	133.2	684.6
		ENP	173.0	173.0	196.8	722.7
15	Dharampani	**All (total)**	**220.0**	**237.6**	**307.7**	**1,192.4**
		EP	0.0	17.4	75.4	387.5
		ENP	220.0	220.2	232.3	804.8
16	Dharmawoti	**All (total)**	**1,126.0**	**1,147.1**	**1,219.5**	**2,021.8**
		EP	0.0	21.3	92.4	475.3
		ENP	1,126.0	1,125.8	1,127.0	1,546.6
17	Udayapurkot	**All (total)**	**97.0**	**122.8**	**222.4**	**1,014.3**
		EP	0.0	18.9	81.8	420.6
		ENP	97.0	104.0	140.6	593.8
18	Dhuwang	**All (total)**	**81.0**	**101.0**	**235.6**	**1,189.0**
		EP	0.0	19.6	85.0	436.8
		ENP	81.0	81.4	150.6	752.2
19	Dhungegadhi	**All (total)**	**311.0**	**338.8**	**447.9**	**1,338.1**
		EP	0.2	17.6	76.3	392.3
		ENP	311.0	321.2	371.6	945.8
20	Gothiwang	**All (total)**	**232.0**	**252.1**	**436.0**	**1,998.5**
		EP	0.0	15.0	64.8	333.1
		ENP	232.0	237.1	371.2	1,665.4
21	Hansapur	**All (total)**	**50.0**	**78.1**	**236.5**	**1,215.9**
		EP	0.0	27.8	120.7	620.3
		ENP	50.0	50.3	115.8	595.5
22	Jumrikanda	**All (total)**	**114.0**	**151.2**	**327.3**	**1,508.1**
		EP	0.0	26.5	115.0	591.4
		ENP	114.0	124.7	212.3	916.7
23	Khaira	**All (total)**	**425.0**	**425.4**	**474.5**	**1,553.7**
		EP	0.0	0.0	0.0	0.0
		ENP	425.0	425.4	474.5	1,553.7

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
24	Khawang	**All (total)**	**34.0**	**233.6**	**374.7**	**1,926.3**
		EP	0.0	0.0	0.0	0.0
		ENP	34.0	233.6	374.7	1,926.3
25	Khung	**All (total)**	**20.0**	**155.0**	**214.0**	**1,100.0**
		EP	0.0	3.7	16.1	83.0
		ENP	20.0	151.2	197.8	1,017.0
26	Kochiwang	**All (total)**	**16.0**	**97.6**	**230.6**	**1,185.6**
		EP	0.0	3.1	13.3	68.4
		ENP	16.0	94.5	217.3	1117.2
27	Ligha	**All (total)**	**15.0**	**91.6**	**192.1**	**987.5**
		EP	0.0	3.5	15.4	79.0
		ENP	15.0	88.1	176.7	908.5
28	Liwang	**All (total)**	**150.0**	**167.8**	**324.6**	**1566.9**
		EP	0.0	2.7	11.5	59.1
		ENP	150.0	165.2	313.1	1,507.7
29	Lung	**All (total)**	**240.0**	**265.6**	**406.4**	**1,711.3**
		EP	0.0	16.6	71.8	369.1
		ENP	240.0	249.0	334.6	1,342.2
30	Majhakot	**All (total)**	**240.0**	**259.9**	**337.9**	**1,170.5**
		EP	0.0	19.8	85.9	441.7
		ENP	240.0	240.1	252.0	728.8
31	Maranthana	**All (total)**	**578.0**	**616.5**	**766.7**	**2,443.5**
		EP	0.0	38.4	166.3	855.2
		ENP	578.0	578.1	600.3	1,588.3
32	Markawang	**All (total)**	**332.0**	**343.2**	**382.5**	**1,033.3**
		EP	0.0	11.4	49.5	254.4
		ENP	332.0	331.7	333.0	778.9
33	Narikot	**All (total)**	**145.0**	**162.5**	**264.7**	**1,185.6**
		EP	0.0	16.7	72.4	372.0
		ENP	145.0	145.8	192.4	813.7
34	Nayagaon	**All (total)**	**792.0**	**794.3**	**812.6**	**1,453.0**
		EP	0.0	1.5	6.5	33.6
		ENP	792.0	792.8	806.1	1,419.4
35	Okherkot	**All (total)**	**680.0**	**680.7**	**733.1**	**2,069.4**
		EP	0.0	0.0	0.0	0.0
		ENP	680.0	680.7	733.1	2,069.4

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
36	Pakala	**All (total)**	**351.0**	**351.4**	**404.3**	**1,571.9**
		EP	0.0	0.0	0.0	0.0
		ENP	351.0	351.4	404.3	1,571.9
37	Phopli	**All (total)**	**529.0**	**584.5**	**809.4**	**2,607.4**
		EP	0.0	50.6	219.1	1,126.3
		ENP	529.0	533.9	590.3	1,481.1
38	Puja	**All (total)**	**126.0**	**169.1**	**378.0**	**1,825.5**
		EP	0.0	22.5	97.5	501.1
		ENP	126.0	146.6	280.5	1,324.4
39	Khalanga	**All (total)**	**1,468.0**	**1,488.0**	**1,561.6**	**2,800.5**
		EP	0.0	19.7	85.2	438.0
		ENP	1,468.0	1,468.4	1,476.4	2,362.5
40	Rajbara	**All (total)**	**35.0**	**73.4**	**276.0**	**1,419.1**
		EP	0.0	29.0	125.5	645.0
		ENP	35.0	44.4	150.6	774.0
41	Ramdi	**All (total)**	**162.0**	**161.8**	**207.8**	**881.7**
		EP	0.0	0.0	0.0	0.0
		ENP	162.0	161.8	207.8	881.7
42	Raspurkot	**All (total)**	**369.0**	**370.7**	**410.6**	**1,292.2**
		EP	0.0	1.3	5.5	28.4
		ENP	369.0	369.5	405.0	1,263.8
43	Saari	**All (total)**	**297.0**	**307.3**	**388.6**	**1,427.5**
		EP	0.0	2.6	11.1	57.1
		ENP	297.0	304.8	377.5	1,370.4
44	Swargadwari Khaal	**All (total)**	**77.0**	**100.3**	**245.8**	**1,068.1**
		EP	0.0	9.8	42.3	217.6
		ENP	77.0	90.6	203.5	850.5
45	Syauliwang	**All (total)**	**137.0**	**163.2**	**364.8**	**1,776.8**
		EP	0.0	6.9	30.1	154.5
		ENP	137.0	156.3	334.8	1622.3
46	Tiram	**All (total)**	**592.0**	**611.1**	**713.3**	**1,954.2**
		EP	0.0	18.6	80.6	414.5
		ENP	592.0	592.5	632.6	1,539.7
47	Turwang	**All (total)**	**612.0**	**619.9**	**681.2**	**1,622.2**
		EP	0.0	7.4	32.2	165.6
		ENP	612.0	612.5	648.9	1,456.5

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
48	Tusara	**All (total)**	**511.0**	**527.7**	**627.2**	**2,024.6**
		EP	0.0	16.7	72.5	372.7
		ENP	511.0	510.9	554.7	1,651.9
49	Bangemaroth	**All (total)**	**391.0**	**408.3**	**599.4**	**2,230.2**
		EP	0.0	16.9	73.4	377.3
		ENP	391.0	391.3	526.0	1,852.9
	Total Pyuthan	**All (total)**	**17,351.2**	**18,789.2**	**24,551.3**	**81,279.2**
		EP	0.2	740.5	3208.7	16,496.5
		ENP	17,351.0	18,048.7	21,342.6	64,782.7

ELA = electricity access case, ENP = electricity non-poor households, EP = electricity poor households, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Appendix 9

Table A9: Village Development Committee-Wise Estimated Electricity Demand under Different Scenarios in 2030

(MWh)

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
1	Arkha	**All (total)**	**56.0**	**337.3**	**1,734.2**	**2,685.5**
		EP	0.0	82.3	423.0	655.0
		ENP	56.0	255.0	1,311.2	2,030.5
2	Badikot	**All (total)**	**688.0**	**837.5**	**2,323.8**	**3,503.2**
		EP	0.0	72.7	373.9	579.0
		ENP	688.0	764.8	1,949.9	2,924.2
3	Bangesal	**All (total)**	**248.0**	**471.6**	**1,934.6**	**2,995.9**
		EP	0.0	154.9	796.6	1,233.6
		ENP	248.0	316.7	1,138.0	1,762.3
4	Baraula	**All (total)**	**657.0**	**725.9**	**1,903.2**	**2,775.7**
		EP	0.0	50.4	258.9	400.9
		ENP	657.0	675.6	1,644.3	2,374.8
5	Barjiwang	**All (total)**	**368.0**	**392.1**	**1,148.4**	**1,778.4**
		EP	0.0	17.2	88.3	136.8
		ENP	368.0	374.9	1,060.1	1,641.6
6	Belbas	**All (total)**	**570.0**	**802.2**	**2,622.4**	**3,958.8**
		EP	0.0	20.2	103.7	160.5
		ENP	570.0	782.0	2,518.7	3,798.2
7	Bhingri	**All (total)**	**1,114.0**	**1,166.3**	**2,562.7**	**3,907.4**
		EP	0.0	43.3	222.8	345.1
		ENP	1,114.0	1,123.0	2,339.9	3,562.3
8	Bijayanagar	**All (total)**	**538.0**	**624.9**	**1,805.5**	**2,795.9**
		EP	0.0	53.0	272.5	422.0
		ENP	538.0	571.9	1,532.9	2,373.9
9	Bijuwar	**All (total)**	**1,787.0**	**1,960.7**	**3,627.8**	**5,546.8**
		EP	0.0	173.4	891.6	1,380.8
		ENP	1,787.0	1,787.3	2,736.1	4,166.0
10	Bijuli	**All (total)**	**713.0**	**712.7**	**1,830.7**	**2,778.5**
		EP	0.0	0.0	0.0	0.0
		ENP	713.0	712.7	1,830.7	2,778.5
11	Chuja	**All (total)**	**129.0**	**485.7**	**2,373.9**	**3,676.2**
		EP	0.0	304.3	1,564.6	2,423.0
		ENP	129.0	181.4	809.3	1,253.3

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
12	Dakhakwadi	**All (total)**	**1,272.0**	**1,286.9**	**2,763.1**	**4,279.0**
		EP	0.0	0.0	0.0	0.0
		ENP	1,272.0	1,286.9	2,763.1	4,279.0
13	Damri	**All (total)**	**21.0**	**330.6**	**1,699.5**	**2,631.8**
		EP	0.0	153.2	787.6	1,219.6
		ENP	21.0	177.4	911.9	1,412.2
14	Dangwang	**All (total)**	**251.0**	**410.0**	**1,614.7**	**2,500.5**
		EP	0.0	152.8	785.5	1,216.5
		ENP	251.0	257.2	829.2	1,284.1
15	Dharampani	**All (total)**	**320.0**	**410.6**	**1,368.1**	**2,118.6**
		EP	0.0	86.5	444.6	688.5
		ENP	320.0	324.1	923.4	1430.0
16	Dharmawoti	**All (total)**	**1,634.0**	**1,740.0**	**2,423.2**	**3,481.7**
		EP	0.0	106.1	545.3	844.5
		ENP	1,634.0	1,633.9	1,877.9	2,637.3
17	Udayapurkot	**All (total)**	**141.0**	**279.9**	**1,163.8**	**1,802.3**
		EP	0.0	93.9	482.6	747.3
		ENP	141.0	186.1	681.3	1,055.0
18	Dhuwang	**All (total)**	**117.0**	**273.1**	**1,364.2**	**2,112.6**
		EP	0.0	97.5	501.1	776.1
		ENP	117.0	175.6	863.1	1,336.6
19	Dhungegadhi	**All (total)**	**452.0**	**595.1**	**1,568.4**	**2,342.1**
		EP	0.2	87.5	450.1	697.0
		ENP	452.0	507.5	1,118.4	1,645.1
20	Gothiwang	**All (total)**	**337.0**	**534.3**	**2,292.9**	**3,550.9**
		EP	0.0	74.3	382.2	591.8
		ENP	337.0	460.0	1,910.8	2,959.1
21	Hansapur	**All (total)**	**73.0**	**271.3**	**1,395.0**	**2,160.4**
		EP	0.0	138.4	711.8	1,102.2
		ENP	73.0	132.9	683.3	1,058.1
22	Jumrikanda	**All (total)**	**165.0**	**394.6**	**1,730.3**	**2,679.6**
		EP	0.0	132.0	678.6	1,050.8
		ENP	165.0	262.6	1,051.8	1,628.8
23	Khaira	**All (total)**	**617.0**	**631.8**	**1,797.5**	**2,744.7**
		EP	0.0	0.0	0.0	0.0
		ENP	617.0	631.8	1,797.5	2,744.7

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
24	Khawang	**All (total)**	**50.0**	**429.9**	**2,210.1**	**3,422.6**
		EP	0.0	0.0	0.0	0.0
		ENP	50.0	429.9	2,210.1	3,422.6
25	Khung	**All (total)**	**30.0**	**245.5**	**1,262.1**	**1,954.5**
		EP	0.0	18.5	95.3	147.5
		ENP	30.0	227.0	1,166.8	1,807.0
26	Kochiwang	**All (total)**	**23.0**	**264.6**	**1,360.4**	**2,106.7**
		EP	0.0	15.3	78.5	121.5
		ENP	23.0	249.3	1,281.9	1,985.1
27	Ligha	**All (total)**	**22.0**	**220.4**	**1,133.0**	**1,754.6**
		EP	0.0	17.6	90.6	140.4
		ENP	22.0	202.7	1,042.3	1,614.2
28	Liwang	**All (total)**	**218.0**	**387.2**	**1,797.7**	**2,784.0**
		EP	0.0	13.2	67.8	105.1
		ENP	218.0	374.0	1,729.9	2,679.0
29	Lung	**All (total)**	**348.0**	**514.4**	**1,963.5**	**3,040.6**
		EP	0.0	82.4	423.5	655.8
		ENP	348.0	432.0	1,540.0	2,384.8
30	Majhakot	**All (total)**	**348.0**	**448.6**	**1,343.0**	**2,079.8**
		EP	0.0	98.6	506.8	784.8
		ENP	348.0	350.0	836.2	1,295.0
31	Maranthana	**All (total)**	**8,39.0**	**1,015.2**	**2,803.6**	**4,341.6**
		EP	0.0	190.9	981.2	1,519.6
		ENP	8,39.0	824.3	1,822.3	2,822.1
32	Markawang	**All (total)**	**481.0**	**538.3**	**1,197.4**	**1,823.4**
		EP	0.0	56.8	291.9	452.1
		ENP	481.0	481.5	905.4	1,371.3
33	Narikot	**All (total)**	**211.0**	**327.9**	**1,360.4**	**2,106.7**
		EP	0.0	83.0	426.8	660.9
		ENP	211.0	244.9	933.6	1,445.7
34	Nayagaon	**All (total)**	**1,149.0**	**1,163.4**	**1,782.1**	**2,458.6**
		EP	0.0	7.5	38.5	59.7
		ENP	1,149.0	1,155.9	1,743.5	2,398.9
35	Okherkot	**All (total)**	**987.0**	**1,013.6**	**2,413.4**	**3,635.1**
		EP	0.0	0.0	0.0	0.0
		ENP	987.0	1,013.6	2,413.4	3,635.1

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
36	Pakala	**All (total)**	**510.0**	**527.2**	**1,803.5**	**2,793.0**
		EP	0.0	0.0	0.0	0.0
		ENP	510.0	527.2	1,803.5	2,793.0
37	Phopli	**All (total)**	**767.0**	**1,063.4**	**3,013.9**	**4,609.1**
		EP	0.0	251.4	1,292.3	2,001.3
		ENP	767.0	812.0	1,721.5	2,607.8
38	Puja	**All (total)**	**183.0**	**466.0**	**2,094.5**	**3,243.5**
		EP	0.0	111.8	575.0	890.4
		ENP	183.0	354.2	1,519.5	2,353.2
39	Khalanga	**All (total)**	**2,130.0**	**2,236.6**	**3,369.1**	**4,809.0**
		EP	0.0	97.8	502.6	778.3
		ENP	2,130.0	2,138.9	2,866.5	4,030.7
40	Rajbara	**All (total)**	**51.0**	**316.7**	**1,628.2**	**2,521.4**
		EP	0.0	144.0	740.1	1,146.1
		ENP	51.0	172.7	888.1	1,375.3
41	Ramdi	**All (total)**	**235.0**	**258.3**	**1,011.6**	**1,566.6**
		EP	0.0	0.0	0.0	0.0
		ENP	235.0	258.3	1,011.6	1,566.6
42	Raspurkot	**All (total)**	**536.0**	**555.6**	**1,495.5**	**2,282.1**
		EP	0.0	6.3	32.6	50.5
		ENP	536.0	549.2	1,462.9	2,231.7
43	Saari	**All (total)**	**432.0**	**513.7**	**1,637.8**	**2,536.3**
		EP	0.0	12.7	65.5	101.5
		ENP	432.0	501.0	1,572.3	2,434.9
44	Swargadwari Khaal	**All (total)**	**112.0**	**298.3**	**1,225.5**	**1,897.8**
		EP	0.0	48.6	249.6	386.6
		ENP	112.0	249.8	975.8	1,511.2
45	Syauliwang	**All (total)**	**199.0**	**433.6**	**2,038.6**	**3,157.0**
		EP	0.0	34.5	177.3	274.5
		ENP	199.0	399.1	1,861.3	2,882.5
46	Tiram	**All (total)**	**859.0**	**966.1**	**2,297.8**	**3,412.7**
		EP	0.0	92.5	475.6	736.6
		ENP	859.0	873.6	1,822.2	2,676.2
47	Turwang	**All (total)**	**888.0**	**945.6**	**1,901.2**	**2,839.5**
		EP	0.0	37.0	190.0	294.3
		ENP	888.0	908.6	1,711.1	2,545.2

continued on next page

Table *continued*

S.No.	Village Development Committee	Household Type	Cases			
			Base	ELA1	ELA2	ELA3
48	Tusara	**All (total)**	**742.0**	**835.9**	**2,43.5**	**3,575.3**
		EP	0.0	83.2	427.7	662.3
		ENP	742.0	752.7	1,915.9	2,913.0
49	Bangemaroth	**All (total)**	**568.0**	**761.2**	**2,577.3**	**3,942.9**
		EP	0.0	84.2	432.9	670.4
		ENP	568.0	677.0	2,144.3	3,272.5
	Total Pyuthan	**All (total)**	**25,186.2**	**32,422.2**	**94,112.1**	**143,501.0**
		EP	0.2	3,681.5	18,927.3	29,311.1
		ENP	25,186.0	28,740.7	75,184.8	114,189.9

ELA = electricity access case, ENP = electricity non-poor households, EP = electricity poor households, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Appendix 10

Table A10: Estimated Final Energy Consumption by End Use for Different Village Development Committees, 2014

		Final Energy Consumption (thousand kgoe)						
S.No.	**Village Development Committee**	**Cooking**	**Animal Feed Preparation**	**Water Heating**	**Space Heating**	**Lighting**	**Electrical Appliances**	**Total**
1	Arkha	1,882.1	751.3	336.5	0.0	2.1	0.2	2,972.2
2	Badikot	1,275.5	351.2	403.9	0.0	31.9	8.7	2071.2
3	Bangesal	1,642.4	556.7	91.0	0.0	7.3	2.4	2,299.8
4	Baraula	1,420.8	826.4	509.0	0.0	28.6	8.0	2,792.8
5	Barjiwang	813.6	292.1	145.5	0.0	18.3	1.4	1,270.9
6	Belbas	1,356.5	410.7	180.8	0.0	34.3	7.6	1,989.9
7	Bhingri	773.9	472.2	194.8	0.0	52.2	14.3	1,507.4
8	Bijayanagar	808.4	337.7	171.4	0.0	34.1	2.8	1,354.4
9	Bijuwar	1,247.6	729.5	160.5	0.0	90.2	9.0	2,236.8
10	Bijuli	955.4	608.3	447.5	44.4	34.5	5.6	2,095.8
11	Chuja	1,555.2	569.2	598.1	0.0	30.7	0.7	2,753.9
12	Dakhakwadi	1,013.6	691.0	0.0	.0	52.3	9.2	1,766.1
13	Damri	2,094.4	899.7	225.8	0.0	27.8	0.1	3,247.9
14	Dangwang	2,139.2	973.4	548.7	0.0	26.9	1.1	3,689.3
15	Dharampani	610.3	233.7	241.2	0.0	22.2	2.2	1,109.7
16	Dharmawoti	537.8	325.5	79.7	18.1	65.4	14.6	1,041.1
17	Udayapurkot	578.4	182.3	82.3	0.0	14.4	0.5	857.9
18	Dhuwang	755.1	269.6	84.1	0.0	19.8	0.7	1,129.2
19	Dhungegadhi	393.5	107.4	56.8	0.0	7.9	7.9	5,73.4
20	Gothiwang	1,080.4	367.8	135.2	0.0	26.6	1.1	1611.1
21	Hansapur	1,058.4	303.7	55.4	0.0	4.1	0.2	1,421.8
22	Jumrikanda	1,091.9	340.4	0.0	0.0	24.5	0.3	1,457.0
23	Khaira	398.8	368.3	89.9	0.0	23.6	8.4	889.1
24	Khawang	1,224.1	395.7	251.4	0.0	1.8	0.6	1,873.6
25	Khung	441.1	242.4	79.1	0.0	1.1	0.1	763.8
26	Kochiwang	965.2	221.0	111.7	0.0	4.3	0.1	1,302.3
27	Ligha	775.9	249.4	147.4	0.0	13.7	0.2	1,186.6
28	Liwang	2,330.9	572.8	588.1	0.0	18.8	0.4	3,510.9
29	Lung	1,045.2	311.6	187.7	0.0	32.3	0.9	1,577.7
30	Majhakot	464.8	121.8	53.6	0.0	24.5	0.9	665.6
31	Maranthana	1,927.5	820.2	720.2	0.0	61.7	5.7	3,535.4
32	Markawang	750.6	183.1	71.7	0.0	25.7	2.1	1,033.3
33	Narikot	892.2	252.5	258.5	0.0	15.8	0.5	1,419.5
34	Nayagaon	335	250.8	71.9	0.0	26.8	25.2	709.7

continued on next page

Table *continued*

S.No.	Village Development Committee	Final Energy Consumption (thousand kgoe)						
		Cooking	Animal Feed Preparation	Water Heating	Space Heating	Lighting	Electrical Appliances	Total
35	Okherkot	1,122.4	861.8	422.3	0.0	43.3	8.4	2,458.2
36	Pakala	3,242.9	1509.1	872.8	0.0	30.5	1.5	5,656.9
37	Phopli	1,471.4	449.6	216.6	0.0	23.7	5.1	2,166.4
38	Puja	637.9	411.5	137.7	0.0	7.2	0.3	1,194.6
39	Khalanga	865.3	562.4	113.7	0.0	79.1	29.2	1,649.6
40	Rajbara	910.1	405.8	169.5	0.0	2.5	0.2	1,488.0
41	Ramdi	362.5	112.6	46.1	316.2	13.6	1.4	852.4
42	Raspurkot	1,574.7	682.3	599.3	0.0	21.9	5.6	2,883.7
43	Saari	461.9	171.8	69.2	0.0	23.3	5.1	731.3
44	Swargadwari Khaal	424.1	124.1	59.0	0.0	2.1	1.3	610.6
45	Syauliwang	1,780.4	743.9	289.1	0.0	7.4	1.1	2,821.8
46	Tiram	1,107.7	245.1	301.2	0.0	36.5	10.8	1,701.3
47	Turwang	881.5	326.4	284.8	12.0	36.3	9.9	1,550.9
48	Tusara	1,452.1	471.9	515.0	42.9	36.5	5.9	2,524.3
49	Bangemaroth	1,629.5	709.1	485.0	0.0	40.7	4.5	2,868.9
	Total Pyuthan	**50,754.9**	**20,476.6**	**10,494.2**	**169.3**	**1,299.8**	**262.1**	**83,456.9**

kgoe = kilogram of oil equivalent, S.No. = serial number.
Source: Authors.

Appendix 11

Table A11: Estimated Final Energy Consumption by Fuel Type for Cooking by Village Development Committee, 2014

S.No.	Village Development Committee	Final Energy Consumption (thousand kgoe)								
		Agricultural Residue TCS	Agricultural Residue ICS	Fuelwood TCS	Fuelwood ICS	Biogas	LPG	Kerosene	Electricity	Total
1	Arkha	426.6	0.0	1,422.6	32.9	0.0	0.0	0.0	0.0	1,882.1
2	Badikot	48.2	8.1	1,003.3	213.4	0.0	2.4	0.0	0.0	1,275.5
3	Bangesal	0.0	0.0	1,623.3	10.9	5.8	0.8	0.0	1.7	1,642.4
4	Baraula	0.0	10.0	932.1	470.5	1.5	1.1	0.0	5.7	1,420.8
5	Barjiwang	0.0	0.0	794.9	16.0	0.0	0.6	0.0	2.1	813.6
6	Belbas	0.0	0.0	1,220.2	127.8	2.1	3.5	0.0	2.9	1,356.5
7	Bhingri	0.0	0.0	651.3	96.6	2.7	17.4	0.0	5.8	773.9
8	Bijayanagar	0.0	1.6	667.2	129.5	1.3	7.2	0.0	1.5	808.4
9	Bijuwar	0.0	0.0	1,056.2	163.3	8.1	16.2	0.0	3.9	1,247.6
10	Bijuli	0.0	0.0	479.2	471.2	1.4	1.9	0.0	1.7	955.4
11	Chuja	99.3	15.5	1,128.4	312.1	0.0	0.0	0.0	0.0	1,555.2
12	Dakhakwadi	0.8	0.0	714.3	275.5	0.4	16.6	0.0	6.0	1,013.6
13	Damri	10.0	0.0	1,924.9	153.5	0.0	6.0	0.0	0.0	2,094.4
14	Dangwang	2.3	0.0	1,920.6	216.1	0.0	0.2	0.0	0.0	2,139.2
15	Dharampani	23.2	10.7	339.3	235.2	0.8	0.0	0.0	1.1	610.3
16	Dharmawoti	0.0	0.0	358.8	160.9	2.2	10.0	0.0	5.9	537.8
17	Udayapurkot	1.6	7.1	118.0	451.7	0.0	0.0	0.0	0.0	578.4
18	Dhuwang	0.0	0.0	623.3	131.9	0.0	0.0	0.0	0.0	755.1
19	Dhungegadhi	12.5	1.0	333.4	39.9	0.5	3.6	0.0	2.7	393.5
20	Gothiwang	9.0	0.0	852.6	215.9	0.0	2.9	0.0	0.0	1,080.4
21	Hansapur	0.0	0.0	675.7	382.7	0.0	0.0	0.0	0.0	1,058.4
22	Jumrikanda	0.0	0.0	1,091.5	0.0	0.0	0.4	0.0	0.0	1,091.9
23	Khaira	6.6	1.9	260.6	113.1	1.6	11.8	0.0	3.2	398.8
24	Khawang	0.0	0.0	268.7	954.5	0.5	0.5	0.0	0.0	1,224.1
25	Khung	107.6	13.4	283.0	36.4	0.0	0.7	0.0	0.0	441.1
26	Kochiwang	0.0	0.0	947.3	17.9	0.0	0.0	0.0	0.0	965.2
27	Ligha	9.5	0.0	720.0	46.4	0.0	0.0	0.0	0.0	775.9
28	Liwang	38.6	0.0	2,172.4	119.9	0.0	0.0	0.0	0.0	2,330.9
29	Lung	0.0	0.0	493.5	549.5	0.0	2.2	0.0	0.0	1,045.2
30	Majhakot	0.0	0.0	347.0	117.1	0.0	0.4	0.0	0.2	464.8
31	Maranthana	47.1	58.7	1,174.0	639.7	0.0	4.7	0.0	3.4	1,927.5
32	Markawang	1.0	1.5	356.7	389.7	1.8	0.0	0.0	0.0	750.6
33	Narikot	9.6	25.4	548.4	307.4	0.0	1.3	0.0	0.0	892.2
34	Nayagaon	2.0	4.2	126.6	189.3	0.9	8.8	0.0	3.2	335.0

continued on next page

Table *continued*

S.No.	Village Development Committee	Final Energy Consumption (thousand kgoe)								
		Agricultural Residue TCS	Agricultural Residue ICS	Fuelwood TCS	Fuelwood ICS	Biogas	LPG	Kerosene	Electricity	Total
35	Okherkot	20.0	53.6	502.3	530.2	6.8	7.9	0.0	1.7	1,122.4
36	Pakala	0.0	0.0	2633.1	607.5	0.9	0.5	0.0	0.9	3,242.9
37	Phopli	0.0	0.0	1310.1	150.6	0.0	7.9	0.0	2.8	1,471.4
38	Puja	165.1	39.8	339.1	93.8	0.0	0.0	0.0	0.0	637.9
39	Khalanga	3.4	0.0	565.6	269.0	0.8	20.7	0.0	5.9	865.3
40	Rajbara	256.6	0.0	653.5	0.0	0.0	0.0	0.0	0.0	910.1
41	Ramdi	0.0	0.0	186.1	173.8	0.0	2.3	0.0	0.3	362.5
42	Raspurkot	0.0	0.0	643.0	925.8	1.0	1.9	0.0	3.0	1,574.7
43	Saari	6.9	2.4	346.0	99.8	0.5	4.0	0.0	2.2	461.9
44	Swargadwari Khaal	0.0	0.0	300.1	119.3	0.0	3.0	0.0	1.8	424.1
45	Syauliwang	30.3	0.0	1748.9	0.0	0.0	1.2	0.0	0.0	1,780.4
46	Tiram	7.8	5.6	688.0	402.3	2.7	1.2	0.0	0.0	1,107.7
47	Turwang	66.7	19.5	472.5	309.7	1.8	5.7	0.0	5.5	881.5
48	Tusara	19.6	11.2	860.9	553.0	0.0	5.0	0.0	2.4	1,452.1
49	Bangemaroth	44.2	10.6	1226.7	336.1	0.0	10.0	0.0	2.0	1,629.5
Total Pyuthan		**648.0**	**138.1**	**38,331.2**	**11,429.6**	**18.2**	**141.1**	**0.0**	**48.6**	**50,754.8**

kgoe = kilogram of oil equivalent, ICS = , LPG = liquefied petroleum gas, S.No. = serial number, TCS = traditional cookstoves.
Source: Authors.

Appendix 12

Table A12: Average Energy Consumption per Household for Cooking by Fuel and Technology Type in 2014

(kgoe per household)

S.No.	Village Development Committee	Fuel/Technology Type							
		Agricultural Residue TCS	Agricultural Residue ICS	Fuelwood TCS	Fuelwood ICS	Biogas	LPG	Kerosene	Electricity
1	Arkha	1,422.2	0.0	2,431.7	2191.7	0.0	0.0	0.0	0.0
2	Badikot	281.8	214.3	1,466.8	1,021.0	0.0	64.1	0.0	0.0
3	Bangesal	0.0	0.0	1,946.8	640.1	84.5	48.1	0.0	25.1
4	Bangemarot	301.6	252.0	1,721.9	1,336.7	0.0	95.7	0.0	31.4
5	Baraula	0.0	576.0	1,922.8	1,811.5	43.2	30.8	0.0	108.8
6	Barjiwang	0.0	0.0	1,573.7	1,584.3	0.0	31.2	0.0	34.5
7	Belbas	0.0	0.0	1,212.4	888.9	86.3	48.4	0.0	40.3
8	Bhingri	0.0	0.0	931.8	828.9	35.1	74.8	0.0	33.5
9	Bijayanagar	0.0	108.0	1,076.4	1,123.3	45.0	62.6	0.0	35.6
10	Bijuwar	0.0	0.0	974.2	882.0	61.1	51.0	0.0	29.7
11	Bijuli	0.0	0.0	991.1	1,649.4	32.4	28.2	0.0	39.2
12	Chuja	280.0	207.4	1,777.9	1,857.5	0.0	0.0	0.0	0.0
13	Dakhakwadi	54.0	0.0	1,103.0	1,624.3	28.8	41.3	0.0	32.4
14	Damri	259.6	0.0	2,641.9	2,669.0	0.0	104.7	0.0	0.0
15	Dangwang	108.0	0.0	2,883.3	1,676.2	0.0	8.8	0.0	0.0
16	Dharampani	210.5	145.7	1,154.9	1,200.9	64.7	0.0	0.0	44.7
17	Dharmawoti	0.0	0.0	851.9	643.4	55.1	44.8	0.0	29.7
18	Dhuwang	0.0	0.0	1,106.1	912.6	0.0	0.0	0.0	0.0
19	Dhungegadhi	106.0	90.0	795.4	618.7	43.2	47.7	0.0	42.4
20	Gothiwang	62.6	0.0	1,038.8	1,315.5	0.0	47.0	0.0	0.0
21	Hansapur	0.0	0.0	1,475.1	1,438.9	0.0	0.0	0.0	0.0
22	Jumrikanda	0.0	0.0	1,239.8	0.0	0.0	24.0	0.0	0.0
23	Khaira	210.0	180.0	751.8	828.1	75.5	51.1	0.0	23.1
24	Khawang	0.0	0.0	1,043.5	1,132.6	21.6	20.6	0.0	0.0
25	Khung	464.6	836.3	787.4	910.5	0.0	86.5	0.0	0.0
26	Kochiwang	0.0	0.0	1,423.9	439.0	0.0	0.0	0.0	0.0
27	Ligha	285.3	0.0	1,380.7	1,394.8	0.0	0.0	0.0	0.0
28	Liwang	480.0	0.0	2,700.9	2,485.1	0.0	0.0	0.0	0.0
29	Lung	0.0	0.0	1026.8	1,099.3	0.0	56.1	0.0	0.0
30	Majhakot	0.0	0.0	667.8	770.3	0.0	32.1	0.0	18.8
31	Maranthana	244.4	274.5	2,493.9	1,660.8	0.0	36.7	0.0	52.3

continued on next page

Table *continued*

S.No.	Village Development Committee	Fuel/Technology Type: Agricultural Residue TCS	Agricultural Residue ICS	Fuelwood TCS	Fuelwood ICS	Biogas	LPG	Kerosene	Electricity
32	Markawang	40.5	41.4	1,305.2	1,561.7	75.5	0.0	0.0	0.0
33	Narikot	401.1	531.0	1,388.8	1,427.4	0.0	56.1	0.0	0.0
34	Nayagaon	180.0	126.0	1,277.5	661.1	39.6	42.1	0.0	32.1
35	Okherkot	632.2	1,128.8	1,270.3	1,289.2	71.9	49.7	0.0	27.5
36	Pakala	0.0	0.0	4,420.6	2,596.0	21.6	11.4	0.0	43.9
37	Phopli	0.0	0.0	1,118.7	881.8	0.0	64.9	0.0	38.7
38	Puja	479.2	600.8	609.1	786.5	0.0	0.0	0.0	0.0
39	Khalanga	180.0	0.0	718.9	1,595.4	43.2	58.0	0.0	31.5
40	Rajbara	1,006.8	0.0	1,107.3	0.0	0.0	0.0	0.0	0.0
41	Ramdi	0.0	0.0	708.9	834.9	0.0	51.8	0.0	31.4
42	Raspurkot	0.0	0.0	2,190.2	2,425.8	32.4	64.1	0.0	68.0
43	Saari	140.5	197.2	702.2	899.8	43.2	36.0	0.0	36.2
44	Swargadwari Khaal	0.0	0.0	835.8	726.9	0.0	41.4	0.0	43.9
45	Syauliwang	543.3	0.0	2,048.3	0.0	0.0	64.1	0.0	0.0
46	Tiram	144.0	51.9	1,311.0	1,058.7	75.5	64.1	0.0	0.0
47	Turwang	521.7	459.0	1,447.2	1,454.1	64.7	57.6	0.0	55.6
48	Tusara	234.7	134.1	1,645.3	1,651.3	0.0	48.1	0.0	37.7
49	Udayapurkot	126.0	93.9	852.4	1,196.6	0.0	0.0	0.0	0.0
	Total Pyuthan	**191.8**	**127.5**	**1,419.4**	**1,218.0**	**23.3**	**37.7**	**0.0**	**21.8**

kgoe = kilogram of oil equivalent, ICS = , LPG = liquefied petroleum gas, S.No. = serial number, TCS = traditional cookstoves.
Source: Authors.

Appendix 13

Table A13: Estimated Projected Demand for Cooking for Different Village Development Committees in Selected Years under the Base Case
(thousand kgoe)

S.No.	Village Development Committee	2014	2017	2022	2030
1	Arkha	191.5	202.7	222.8	259.2
2	Badikot	150.9	159.7	175.6	204.3
3	Bangesal	169.5	179.4	197.2	229.5
4	Baraula	195.3	206.7	227.2	264.3
5	Barjiwang	84.7	89.7	98.6	114.7
6	Belbas	153.1	162.1	178.1	207.3
7	Bhingri	101.1	107.0	117.6	136.8
8	Bijayanagar	99.2	105.0	115.4	134.3
9	Bijuwar	155.6	164.6	181.0	210.6
10	Bijuli	145.4	153.9	169.2	196.9
11	Chuja	188.3	199.3	219.0	254.8
12	Dakhakwadi	141.6	149.9	164.7	191.7
13	Damri	227.8	241.1	265.0	308.3
14	Dangwang	235.6	249.4	274.1	318.9
15	Dharampani	86.7	91.8	100.9	117.4
16	Dharmawoti	80.0	84.6	93.0	108.2
17	Udayapurkot	103.7	109.8	120.7	140.4
18	Dhuwang	88.7	93.9	103.2	120.1
19	Dhungegadhi	47.4	50.1	55.1	64.1
20	Gothiwang	131.1	138.7	152.5	177.4
21	Hansapur	144.1	152.5	167.7	195.0
22	Jumrikanda	109.4	115.8	127.3	148.1
23	Khaira	60.2	63.7	70.0	81.5
24	Khawang	218.3	231.1	254.0	295.5
25	Khung	49.4	52.3	57.5	66.9
26	Kochiwang	98.3	104.0	114.4	133.1
27	Ligha	82.2	87.0	95.7	111.3
28	Liwang	245.1	259.4	285.1	331.7
29	Lung	160.6	169.9	186.8	217.3
30	Majhakot	58.6	62.0	68.1	79.3
31	Maranthana	267.3	282.9	311.0	361.8
32	Markawang	115.0	121.7	133.8	155.6
33	Narikot	123.2	130.4	143.3	166.7
34	Nayagaon	59.9	63.4	69.7	81.0
35	Okherkot	178.8	189.3	208.1	242.1

continued on next page

Table *continued*

S.No.	Village Development Committee	2014	2017	2022	2030
36	Pakala	386.3	408.9	449.5	522.9
37	Phopli	168.1	178.0	195.6	227.6
38	Puja	77.2	81.7	89.8	104.4
39	Khalanga	128.3	135.7	149.2	173.6
40	Rajbara	91.0	96.3	105.9	123.2
41	Ramdi	55.0	58.2	64.0	74.5
42	Raspurkot	253.5	268.3	294.9	343.1
43	Saari	60.2	63.7	70.0	81.5
44	Swargadwari Khaal	57.1	60.4	66.4	77.3
45	Syauliwang	180.5	191.0	209.9	244.2
46	Tiram	153.4	162.3	178.4	207.6
47	Turwang	128.6	136.1	149.6	174.1
48	Tusara	205.8	217.8	239.4	278.6
49	Bangemaroth	204.0	215.9	237.4	276.1
	Total Pyuthan	**6,345.0**	**6,715.6**	**7,381.9**	**8,588.1**

kgoe = kilogram of oil equivalent, S.No. = serial number.
Source: Authors.

Appendix 14

Table A14: Sustainability Dimensions and their Indicators Using the Multiattribute Average Scoring Approach

Dimensions	Indicator
Technical	Ability to respond to peak demand[a]
	Ability to meet present and future domestic needs
	Ability to meet present and future productive needs
	Reliability of supply
	Reliance on clean energy sources
	Reliance on local resources
	Availability of support services
Economic	Cost-effectiveness
	Cost recovery potential
	Capital cost burden on the user
	Operating cost burden on the user
	Financial support needs
	Contribution to income generating opportunities
Social	Wider usability amongst the poor
	Need financial support system
	Potential to reduce human drudgery
	Potential to reduce adverse effects on women and children
	Job-years of full time employment created over the entire lifecycle of the unit
	Risk of supply shock incidence due to fuel imports
	External costs related to human health
Environmental	Contribution to reduction in carbon emissions
	Contribution to reduction in indoor pollution
	Contribution to reductions in land degradation
	Contribution to reduction in water pollution
	Cost generated over the entire lifecycle (environmental costs)
Institutional	Degree of local ownership
	Need for skilled staff
	Ability to protect consumers
	Ability to protect investors
	Ability to monitor and control systems

[a] Only for power generation options.
Source: Bhattacharya (2012).

Appendix 15

Table A15: Sustainability Dimensions and their Indicators Using the Multiattribute Utility Method

Dimensions	Indicator	Definition
Economic	Levelized cost of electricity	The average cost of producing electricity over the entire lifetime of the unit; it takes into account all investment, operation and maintenance, fuel, decommissioning and CO_2 emission costs
Technical	Ability to respond to demand	The ability and the time required to respond to grid demand; a shorter response time means that the technology can be used for grid balancing, while inability creates grid instability
	Efficiency	The efficiency with which input energy is transformed into useful output energy
	Capacity factor	The efficiency with which a unit's generation capacity is used, calculated as a ratio between actual output and maximum theoretical output
Environmental	Land use	The use of land over the entire life cycle (fuel extraction, processing and delivery, construction, operation, and decommissioning)
	External costs (environmental)	The costs which the production of electricity creates by polluting the environment (e.g., the cost to clean up dust or to decontaminate crop fields)
Social	External costs (human health)	The costs that the production of electricity creates by affecting health (e.g. the cost of treatment for respiratory illnesses)
	Job creation	The number of people hired during the implementation and operation of an electricity generation project
	Social acceptability	The measure in which the public agrees with the development of electricity production using various technologies
	External supply risk	The risk of supply shock incidence due to fuel imports

CO_2 = carbon dioxide.
Source: Maxim (2014).

Appendix 16

Methodology to Calculate "Energy Sustainability Index" Using Multiattribute Utility Approach

The following steps describes the procedures to calculate "Energy Sustainability Index" using the multiattribute utility approach (based on Maxim 2014):

(i) Identify the energy technology options, whose sustainability is to be assessed. This study has considered four electricity generation options, i.e., grid extension, solar home system, biomass-based power plant, and microhydro power plants.

(ii) Define indicators to represent each of the sustainability dimensions; the dimensions and indicators considered in this study are in Table 7.2 of Chapter 7 in this report.

(iii) Obtain "familiarity score" for evaluating the understanding about the matters related to the electricity sector. To obtain the familiarity score, the respondents were asked to assess their own level of familiarity with the issues concerning the electricity sector by rating in a scale of 1 to 10, in which 1 indicates "not at all familiar" and 10 indicates "very familiar." The familiarity score obtained from the experts survey varied between 7 to 10. Thus, on an average the total familiarity score obtained in this study was 4.

(iv) Assign specific a importance score to each indicator. The importance score is given to each indicator to rank the different electricity generation technologies from the point of view of their compatibility with sustainable development. In this study, the importance scores were assigned to each specific indicator through expert's survey. Experts were asked to provide a score on a scale of 1 to 10 (in which 1 means "not at all important" and 10 means "very important") to each indicator depending on the importance that they consider the technology has for long-term development. The average importance score obtained from a panel of 18 experts survey is presented in Table 7.2 of Chapter 7 in this report.

(v) Calculate weights for each indicator using the familiarity and importance scores using the following relation:

$$W_{ijd} = IMP_{ijd} \times \frac{AFAM}{10}$$

Where,
W_{ij} = weight of indicator i for technology j and dimension d
IMP_{ij} = importance score for indicator i and technology j and dimension d obtained from experts survey
AFAM = Average familiarity score obtained from experts survey

(vi) Calculate the average weight for each indicator and dimension using the following relation:

$$AW_{id} = \frac{\sum W_{ijd}}{N}$$

Where,
AW_{id} = average weight for indicator i and dimension d
N = total number of electricity generation technologies

(vii) Calculate the final weight for each indicator and dimension using the following relation:

$$FW_{id} = \frac{AW_{id}}{\sum AW_{id}}$$

These final weights are indicated in Table 7.3 of Chapter 7 in this report.

(viii) Rank the various electricity generation technologies using the multiattribute utility method for value normalization as given in Maxim (2014) using the following relations:

$$Direct\ corelation\ with\ utility: u(x_{ji}) = \frac{(x_{ji} - x_{min})}{(x_{max} - x_{min})}$$

$$Inverse\ corelation\ with\ utility: u(x_{ji}) = \frac{(x_{max} - x_{ji})}{(x_{max} - x_{min})}$$

Where,
x_j = parameter for technology j and indicator i
x_{min} = minimum value of the parameter
x_{max} = maximum value of the parameter

The parameter value used in this study is presented in Table 7.4 of Chapter 7 in this report which is borrowed from Maxim (2014).

(ix) Calculate the total sustainability value for each technology j using the following relation:

$$TSV_j = \sum SV_{ijd}$$

Where,
SV_{ijd} is the sustainability value for each indicator i, dimension d and technology j, and is calculated using the following relation.

$$SV_{ijd} = u(x_{ji}) \times FW_{id}$$

(x) Rank the energy technology option with the highest score as the most sustainable among the selected options.

Appendix 17

Derivation of Load Profile

The following steps are involved in the derivation of power demand (or "load") profile for a VDC.

(i) Determine the total electricity demand of the VDC (in megawatt hours [MWh]) for a given year (2017, 2022, and 2030) and electricity access program (ELA 1 or ELA 2 or ELA 3).

(ii) Because of the lack of availability of the VDC-wise hourly load patterns, a normalized load pattern was derived in this study based on actual load pattern data of the selected presently operating micro hydro plants in the country. This was done as follows:

- (a) Hourly power demand (in megawatt [MW]) as a fraction of the daily peak power demand (in MW) is calculated for each hour of a day for each of the selected existing micro hydropower based supply system.
- (b) For each hour of the day, calculate the average values of the corresponding power demands (in fraction) of the selected existing micro hydropower systems.

(iii) Determine the peak load in year i under electricity access program (ELA) j using the following relation:

$$Peak\ Load_{i,j}(in\ MW) = \frac{Annual\ Electricity\ Demand_{i,j}(in\ MWh)}{Load\ Factor \times 365 \times 24} \quad \text{Eq. B}$$

where, Annual Electricity Demandi,j = demand for electricity (in MWh) in year i and electricity access case j.

$$Load\ Factor = \frac{Average\ power\ demand\ of\ a\ system}{Peak\ power\ demand\ of\ the\ system} \quad \text{Eq. C}$$

(iv) As the load pattern for the areas to be newly electrified is not known, use the load factor of the existing power supply system of similar district(s) or VDC(s) in Equation A to derive the value of Peak $Load_{i,j}$.

(v) Calculate the power demand ("load") for hour k of a day in year i under electricity access program j (denoted as "$Load_{i,j,k}$") using the following relation:

$$Load_{i,j,k} = Peak\ Load_{i,j} \times FL_k$$

where,
FLk = Load in hour k as fraction of daily peak load (where k = 1, 2, 3, 24) as calculated in Step 2.

Appendix 18

Capacity Requirement in 2017 by Village Development Committee

Table A18: Capacity Requirement in 2017 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Off-grid)

(kW)

Village Development Committee	Case	Technology					Transmission Line Capacity
		PV	Microhydro	BMG	Grid	Total	
Arkha	Base	0.0	5.8	0.0	0.0	5.8	0.0
	ELA1	0.0	6.0	0.0	0.0	6.0	0.0
	ELA2	0.0	12.0	0.0	0.0	12.0	0.0
	ELA3	5.0	23.0	30.0	0.0	58.0	0.0
Damri	Base	0.0	2.7	0.0	0.0	2.7	0.0
	ELA1	0.0	17.0	0.0	0.0	17.0	0.0
	ELA2	0.0	17.0	0.0	0.0	17.0	0.0
	ELA3	70.0	17.0	10.0	0.0	97.0	0.0
Khawang	Base	0.0	0.0	5.0	0.0	5.0	0.0
	ELA1	0.0	0.0	40.0	0.0	40.0	0.0
	ELA2	0.0	0.0	40.0	0.0	40.0	0.0
	ELA3	0.0	0.0	0.0	65.4	65.4	65.4
Khung	Base	15.0	0.0	0.0	0.0	15.0	0.0
	ELA1	0.0	0.0	0.0	25.8	25.8	25.8
	ELA2	0.0	0.0	0.0	27.1	27.1	27.1
	ELA3	0.0	0.0	0.0	37.4	37.4	37.4
Kochiwang	Base	10.0	0.0	0.0	0.0	10.0	0.0
	ELA1	0.0	0.0	15.0	0.0	15.0	0.0
	ELA2	0.0	0.0	15.0	0.0	15.0	0.0
	ELA3	0.0	0.0	0.0	82.0	82.0	82.0
Ligha	Base	10.0	0.0	0.0	0.0	10.0	0.0
	ELA1	70.0	0.0	0.0	0.0	70.0	0.0
	ELA2	80.0	0.0	0.0	0.0	80.0	0.0
	ELA3	20.0	0.0	30.0	0.0	50.0	0.0
Syauliwang	Base	0.0	0.0	20.0	0.0	20.0	0.0
	ELA1	0.0	0.0	20.0	0.0	20.0	0.0
	ELA2	0.0	0.0	30.0	0.0	30.0	0.0
	ELA3	30.0	0.0	60.0	0.0	90.0	0.0

BMG = biomass-based power plant, ELA = energy access case, kW = kilowatt, PV = solar photovoltaic.
Source: Authors.

Table A19: Capacity Requirement in 2017 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Grid)

(kW)

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity	S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
1	Badikot	Base	71.5	71.5	19	Liwang	Base	22.6	22.6
		ELA1	71.6	71.6			ELA1	22.7	22.7
		ELA2	74.6	74.6			ELA2	26.1	26.1
		ELA3	99.3	99.3			ELA3	55.5	55.5
2	Bangesal	Base	25.8	25.8	20	Lung	Base	36.2	36.2
		ELA1	26.0	26.0			ELA1	36.3	36.3
		ELA2	31.7	31.7			ELA2	40.8	40.8
		ELA3	65.7	65.7			ELA3	67.2	67.2
3	Baraula	Base	68.3	68.3	21	Majhakot	Base	36.2	36.2
		ELA1	68.4	68.4			ELA1	36.3	36.3
		ELA2	70.4	70.4			ELA2	39.7	39.7
		ELA3	86.5	86.5			ELA3	54.2	54.2
4	Barjiwang	Base	38.2	38.2	22	Maranthana	Base	87.4	87.4
		ELA1	38.2	38.2			ELA1	87.7	87.7
		ELA2	38.9	38.9			ELA2	93.8	93.8
		ELA3	46.2	46.2			ELA3	123.2	123.2
5	Belbas	Base	59.2	59.2	23	Markhawang	Base	50.0	50.0
		ELA1	59.3	59.3			ELA1	50.1	50.1
		ELA2	65.3	65.3			ELA2	46.7	46.7
		ELA3	101.6	101.6			ELA3	59.8	59.8
6	Bhingri	Base	115.7	115.7	24	Narikot	Base	21.9	21.9
		ELA1	115.8	115.8			ELA1	22.0	22.0
		ELA2	117.4	117.4			ELA2	25.0	25.0
		ELA3	130.1	130.1			ELA3	44.3	44.3
7	Bijayanagar	Base	55.9	55.9	25	Nayagaon	Base	119.3	119.3
		ELA1	55.9	55.9			ELA1	119.3	119.3
		ELA2	58.5	58.5			ELA2	119.8	119.8
		ELA3	75.5	75.5			ELA3	124.2	124.2
8	Bijuwar	Base	185.6	185.6	26	Phopli	Base	79.7	79.7
		ELA1	185.9	185.9			ELA1	80.1	80.1
		ELA2	191.7	191.7			ELA2	89.6	89.6
		ELA3	216.4	216.4			ELA3	130.9	130.9
9	Chuja	Base	13.4	13.4	27	Puja	Base	19.0	19.0
		ELA1	13.9	13.9			ELA1	19.2	19.2
		ELA2	24.6	24.6			ELA2	27.0	27.0
		ELA3	72.2	72.2			ELA3	63.7	63.7

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity	S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
10	Dangwang	Base	26.1	26.1	28	Khalanga	Base	221.2	221.2
		ELA1	26.3	26.3			ELA1	221.4	221.4
		ELA2	31.5	31.5			ELA2	224.8	224.8
		ELA3	55.2	55.2			ELA3	239.2	239.2
11	Dharampani	Base	33.1	33.1	29	Rajbara	Base	5.3	5.3
		ELA1	33.2	33.2			ELA1	5.6	5.6
		ELA2	36.2	36.2			ELA2	7.8	7.8
		ELA3	50.0	50.0			ELA3	48.2	48.2
12	Dharmawoti	Base	169.7	169.7	30	Saari	Base	44.8	44.8
		ELA1	169.9	169.9			ELA1	44.8	44.8
		ELA2	173.4	173.4			ELA2	46.8	46.8
		ELA3	186.5	186.5			ELA3	62.8	62.8
13	Udayapurkot	Base	14.7	14.7	31	Swargadwari Khaal	Base	11.6	11.6
		ELA1	14.8	14.8			ELA1	11.7	11.7
		ELA2	19.2	19.2			ELA2	16.1	16.1
		ELA3	37.3	37.3			ELA3	41.6	41.6
14	Dhuwang	Base	12.2	12.2	32	Tiram	Base	89.2	89.2
		ELA1	12.3	12.3			ELA1	89.4	89.4
		ELA2	15.9	15.9			ELA2	92.6	92.6
		ELA3	40.9	40.9			ELA3	112.9	112.9
15	Dhungegadhi	Base	46.9	46.9	33	Turwang	Base	92.3	92.3
		ELA1	41.3	41.3			ELA1	92.3	92.3
		ELA2	51.8	51.8			ELA2	93.8	93.8
		ELA3	72.0	72.0			ELA3	106.3	106.3
16	Gothiwang	Base	35.0	35.0	34	Tusara	Base	77.0	77.0
		ELA1	35.1	35.1			ELA1	77.1	77.1
		ELA2	39.0	39.0			ELA2	79.9	79.9
		ELA3	73.4	73.4			ELA3	100.4	100.4
17	Hansapur	Base	7.6	7.6	35	Bangemaroth	Base	59.0	59.0
		ELA1	7.8	7.8			ELA1	59.1	59.1
		ELA2	12.6	12.6			ELA2	62.1	62.1
		ELA3	41.3	41.3			ELA3	98.9	98.9
18	Jumrikanda	Base	17.1	17.1					
		ELA1	17.3	17.3					
		ELA2	23.8	23.8					
		ELA3	55.6	55.6					

ELA = energy access case, kW = kilowatt, S.No. = serial number.
Source: Authors.

Table A20: Capacity Requirement in 2017 (Light Emitting Diode Equivalent) for Completely Electrified Village Development Committees (Grid)
(kW)

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
1	Bijuli	Base	74.0	74.0
		ELA1	74.0	74.0
		ELA2	74.0	74.0
		ELA3	83.4	83.4
2	Dakhakwadi	Base	132.1	132.1
		ELA1	132.1	132.1
		ELA2	132.3	132.3
		ELA3	144.7	144.7
3	Khaira	Base	64.1	64.1
		ELA1	64.1	64.1
		ELA2	64.1	64.1
		ELA3	76.0	76.0
4	Okherkot	Base	102.5	102.5
		ELA1	102.5	102.5
		ELA2	102.7	102.7
		ELA3	114.5	114.5
5	Pakala	Base	53.0	53.0
		ELA1	53.0	53.0
		ELA2	53.0	53.0
		ELA3	65.6	65.6
6	Ramdi	Base	24.4	24.4
		ELA1	24.4	24.4
		ELA2	24.4	24.4
		ELA3	34.7	34.7
7	Raspurkot	Base	55.8	55.8
		ELA1	55.8	55.8
		ELA2	56.1	56.1
		ELA3	66.0	66.0

ELA = energy access case, S.No. = serial number.
Source: Authors.

Table A21: Summary of Capacity Requirements in 2017 (Light Emitting Diode Equivalent)

(kW)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified Village Development Committees (Off-grid)					
Base	35.0	8.5	25.0	0.0	68.5
ELA1	70.0	23.0	75.0	25.8	193.8
ELA2	80.0	29.0	85.0	27.1	221.1
ELA3	125.0	40.0	130.0	184.7	479.7
Partially Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	2,068.7	2,068.7
ELA1	0.0	0.0	0.0	2,068.1	2,068.1
ELA2	0.0	0.0	0.0	2,209.1	2,209.1
ELA3	0.0	0.0	0.0	3,039.4	3,039.4
Completely Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	505.9	505.9
ELA1	0.0	0.0	0.0	505.9	505.9
ELA2	0.0	0.0	0.0	506.6	506.6
ELA3	0.0	0.0	0.0	585.0	585.0
Total (ALL)					
Base	35.0	8.5	25.0	2,574.6	2,643.1
ELA1	70.0	23.0	75.0	2,599.8	2,767.8
ELA2	80.0	29.0	85.0	2,742.7	2,936.7
ELA3	125.0	40.0	130.0	3,809.1	4,104.1

BMG = biomass-based power plant, ELA = energy access case, kW = kilowatt, PV = solar photovoltaic.
Source: Authors.

Appendix 19

Capacity Requirement in 2022 (Light Emitting Diode Equivalent) by Village Development Committee

Table A22: Capacity Requirement in 2022 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Off-grid)
(kW)

Village Development Committee	Case	Technology					Transmission Line Capacity
		PV	Microhydro	BMG	Grid	Total	
Arkha	Base	0.0	7.4	0.0	0.0	7.4	0.0
	ELA1	0.0	13.1	0.0	0.0	13.1	0.0
	ELA2	0.0	0.0	0.0	56.0	56.0	56.0
	ELA3	0.0	0.0	0.0	288.0	288.0	288.0
Damri	Base	0.0	3.0	0.0	0.0	3.0	0.0
	ELA1	0.0	13.1	0.0	0.0	13.1	0.0
	ELA2	80.0	17.0	0.0	0.0	97.0	0.0
	ELA3	0.0	0.0	0.0	282.0	282.0	282.0
Khawang	Base	0.0	0.0	10.0	0.0	10.0	0.0
	ELA1	0.0	0.0	0.0	44.5	44.5	44.5
	ELA2	0.0	0.0	0.0	71.3	71.3	71.3
	ELA3	0.0	0.0	0.0	366.5	366.5	366.5
Khung	Base	20.0	0.0	0.0	0.0	20.0	0.0
	ELA1	0.0	0.0	0.0	29.5	29.5	29.5
	ELA2	0.0	0.0	0.0	40.7	40.7	40.7
	ELA3	0.0	0.0	0.0	209.3	209.3	209.3
Kochiwang	Base	15.0	0.0	0.0	0.0	15.0	0.0
	ELA1	0.0	0.0	0.0	18.6	18.6	18.6
	ELA2	0.0	0.0	0.0	43.9	43.9	43.9
	ELA3	0.0	0.0	0.0	252.3	252.3	252.3
Ligha	Base	20.0	0.0	0.0	0.0	20.0	0.0
	ELA1	10.0	0.0	10.0	0.0	20.0	0.0
	ELA2	20.0	0.0	30.0	0.0	50.0	0.0
	ELA3	0.0	0.0	0.0	187.9	187.9	187.9
Syauliwang	Base	0.0	0.0	30.0	0.0	30.0	0.0
	ELA1	0.0	0.0	30.0	0.0	30.0	0.0
	ELA2	0.0	0.0	0.0	69.4	69.4	69.4
	ELA3	0.0	0.0	0.0	338.0	338.0	338.0

BMG = biomass-based power plant, ELA = energy access case, kW = kilowatt, PV = solar photovoltaic.
Source: Authors.

Table A23: Capacity Requirement in 2022 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Grid)
(kW)

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity	S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
1	Badikot	Base	90.2	90.2	19	Liwang	Base	28.6	28.6
		ELA1	93.2	93.2			ELA1	31.4	31.4
		ELA2	118.6	118.6			ELA2	61.8	61.8
		ELA3	379.3	379.3			ELA3	298.1	298.1
2	Bangesal	Base	32.5	32.5	20	Lung	Base	45.6	45.6
		ELA1	38.8	38.8			ELA1	50.5	50.5
		ELA2	73.9	73.9			ELA2	77.3	77.3
		ELA3	320.8	320.8			ELA3	325.6	325.6
3	Baraula	Base	86.2	86.2	21	Majhakot	Base	45.7	45.7
		ELA1	88.5	88.5			ELA1	49.4	49.4
		ELA2	102.9	102.9			ELA2	64.3	64.3
		ELA3	304.7	304.7			ELA3	222.7	222.7
4	Barjiwang	Base	48.2	48.2	22	Maranthana	Base	110.0	110.0
		ELA1	49.0	49.0			ELA1	117.3	117.3
		ELA2	54.8	54.8			ELA2	145.9	145.9
		ELA3	190.4	190.4			ELA3	464.9	464.9
5	Belbas	Base	74.8	74.8	23	Markhawang	Base	63.1	63.1
		ELA1	80.8	80.8				65.3	65.3
		ELA2	117.6	117.6				72.8	72.8
		ELA3	428.4	428.4				196.6	196.6
6	Bhingri	Base	146.0	146.0	24	Narikot	Base	27.6	27.6
		ELA1	147.9	147.9			ELA1	30.9	30.9
		ELA2	157.9	157.9			ELA2	50.4	50.4
		ELA3	421.1	421.1			ELA3	225.6	225.6
7	Bijayanagar	Base	70.5	70.5	25	Nayagaon	Base	150.6	150.6
		ELA1	73.3	73.3			ELA1	151.1	151.1
		ELA2	89.3	89.3			ELA2	154.6	154.6
		ELA3	299.4	299.4			ELA3	276.4	276.4
8	Bijuwar	Base	234.3	234.3	26	Phopli	Base	100.6	100.6
		ELA1	240.9	240.9			ELA1	111.2	111.2
		ELA2	265.4	265.4			ELA2	154.0	154.0
		ELA3	597.1	597.1			ELA3	496.1	496.1
9	Chuja	Base	16.9	16.9	27	Puja	Base	24.0	24.0
		ELA1	28.8	28.8			ELA1	32.2	32.2
		ELA2	79.3	79.3			ELA2	71.9	71.9
		ELA3	393.6	393.6			ELA3	347.3	347.3

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity	S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
10	Dangwang	Base	32.9	32.9	28	Khalanga	Base	279.2	279.2
		ELA1	38.8	38.8			ELA1	283.1	283.1
		ELA2	62.8	62.8			ELA2	297.1	297.1
		ELA3	267.8	267.8			ELA3	532.8	532.8
11	Dharampani	Base	41.9	41.9	29	Rajbara	Base	6.7	6.7
		ELA1	45.2	45.2			ELA1	14.0	14.0
		ELA2	58.5	58.5			ELA2	31.0	31.0
		ELA3	226.9	226.9			ELA3	270.0	270.0
12	Dharmawoti	Base	214.2	214.2	30	Saari	Base	56.6	56.6
		ELA1	218.2	218.2			ELA1	58.5	58.5
		ELA2	232.0	232.0			ELA2	73.9	73.9
		ELA3	384.7	384.7			ELA3	271.6	271.6
13	Udayapurkot	Base	18.5	18.5	31	Swargadwari Khaal	Base	14.6	14.6
		ELA1	23.4	23.4			ELA1	19.1	19.1
		ELA2	42.3	42.3			ELA2	46.8	46.8
		ELA3	193.0	193.0			ELA3	203.2	203.2
14	Dhuwang	Base	15.3	15.3	32	Tiram	Base	112.6	112.6
		ELA1	19.2	19.2			ELA1	116.3	116.3
		ELA2	44.8	44.8			ELA2	135.7	135.7
		ELA3	226.2	226.2			ELA3	371.8	371.8
15	Dhungegadhi	Base	59.2	59.2	33	Turwang	Base	116.5	116.5
		ELA1	62.6	62.6			ELA1	117.9	117.9
		ELA2	85.2	85.2			ELA2	129.6	129.6
		ELA3	254.6	254.6			ELA3	308.6	308.6
16	Gothiwang	Base	44.2	44.2	34	Tusara	Base	97.2	97.2
		ELA1	47.0	47.0			ELA1	100.4	100.4
		ELA2	83.0	83.0			ELA2	119.3	119.3
		ELA3	380.2	380.2			ELA3	385.2	385.2
17	Hansapur	Base	9.6	9.6	35	Bangemaroth	Base	74.5	74.5
		ELA1	14.9	14.9			ELA1	77.7	77.7
		ELA2	45.0	45.0			ELA2	114.0	114.0
		ELA3	231.3	231.3			ELA3	424.3	424.3
18	Jumrikanda	Base	21.6	21.6					
		ELA1	26.7	26.7					
		ELA2	62.3	62.3					
		ELA3	286.9	286.9					

ELA = energy access case, S.No. = serial number.
Source: Authors.

Table A24: Capacity Requirement in 2022 (Light Emitting Diode Equivalent) for Completely Electrified Village Development Committees (Grid)

(kW)

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
1	Bijuli	Base	93.4	93.4
		ELA1	93.4	93.4
		ELA2	100.1	100.1
		ELA3	300.0	300.0
2	Dakhakwadi	Base	166.7	166.7
		ELA1	166.7	166.7
		ELA2	176.4	176.4
		ELA3	458.2	458.2
3	Khaira	Base	80.9	80.9
		ELA1	80.9	80.9
		ELA2	90.3	90.3
		ELA3	295.6	295.6
4	Okherkot	Base	129.4	129.4
		ELA1	129.5	129.5
		ELA2	139.5	139.5
		ELA3	393.7	393.7
5	Pakala	Base	66.9	66.9
		ELA1	66.9	66.9
		ELA2	76.9	76.9
		ELA3	299.1	299.1
6	Ramdi	Base	30.8	30.8
		ELA1	30.8	30.8
		ELA2	39.5	39.5
		ELA3	167.7	167.7
7	Raspurkot	Base	70.5	70.5
		ELA1	70.8	70.8
		ELA2	79.2	79.2
		ELA3	251.3	251.3

ELA = electricity access case, kW = kilowatt, S.No. = serial number.
Source: Authors.

Table A25: Summary of Capacity Requirements in 2022 (Light Emitting Diode Equivalent)
(kW)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified Village Development Committees (Off-grid)					
Base	55.0	10.4	40.0	0.0	105.4
ELA1	10.0	26.2	40.0	92.6	168.8
ELA2	100.0	17.0	30.0	281.3	428.3
ELA3	0.0	0.0	0.0	1,924.0	1,924.0
Partially Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	2,610.7	2,610.7
ELA1	0.0	0.0	0.0	2,763.5	2,763.5
ELA2	0.0	0.0	0.0	3,576.2	3,576.2
ELA3	0.0	0.0	0.0	11,407.3	11,407.3
Completely Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	638.6	638.6
ELA1	0.0	0.0	0.0	639.0	639.0
ELA2	0.0	0.0	0.0	701.9	701.9
ELA3	0.0	0.0	0.0	2,165.6	2,165.6
Total (ALL)					
Base	55.0	10.4	40.0	3,249.3	3,354.7
ELA1	10.0	26.2	40.0	3,495.1	3,571.3
ELA2	100.0	17.0	30.0	4,559.4	4,706.4
ELA3	0.0	0.0	0.0	15,496.8	15,496.8

BMG = biomass based power plant, ELA = energy access case, kW = kilowatt, PV = solar photovoltaic.
Source: Authors.

Appendix 20

Capacity Requirement in 2030 (Light Emitting Diode Equivalent) by Village Development Committee

Table A26: Capacity Requirement in 2030 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Off-grid)
(kW)

Village Development Committee	Case	Technology					Transmission Line Capacity
		PV	Microhydro	BMG	Grid	Total	
Arkha	Base	0.0	23.6	0.0	0.0	23.6	0.0
	ELA1	11.6	44.3	23.4	0.0	79.3	0.0
	ELA2	0.0	0.0	0.0	329.9	329.9	329.9
	ELA3	0.0	0.0	0.0	510.9	510.9	510.9
Damri	Base	0.0	10.2	0.0	0.0	10.2	0.0
	ELA1	0.0	0.0	0.0	62.9	62.9	62.9
	ELA2	0.0	0.0	0.0	323.3	323.3	323.3
	ELA3	0.0	0.0	0.0	500.7	500.7	500.7
Khawang	Base	0.0	0.0	9.5	0.0	9.5	0.0
	ELA1	0.0	0.0	0.0	81.8	81.8	81.8
	ELA2	0.0	0.0	0.0	420.5	420.5	420.5
	ELA3	0.0	0.0	0.0	651.2	651.2	651.2
Khung	Base	6.9	0.0	0.0	0.0	6.9	0.0
	ELA1	0.0	0.0	0.0	46.7	46.7	46.7
	ELA2	0.0	0.0	0.0	240.1	240.1	240.1
	ELA3	0.0	0.0	0.0	371.9	371.9	371.9
Kochiwang	Base	5.6	0.0	0.0	0.0	5.6	0.0
	ELA1	0.0	0.0	0.0	50.3	50.3	50.3
	ELA2	0.0	0.0	0.0	258.8	258.8	258.8
	ELA3	0.0	0.0	0.0	400.8	400.8	400.8
Ligha	Base	5.8	0.0	0.0	0.0	5.8	0.0
	ELA1	0.0	0.0	42.4	0.0	42.4	0.0
	ELA2	0.0	0.0	0.0	215.6	215.6	215.6
	ELA3	0.0	0.0	0.0	333.8	333.8	333.8
Syauliwang	Base	0.0	0.0	0.0	0.0	0.0	0.0
	ELA1	0.0	0.0	0.0	82.5	82.5	82.5
	ELA2	0.0	0.0	0.0	387.9	387.9	387.9
	ELA3	0.0	0.0	0.0	600.6	600.6	600.6

BMG = biomass based power plant, ELA = energy access case, kW = kilowatt, PV = solar photovoltaic.
Source: Authors.

Table A27: Capacity Requirement in 2030 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Grid)

(kW)

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity	S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
1	Badikot	Base	131.0	131.0	19	Liwang	Base	41.5	41.5
		ELA1	159.3	159.3			ELA1	73.7	73.7
		ELA2	442.1	442.1			ELA2	342.0	342.0
		ELA3	666.5	666.5			ELA3	529.7	529.7
2	Bangesal	Base	47.2	47.2	20	Lung	Base	66.2	66.2
		ELA1	89.7	89.7			ELA1	97.9	97.9
		ELA2	368.1	368.1			ELA2	373.6	373.6
		ELA3	570.0	570.0			ELA3	578.5	578.5
3	Baraula	Base	125.1	125.1	21	Majhakot	Base	66.3	66.3
		ELA1	138.1	138.1			ELA1	85.4	85.4
		ELA2	362.1	362.1			ELA2	255.5	255.5
		ELA3	528.1	528.1			ELA3	395.7	395.7
4	Barjiwang	Base	70.0	70.0	22	Maranthana	Base	159.6	159.6
		ELA1	74.6	74.6			ELA1	193.1	193.1
		ELA2	218.5	218.5			ELA2	533.4	533.4
		ELA3	338.4	338.4			ELA3	826.0	826.0
5	Belbas	Base	108.5	108.5	23	Markhawang	Base	91.6	91.6
		ELA1	148.8	148.8			ELA1	102.4	102.4
		ELA2	498.9	498.9			ELA2	227.8	227.8
		ELA3	753.2	753.2			ELA3	346.9	346.9
6	Bhingri	Base	211.9	211.9	24	Narikot	Base	40.1	40.1
		ELA1	221.9	221.9			ELA1	62.4	62.4
		ELA2	487.6	487.6			ELA2	258.8	258.8
		ELA3	743.4	743.4			ELA3	400.8	400.8
7	Bijayanagar	Base	102.3	102.3	25	Nayagaon	Base	218.6	218.6
		ELA1	118.9	118.9			ELA1	221.4	221.4
		ELA2	343.5	343.5			ELA2	339.1	339.1
		ELA3	532.0	532.0			ELA3	467.8	467.8
8	Bijuwar	Base	340.0	340.0	26	Phopli	Base	146.0	146.0
		ELA1	373.0	373.0			ELA1	202.3	202.3
		ELA2	690.2	690.2			ELA2	573.4	573.4
		ELA3	1,055.3	1,055.3			ELA3	876.9	876.9
9	Chuja	Base	24.5	24.5	27	Puja	Base	34.8	34.8
		ELA1	92.4	92.4			ELA1	88.7	88.7
		ELA2	451.6	451.6			ELA2	398.5	398.5
		ELA3	699.4	699.4			ELA3	617.1	617.1

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity	S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
10	Dangwang	Base	47.7	47.7	28	Khalanga	Base	405.3	405.3
		ELA1	78.0	78.0			ELA1	425.5	425.5
		ELA2	307.2	307.2			ELA2	641.0	641.0
		ELA3	475.7	475.7			ELA3	915.0	915.0
11	Dharampani	Base	60.8	60.8	29	Rajbara	Base	9.8	9.8
		ELA1	78.1	78.1			ELA1	60.3	60.3
		ELA2	260.3	260.3			ELA2	183.0	183.0
		ELA3	403.1	403.1			ELA3	479.7	479.7
12	Dharmawoti	Base	310.9	310.9	30	Saari	Base	82.1	82.1
		ELA1	331.1	331.1			ELA1	97.7	97.7
		ELA2	461.0	461.0			ELA2	311.6	311.6
		ELA3	662.4	662.4			ELA3	482.6	482.6
13	Udayapurkot	Base	26.9	26.9	31	Swargadwari Khaal	Base	21.2	21.2
		ELA1	53.3	53.3			ELA1	56.8	56.8
		ELA2	221.4	221.4			ELA2	233.2	233.2
		ELA3	342.9	342.9			ELA3	361.1	361.1
14	Dhuwang	Base	22.3	22.3	32	Tiram	Base	163.4	163.4
		ELA1	33.4	33.4			ELA1	183.8	183.8
		ELA2	259.6	259.6			ELA2	437.2	437.2
		ELA3	401.9	401.9			ELA3	649.3	649.3
15	Dhungegadhi	Base	85.9	85.9	33	Turwang	Base	169.0	169.0
		ELA1	102.6	102.6			ELA1	179.9	179.9
		ELA2	298.4	298.4			ELA2	361.7	361.7
		ELA3	445.6	445.6			ELA3	540.2	540.2
16	Gothiwang	Base	64.1	64.1	34	Tusara	Base	141.1	141.1
		ELA1	78.3	78.3			ELA1	159.0	159.0
		ELA2	436.3	436.3			ELA2	445.9	445.9
		ELA3	675.6	675.6			ELA3	680.2	680.2
17	Hansapur	Base	13.9	13.9	35	Bangemaroth	Base	108.1	108.1
		ELA1	40.2	40.2			ELA1	144.8	144.8
		ELA2	265.4	265.4			ELA2	490.3	490.3
		ELA3	411.0	411.0			ELA3	750.2	750.2
18	Jumrikanda	Base	31.4	31.4					
		ELA1	56.5	56.5					
		ELA2	329.2	329.2					
		ELA3	509.8	509.8					

ELA = energy access case, kW = kilowatt, S.No. = serial number.
Source: Authors.

Table A28: Capacity Requirement in 2030 (Light Emitting Diode Equivalent) for Completely Electrified Village Development Committees (Grid)
(kW)

S.No.	Village Development Committee	Case	Technology Grid	Transmission Line Capacity
1	Bijuli	Base	135.6	135.6
		ELA1	135.6	135.6
		ELA2	348.3	348.3
		ELA3	528.6	528.6
2	Dakhakwadi	Base	241.9	241.9
		ELA1	241.9	241.9
		ELA2	525.7	525.7
		ELA3	814.1	814.1
3	Khaira	Base	136.3	136.3
		ELA1	136.3	136.3
		ELA2	342.0	342.0
		ELA3	522.2	522.2
4	Okherkot	Base	187.8	187.8
		ELA1	192.8	192.8
		ELA2	459.2	459.2
		ELA3	691.6	691.6
5	Pakala	Base	97.0	97.0
		ELA1	100.3	100.3
		ELA2	343.1	343.1
		ELA3	531.4	531.4
6	Ramdi	Base	44.7	44.7
		ELA1	49.1	49.1
		ELA2	192.5	192.5
		ELA3	298.1	298.1
7	Raspurkot	Base	102.3	102.3
		ELA1	106.9	106.9
		ELA2	290.7	290.7
		ELA3	443.8	443.8

ELA = energy access case, kW = kilowatt, S.No. = serial number.
Source: Authors.

Table A29: Summary of Capacity Requirements in 2030 (Light Emitting Diode Equivalent)
(kW)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified VDCs (Off-grid)					
Base	18.3	33.8	9.5	0.0	61.6
ELA1	11.6	44.3	65.8	324.2	445.9
ELA2	0.0	0.0	0.0	2,176.1	2,176.1
ELA3	0.0	0.0	0.0	3,369.9	3,369.9
Partially Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	3,789.1	3,789.1
ELA1	0.0	0.0	0.0	4,703.3	4,703.3
ELA2	0.0	0.0	0.0	13,107.4	13,107.4
ELA3	0.0	0.0	0.0	20,112.0	20,112.0
Completely Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	945.6	945.6
ELA1	0.0	0.0	0.0	962.9	962.9
ELA2	0.0	0.0	0.0	2,501.5	2,501.5
ELA3	0.0	0.0	0.0	3,829.8	3,829.8
Total (ALL)					
Base	18.3	33.8	9.5	4,734.9	4,796.5
ELA1	11.6	44.3	65.8	5,990.5	6,112.2
ELA2	0.0	0.0	0.0	17,785.1	17,785.1
ELA3	0.0	0.0	0.0	27,311.9	27,311.9

BMG = biomass based power plant, ELA = energy access case, kW = kilowatt, PV = solar photovoltaic.
Source: Authors.

Appendix 21

Table A30: Electricity Generation Mix in 2017 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Off-grid) by Village Development Committee

(MWh)

Village Development Committee	Case	Technology				
		PV	Microhydro	BMG	Grid	Total
Arkha	Base	0.0	65.1	0.0	0.0	65.1
	ELA1	0.0	67.1	0.0	0.0	67.1
	ELA2	0.0	134.1	0.0	0.0	134.1
	ELA3	7.6	232.7	89.8	0.0	330.1
Damri	Base	0.0	32.0	0.0	0.0	32.0
	ELA1	0.0	204.9	0.0	0.0	204.9
	ELA2	0.0	204.9	0.0	0.0	204.9
	ELA3	106.6	204.9	6.3	0.0	317.9
Khawang	Base	0.0	0.0	27.5	27.2	54.6
	ELA1	0.0	0.0	0.0	203.3	203.3
	ELA2	0.0	0.0	0.0	203.3	203.3
	ELA3	0.0	0.0	0.0	343.8	343.8
Khung	Base	21.9	0.0	0.0	0.0	21.9
	ELA1	0.0	0.0	0.0	135.4	135.4
	ELA2	0.0	0.0	0.0	142.2	142.2
	ELA3	0.0	0.0	0.0	196.3	196.3
Kochiwang	Base	14.6	0.0	0.0	0.0	14.6
	ELA1	0.0	0.0	0.0	82.5	82.5
	ELA2	0.0	0.0	0.0	89.5	89.5
	ELA3	0.0	0.0	0.0	430.7	430.7
Ligha	Base	15.2	0.0	0.0	0.0	15.2
	ELA1	106.6	0.0	0.0	0.0	106.6
	ELA2	121.9	0.0	0.0	0.0	121.9
	ELA3	30.5	0.0	150.7	0.0	181.2
Syauliwang	Base	0.0	0.0	109.7	0.0	109.7
	ELA1	0.0	0.0	110.1	0.0	110.1
	ELA2	0.0	0.0	150.6	0.0	150.6
	ELA3	43.8	0.0	294.0	0.0	337.8

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic.
Source: Authors.

Table A31: Electricity Generation Mix in 2017 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Grid) by Village Development Committee
(MWh)

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
1	Badikot	Base	375.8	19	Liwang	Base	119.0
		ELA1	376.3			ELA1	119.1
		ELA2	392.1			ELA2	137.3
		ELA3	521.8			ELA3	291.8
2	Bangesal	Base	135.4	20	Lung	Base	190.0
		ELA1	136.7			ELA1	190.7
		ELA2	166.7			ELA2	214.6
		ELA3	345.5			ELA3	353.1
3	Baraula	Base	358.9	21	Majhakot	Base	190.2
		ELA1	359.3			ELA1	191.0
		ELA2	370.3			ELA2	208.4
		ELA3	454.6			ELA3	284.9
4	Barjiwang	Base	200.9	22	Maranthana	Base	459.6
		ELA1	201.0			ELA1	460.7
		ELA2	204.7			ELA2	493.2
		ELA3	242.9			ELA3	647.6
5	Belbas	Base	311.3	23	Markhawang	Base	262.8
		ELA1	311.4			ELA1	263.3
		ELA2	343.2			ELA2	245.7
		ELA3	533.8			ELA3	314.3
6	Bhingri	Base	608.0	24	Narikot	Base	115.0
		ELA1	608.4			ELA1	115.7
		ELA2	617.1			ELA2	131.5
		ELA3	683.8			ELA3	233.0
7	Bijayanagar	Base	293.6	25	Nayagaon	Base	627.1
		ELA1	294.1			ELA1	627.2
		ELA2	307.6			ELA2	629.7
		ELA3	396.6			ELA3	652.8
8	Bijuwar	Base	975.6	26	Phopli	Base	418.9
		ELA1	977.0			ELA1	420.9
		ELA2	1,007.6			ELA2	470.7
		ELA3	1,137.2			ELA3	688.2
9	Chuja	Base	70.4	27	Puja	Base	99.8
		ELA1	72.8			ELA1	100.7
		ELA2	129.1			ELA2	141.8
		ELA3	379.7			ELA3	335.0

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
10	Dangwang	Base	137.0	28	Khalanga	Base	1,162.9
		ELA1	138.2			ELA1	1,163.7
		ELA2	165.5			ELA2	1,181.7
		ELA3	290.2			ELA3	1,257.4
11	Dharampani	Base	174.0	29	Rajbara	Base	28.1
		ELA1	174.7			ELA1	29.2
		ELA2	190.0			ELA2	41.1
		ELA3	262.7			ELA3	253.3
12	Dharmawoti	Base	891.9	30	Saari	Base	235.6
		ELA1	892.8			ELA1	235.7
		ELA2	911.5			ELA2	245.9
		ELA3	980.4			ELA3	330.2
13	Udayapurkot	Base	77.1	31	Swargadwari Khaal	Base	60.9
		ELA1	77.9			ELA1	61.3
		ELA2	100.9			ELA2	84.6
		ELA3	196.1			ELA3	218.9
14	Dhuwang	Base	63.9	32	Tiram	Base	468.9
		ELA1	64.7			ELA1	469.7
		ELA2	83.7			ELA2	486.7
		ELA3	215.1			ELA3	593.6
15	Dhungegadhi	Base	246.6	33	Turwang	Base	485.0
		ELA1	217.3			ELA1	485.3
		ELA2	272.1			ELA2	492.8
		ELA3	378.5			ELA3	558.9
16	Gothiwang	Base	184.0	34	Tusara	Base	404.8
		ELA1	184.6			ELA1	405.5
		ELA2	204.9			ELA2	420.2
		ELA3	386.1			ELA3	527.6
17	Hansapur	Base	39.8	35	Bangemaroth	Base	310.0
		ELA1	40.9			ELA1	310.7
		ELA2	66.1			ELA2	326.4
		ELA3	217.0			ELA3	519.8
18	Jumrikanda	Base	90.1				
		ELA1	91.2				
		ELA2	125.1				
		ELA3	292.5				

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic, S.No. = serial number.
Note: In 2017, only grid-based electricity generation have been found to be cost-effective.
Source: Authors.

Table A32: Electricity Generation Mix in 2017 (Light Emitting Diode Equivalent) for Completely Electrified Village Development Committees (Grid)
(MWh)

S.No.	Village Development Committee	Case	Technology Grid
1	Bijuli	Base	389.1
		ELA1	389.1
		ELA2	389.1
		ELA3	438.6
2	Dakhakwadi	Base	694.1
		ELA1	694.1
		ELA2	695.3
		ELA3	760.5
3	Khaira	Base	337.1
		ELA1	337.1
		ELA2	337.1
		ELA3	399.5
4	Okherkot	Base	538.8
		ELA1	538.8
		ELA2	539.8
		ELA3	601.7
5	Pakala	Base	278.4
		ELA1	278.4
		ELA2	278.4
		ELA3	344.9
6	Ramdi	Base	128.2
		ELA1	128.2
		ELA2	128.2
		ELA3	182.5
7	Raspurkot	Base	293.4
		ELA1	293.5
		ELA2	295.1
		ELA3	347.0

ELA = energy access case, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Table A33: Summary of Electricity Generation Mix in 2017 (Light Emitting Diode Equivalent)
(MWh)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified VDCs (Off-grid)					
Base	51.7	97.1	137.1	27.2	313.1
ELA1	106.6	272.0	110.1	421.2	909.9
ELA2	121.9	339.1	150.6	435.0	1,046.6
ELA3	188.5	437.6	540.9	970.9	2,137.9
Partially Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	10,872.9	10,872.9
ELA1	0.0	0.0	0.0	10,869.8	10,869.8
ELA2	0.0	0.0	0.0	11,610.8	11,610.8
ELA3	0.0	0.0	0.0	15,974.9	15,974.9
Completely Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	2,659.1	2,659.1
ELA1	0.0	0.0	0.0	2,659.2	2,659.2
ELA2	0.0	0.0	0.0	2,662.8	2,662.8
ELA3	0.0	0.0	0.0	3,074.7	3,074.7
Total (ALL)					
Base	51.7	97.1	137.1	13,559.2	13,845.1
ELA1	106.6	272.0	110.1	13,950.2	14,438.9
ELA2	121.9	339.1	150.6	14,708.6	15,320.2
ELA3	188.5	437.6	540.9	20,020.4	21,187.4

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic, VDC = village development committee.
Source: Authors.

Appendix 22

Electricity Generation Mix in 2022 (Light Emitting Diode Equivalent) by Village Development Committee

Table A34: Electricity Generation Mix in 2022 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Off-grid) by Village Development Committee
(MWh)

Village Development Committee	Case	Technology				
		PV	Microhydro	BMG	Grid	Total
Arkha	Base	0.0	82.8	0.0	0.0	82.8
	ELA1	0.0	146.0	0.0	0.0	146
	ELA2	0.0	0.0	0.0	296.2	296.2
	ELA3	0.0	0.0	0.0	1,513.7	1,513.7
Damri	Base	0.0	39.4	0.0	0.0	39.4
	ELA1	7.6	204.9	0.0	0.0	212.5
	ELA2	0.0	0.0	0.0	289.9	289.9
	ELA3	0.0	0.0	0.0	1,481.2	1,481.2
Khawang	Base	0.0	0.0	40.8	0.0	40.8
	ELA1	0.0	0.0	0.0	233.6	233.6
	ELA2	0.0	0.0	0.0	377.0	377
	ELA3	0.0	0.0	0.0	1,926.3	1,926.3
Khung	Base	29.2	0.0	0.0	0.0	29.2
	ELA1	0.0	0.0	0.0	155.0	155
	ELA2	0.0	0.0	0.0	215.3	215.3
	ELA3	0.0	0.0	0.0	1,100.0	1,100
Kochiwang	Base	21.9	0.0	0.0	0.0	21.9
	ELA1	0.0	0.0	0.0	97.6	97.6
	ELA2	0.0	0.0	0.0	232.0	232
	ELA3	0.0	0.0	0.0	1,325.8	1,325.8
Ligha	Base	30.5	0.0	0.0	0.0	30.5
	ELA1	15.2	0.0	84.8	0.0	100
	ELA2	30.5	0.0	170.0	0.0	200.5
	ELA3	0.0	0.0	0.0	987.5	987.5
Syauliwang	Base	0.0	0.0	153.1	0.0	153.1
	ELA1	0.0	0.0	1,64.9	0.0	164.9
	ELA2	0.0	0.0	0.0	367.1	367.1
	ELA3	0.0	0.0	0.0	1,776.8	1,776.8

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic.
Source: Authors.

Table A35: Electricity Generation Mix in 2022 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committees (Grid) by Village Development Committees
(MWh)

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
1	Badikot	Base	474.3	19	Liwang	Base	150.2
		ELA1	490.0			ELA1	165.2
		ELA2	627.4			ELA2	326.6
		ELA3	1,993.6			ELA3	1,566.9
2	Bangesal	Base	170.9	20	Lung	Base	239.9
		ELA1	204.0			ELA1	265.6
		ELA2	390.7			ELA2	408.9
		ELA3	1,686.1			ELA3	1,711.3
3	Baraula	Base	453.0	21	Majhakot	Base	240.1
		ELA1	465.1			ELA1	259.9
		ELA2	544.4			ELA2	340.0
		ELA3	1,601.7			ELA3	1,170.5
4	Barjiwang	Base	253.5	22	Maranthana	Base	578.1
		ELA1	257.6			ELA1	616.5
		ELA2	290.0			ELA2	771.4
		ELA3	1,000.9			ELA3	2,443.5
5	Belbas	Base	392.9	23	Markhawang	Base	331.7
		ELA1	424.8			ELA1	343.2
		ELA2	622.0			ELA2	384.9
		ELA3	2,251.6			ELA3	1,033.3
6	Bhingri	Base	767.4	24	Narikot	Base	145.1
		ELA1	777.1			ELA1	162.5
		ELA2	835.3			ELA2	266.4
		ELA3	2,213.2			ELA3	1,185.6
7	Bijayanagar	Base	370.6	25	Nayagaon	Base	791.6
		ELA1	385.3			ELA1	794.3
		ELA2	472.4			ELA2	817.6
		ELA3	1,573.6			ELA3	1,453.0
8	Bijuwar	Base	1,231.4	26	Phopli	Base	528.7
		ELA1	1,266.3			ELA1	584.5
		ELA2	1,403.6			ELA2	814.4
		ELA3	3,138.2			ELA3	2,607.4
9	Chuja	Base	88.8	27	Puja	Base	125.9
		ELA1	151.6			ELA1	169.1
		ELA2	419.6			ELA2	380.3
		ELA3	2,069.0			ELA3	1,825.5

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
10	Dangwang	Base	172.9	28	Khalanga	Base	1,467.7
		ELA1	203.8			ELA1	1,488.0
		ELA2	332.0			ELA2	1,571.3
		ELA3	1,407.3			ELA3	2,800.5
11	Dharampani	Base	220.2	29	Rajbara	Base	35.4
		ELA1	237.6			ELA1	73.4
		ELA2	309.6			ELA2	164.1
		ELA3	1,192.4			ELA3	1,419.1
12	Dharmawoti	Base	1,125.8	30	Saari	Base	297.4
		ELA1	1,147.1			ELA1	307.3
		ELA2	1,227.0			ELA2	391.1
		ELA3	2,021.8			ELA3	1,427.5
13	Udayapurkot	Base	97.4	31	Swargadwari Khaal	Base	76.9
		ELA1	122.8			ELA1	100.3
		ELA2	223.8			ELA2	247.4
		ELA3	1,014.3			ELA3	1,068.1
14	Dhuwang	Base	80.7	32	Tiram	Base	591.9
		ELA1	101.0			ELA1	611.1
		ELA2	237.1			ELA2	717.7
		ELA3	1,189.0			ELA3	1,954.2
15	Dhungegadhi	Base	311.3	33	Turwang	Base	612.1
		ELA1	328.9			ELA1	619.9
		ELA2	450.7			ELA2	685.4
		ELA3	1,338.1			ELA3	1,622.2
16	Gothiwang	Base	232.2	34	Tusara	Base	510.9
		ELA1	247.2			ELA1	527.7
		ELA2	438.7			ELA2	631.0
		ELA3	1,998.5			ELA3	2,024.6
17	Hansapur	Base	50.3	35	Bangemaroth	Base	391.3
		ELA1	78.1			ELA1	408.3
		ELA2	238.0			ELA2	603.1
		ELA3	1,215.9			ELA3	2,230.2
18	Jumrikanda	Base	113.7				
		ELA1	140.2				
		ELA2	329.3				
		ELA3	1,508.1				

ELA = energy access case, MWh = megawatt hour, S.No. = serial number.
Note: In 2022, only grid based electricity generation have been found to be cost-effective.
Source: Authors.

Table A36: Electricity Generation Mix in 2022 (Light Emitting Diode Equivalent) for Completely Electrified Village Development Committees (Grid)

(MWh)

S.No.	Village Development Committee	Case	Technology Grid
1	Bijuli	Base	491.0
		ELA1	491.0
		ELA2	529.6
		ELA3	1,576.8
2	Dakhakwadi	Base	876.1
		ELA1	876.1
		ELA2	932.7
		ELA3	2,408.2
3	Khaira	Base	425.4
		ELA1	425.4
		ELA2	477.5
		ELA3	1,553.7
4	Okherkot	Base	680.1
		ELA1	680.7
		ELA2	737.7
		ELA3	2,069.4
5	Pakala	Base	351.4
		ELA1	351.4
		ELA2	406.8
		ELA3	1,571.9
6	Ramdi	Base	161.8
		ELA1	161.8
		ELA2	209.1
		ELA3	881.7
7	Raspurkot	Base	370.4
		ELA1	372.0
		ELA2	418.7
		ELA3	1,320.6

ELA = energy access case, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Table A37: Summary of Electricity Generation Mix in 2022 (Light Emitting Diode Equivalent)
(MWh)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified VDCs (Off-grid)					
Base	81.5	122.3	193.9	0.0	397.7
ELA1	22.9	350.9	249.7	486.2	1,109.6
ELA2	30.5	0.0	170.0	1,777.5	1,977.9
ELA3	0.0	0.0	0.0	10,111.3	10,111.3
Partially Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	13,722.1	13,722.1
ELA1	0.0	0.0	0.0	14,525.2	14,525.2
ELA2	0.0	0.0	0.0	18,912.9	18,912.9
ELA3	0.0	0.0	0.0	59,956.5	59,956.5
Completely Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	3,356.3	3,356.3
ELA1	0.0	0.0	0.0	3,358.5	3,358.5
ELA2	0.0	0.0	0.0	3,712.1	3,712.1
ELA3	0.0	0.0	0.0	11,382.3	11,382.3
Total (ALL)					
Base	81.5	122.3	193.9	17,078.4	17,476.0
ELA1	22.9	350.9	249.7	18,369.9	18,993.3
ELA2	30.5	0.0	170.0	24,402.5	24,602.9
ELA3	0.0	0.0	0.0	81,450.1	81,450.1

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic.
Source: Authors.

Appendix 23

Electricity Generation Mix in 2030 (Light Emitting Diode Equivalent) by Village Development Committee

Table A38: Electricity Generation Mix in 2030 (Light Emitting Diode Equivalent) for Partially Electrified VDCs (Off-grid) by Village Development Committee
(MWh)

Village Development Committee	Case	Technology				
		PV	Microhydro	BMG	Grid	Total
Arkha	Base	0.0	124.3	0.0	0.0	124.3
	ELA1	60.9	232.7	123.1	0.0	416.7
	ELA2	0.0	0.0	0.0	1,746.5	1,746.5
	ELA3	0.0	0.0	0.0	2,685.5	2,685.5
Damri	Base	0.0	53.4	0.0	0.0	53.4
	ELA1	0.0	0.0	0.0	333.8	333.8
	ELA2	0.0	0.0	0.0	1,711.6	1,711.6
	ELA3	0.0	0.0	0.0	2,631.8	2,631.8
Khawang	Base	0.0	0.0	50.2	0.0	50.2
	ELA1	0.0	0.0	0.0	434.1	434.1
	ELA2	0.0	0.0	0.0	2,225.8	2,225.8
	ELA3	0.0	0.0	0.0	3,422.6	3,422.6
Khung	Base	36.5	0.0	0.0	0.0	36.5
	ELA1	0.0	0.0	0.0	247.9	247.9
	ELA2	0.0	0.0	0.0	1,271.1	1,271.1
	ELA3	0.0	0.0	0.0	1,954.5	1,954.5
Kochiwang	Base	29.2	0.0	0.0	0.0	29.2
	ELA1	0.0	0.0	0.0	267.2	267.2
	ELA2	0.0	0.0	0.0	1,370.1	1,370.1
	ELA3	0.0	0.0	0.0	2,106.7	2,106.7
Ligha	Base	30.5	0.0	0.0	0.0	30.5
	ELA1	0.0	0.0	222.9	0.0	222.9
	ELA2	0.0	0.0	0.0	1,141.1	1,141.1
	ELA3	0.0	0.0	0.0	1,754.6	1,754.6
Syauliwang	Base	0.0	0.0	0.0	0.0	0.0
	ELA1	0.0	0.0	0.0	437.8	437.8
	ELA2	0.0	0.0	0.0	2,053.1	2,053.1
	ELA3	0.0	0.0	0.0	3,157.0	3,157.0

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic.
Source: Authors.

Table A39: Electricity Generation Mix in 2030 (Light Emitting Diode Equivalent) for Partially Electrified Village Development Committee (Grid) by Village Development Committee
(MWh)

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
1	Badikot	Base	688.3	19	Liwang	Base	218.1
		ELA1	845.7			ELA1	391.0
		ELA2	2,340.4			ELA2	1,810.6
		ELA3	3,503.2			ELA3	2,784.0
2	Bangesal	Base	248.1	20	Lung	Base	348.1
		ELA1	476.2			ELA1	519.4
		ELA2	1,948.3			ELA2	1,977.5
		ELA3	2,995.9			ELA3	3,040.6
3	Baraula	Base	657.5	21	Majhakot	Base	3,48.4
		ELA1	733.0			ELA1	453.0
		ELA2	1,916.8			ELA2	1,352.6
		ELA3	2,775.7			ELA3	2,079.8
4	Barjiwang	Base	368.0	22	Maranthana	Base	839.0
		ELA1	395.9			ELA1	1,025.1
		ELA2	1,156.6			ELA2	2,823.6
		ELA3	1,778.4			ELA3	4,341.6
5	Belbas	Base	570.2	23	Markhawang	Base	481.5
		ELA1	789.7			ELA1	543.5
		ELA2	2,641.1			ELA2	1,205.9
		ELA3	3,958.8			ELA3	1,823.4
6	Bhingri	Base	1,113.9	24	Narikot	Base	210.6
		ELA1	1,177.7			ELA1	331.1
		ELA2	2,581.0			ELA2	1,370.1
		ELA3	3,907.4			ELA3	2,106.7
7	Bijayanagar	Base	537.9	25	Nayagaon	Base	1,148.9
		ELA1	631.0			ELA1	1,174.8
		ELA2	1,818.3			ELA2	1,794.8
		ELA3	2,795.9			ELA3	2,458.6
8	Bijuwar	Base	1,787.3	26	Phopli	Base	767.4
		ELA1	1,979.8			ELA1	1,073.8
		ELA2	3,653.6			ELA2	3,035.4
		ELA3	5,546.8			ELA3	4,609.1
9	Chuja	Base	128.9	27	Puja	Base	182.8
		ELA1	490.4			ELA1	470.6
		ELA2	2,390.8			ELA2	2109.4
		ELA3	3,676.2			ELA3	3,243.5

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
10	Dangwang	Base	250.9	28	Khalanga	Base	2,130.3
		ELA1	414.0			ELA1	2,258.5
		ELA2	1,626.2			ELA2	3,393.1
		ELA3	2,500.5			ELA3	4,809.0
11	Dharampani	Base	319.6	29	Rajbara	Base	51.4
		ELA1	414.6			ELA1	319.8
		ELA2	1,377.8			ELA2	969.0
		ELA3	2,118.6			ELA3	2,521.4
12	Dharmawoti	Base	1,633.9	30	Saari	Base	431.6
		ELA1	1,757.0			ELA1	518.8
		ELA2	2,440.5			ELA2	1,649.5
		ELA3	3,481.7			ELA3	2,536.3
13	Udayapurkot	Base	141.3	31	Swargadwari Khaal	Base	111.5
		ELA1	282.7			ELA1	301.2
		ELA2	1,172.1			ELA2	1,234.2
		ELA3	1,802.3			ELA3	1,897.8
14	Dhuwang	Base	117.1	32	Tiram	Base	859.1
		ELA1	177.3			ELA1	975.6
		ELA2	1,373.9			ELA2	2,314.2
		ELA3	2,112.6			ELA3	3,412.7
15	Dhungegadhi	Base	451.8	33	Turwang	Base	888.5
		ELA1	544.6			ELA1	954.8
		ELA2	1,579.6			ELA2	1,914.7
		ELA3	2,342.1			ELA3	2839.5
16	Gothiwang	Base	337.0	34	Tusara	Base	741.6
		ELA1	415.4			ELA1	844.0
		ELA2	2,309.3			ELA2	2,360.2
		ELA3	3,550.9			ELA3	3,575.3
17	Hansapur	Base	72.9	35	Bangemaroth	Base	568.0
		ELA1	213.5			ELA1	768.7
		ELA2	1,405.0			ELA2	2,595.7
		ELA3	2,160.4			ELA3	3,942.9
18	Jumrikanda	Base	165.0				
		ELA1	299.9				
		ELA2	1,742.6				
		ELA3	2,679.6				

ELA = energy access case, MWh = megawatt hour, S.No. = serial number.
Note: In 2030, only grid based electricity generation have been found to be cost-effective.
Source: Authors.

Table A40: Electricity Generation Mix in 2030 (Light Emitting Diode Equivalent) for Completely Electrified Village Development Committees (Grid)
(MWh)

S.No.	Village Development Committee	Case	Technology Grid
1	Bijuli	Base	712.7
		ELA1	719.7
		ELA2	1,843.8
		ELA3	2,778.5
2	Dakhakwadi	Base	1,271.6
		ELA1	1,284.0
		ELA2	2,782.8
		ELA3	4,279.0
3	Khaira	Base	716.5
		ELA1	723.5
		ELA2	1,810.3
		ELA3	2,744.7
4	Okherkot	Base	987.1
		ELA1	1,023.5
		ELA2	2,430.6
		ELA3	3,635.1
5	Pakala	Base	510.0
		ELA1	532.4
		ELA2	1,816.4
		ELA3	2,793.0
6	Ramdi	Base	234.9
		ELA1	260.9
		ELA2	1,018.8
		ELA3	1,566.6
7	Raspurkot	Base	537.5
		ELA1	567.4
		ELA2	1,539.0
		ELA3	2,332.6

ELA = energy access case, MWh = megawatt hour, S.No. = serial number.
Source: Authors.

Table A41: Summary of Electricity Generation Mix in 2030 (Light Emitting Diode Equivalent)
(MWh)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified VDCs (Off-grid)					
Base	96.1	177.6	50.2	0.0	323.9
ELA1	60.9	232.7	346.0	1,720.7	2360.4
ELA2	0.0	0.0	0.0	11,519.3	11519.3
ELA3	0.0	0.0	0.0	17,712.6	17712.6
Partially Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	19,916.3	19,916.3
ELA1	0.0	0.0	0.0	24,961.9	24,961.9
ELA2	0.0	0.0	0.0	69,384.3	69,384.3
ELA3	0.0	0.0	0.0	105,709.3	105,709.3
Completely Electrified VDCs (Grid)					
Base	0.0	0.0	0.0	4,970.3	4,970.3
ELA1	0.0	0.0	0.0	5,111.3	5,111.3
ELA2	0.0	0.0	0.0	13,241.7	13,241.7
ELA3	0.0	0.0	0.0	20,129.5	20,129.5
Total (ALL)					
Base	96.1	177.6	50.2	24,886.6	25,210.5
ELA1	60.9	232.7	346.0	31,794.0	32,433.6
ELA2	0.0	0.0	0.0	94,145.2	94,145.2
ELA3	0.0	0.0	0.0	143,551.4	143,551.4

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic.
Source: Authors.

Appendix 24

Total Electricity Supply Cost by Village Development Committee in 2017 with Light Emitting Diode Equivalent Lamps Considered for Lighting

Table A42: Total Electricity Supply Cost in 2017 for Partially Electrified Village Development Committees (Off-grid)
(million NRs)

Village Development Committee	Case	Technology				
		PV	Microhydro	BMG	Grid	Total
Arkha	Base	0.0	7.8	0.0	0.0	7.8
	ELA1	0.0	8.0	0.0	0.0	8.0
	ELA2	0.0	11.7	0.0	0.0	11.7
	ELA3	11.6	18.5	40.6	0.0	70.6
Damri	Base	0.0	6.4	0.0	0.0	6.4
	ELA1	0.0	14.1	0.0	0.0	14.1
	ELA2	0.0	14.1	0.0	0.0	14.1
	ELA3	14.4	13.2	8.4	0.0	36.1
Khawang	Base	0.0	0.0	10.7	0.0	10.7
	ELA1	0.0	0.0	39.1	0.0	39.1
	ELA2	0.0	0.0	40.3	0.0	40.3
	ELA3	0.0	0.0	0.0	48.7	48.7
Khung	Base	7.0	0.0	0.0	0.0	7.0
	ELA1	0.0	0.0	0.0	38.8	38.8
	ELA2	0.0	0.0	0.0	39.4	39.4
	ELA3	0.0	0.0	0.0	44.4	44.4
Kochiwang	Base	6.3	0.0	0.0	0.0	6.3
	ELA1	0.0	0.0	0.0	26.8	26.8
	ELA2	0.0	0.0	0.0	27.4	27.4
	ELA3	0.0	0.0	0.0	58.8	58.8
Ligha	Base	2.2	0.0	0.0	0.0	2.2
	ELA1	12.0	0.0	0.0	0.0	12.0
	ELA2	13.4	0.0	0.0	0.0	13.4
	ELA3	4.4	0.0	24.7	0.0	29.1
Syauliwang	Base	0.0	0.0	15.7	0.0	15.7
	ELA1	0.0	0.0	15.7	0.0	15.7
	ELA2	0.0	0.0	25.7	0.0	25.7
	ELA3	13.0	0.0	40.2	0.0	53.2

BMG = biomass based power plant, ELA = energy access case, MWh = megawatt hour, PV = solar photovoltaic.
Source: Authors.

Table A43: Total Electricity Supply Cost in 2017 for Partially Electrified Village Development Committees (Grid)
(million NRs)

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
1	Badikot	Base	58.3	19	Liwang	Base	14.3
		ELA1	58.3			ELA1	14.4
		ELA2	59.8			ELA2	16.0
		ELA3	71.7			ELA3	30.2
2	Bangesal	Base	18.2	20	Lung	Base	20.0
		ELA1	18.4			ELA1	20.0
		ELA2	21.1			ELA2	22.2
		ELA3	37.6			ELA3	35.0
3	Baraula	Base	34.7	21	Majhakot	Base	19.9
		ELA1	34.7			ELA1	20.0
		ELA2	35.7			ELA2	21.6
		ELA3	43.5			ELA3	28.7
4	Barjiwang	Base	18.5	22	Maranthana	Base	45.8
		ELA1	18.5			ELA1	45.9
		ELA2	18.8			ELA2	48.9
		ELA3	22.4			ELA3	63.1
5	Belbas	Base	33.4	23	Markhawang	Base	25.4
		ELA1	33.4			ELA1	25.4
		ELA2	36.4			ELA2	23.8
		ELA3	53.9			ELA3	30.1
6	Bhingri	Base	56.0	24	Narikot	Base	13.2
		ELA1	56.0			ELA1	13.3
		ELA2	56.8			ELA2	14.8
		ELA3	62.9			ELA3	24.1
7	Bijayanagar	Base	28.3	25	Nayagaon	Base	57.9
		ELA1	28.4			ELA1	57.9
		ELA2	29.6			ELA2	58.2
		ELA3	37.8			ELA3	60.3
8	Bijuwar	Base	90.6	26	Phopli	Base	43.1
		ELA1	90.7			ELA1	43.3
		ELA2	93.5			ELA2	47.8
		ELA3	105.5			ELA3	67.9
9	Chuja	Base	15.6	27	Puja	Base	31.9
		ELA1	15.8			ELA1	32.0
		ELA2	21.0			ELA2	35.8
		ELA3	44.1			ELA3	53.5

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
10	Dangwang	Base	17.9	28	Khalanga	Base	108.0
		ELA1	18.0			ELA1	108.0
		ELA2	20.5			ELA2	109.7
		ELA3	32.0			ELA3	116.7
11	Dharampani	Base	17.6	29	Rajbara	Base	16.4
		ELA1	17.6			ELA1	16.5
		ELA2	19.0			ELA2	17.6
		ELA3	25.7			ELA3	37.1
12	Dharmawoti	Base	83.0	30	Saari	Base	23.0
		ELA1	83.1			ELA1	23.0
		ELA2	84.8			ELA2	23.9
		ELA3	91.2			ELA3	31.7
13	Udayapurkot	Base	10.7	31	Swargadwari Khaal	Base	19.1
		ELA1	10.7			ELA1	19.1
		ELA2	12.9			ELA2	21.3
		ELA3	21.6			ELA3	33.7
14	Dhuwang	Base	10.5	32	Tiram	Base	45.4
		ELA1	10.5			ELA1	45.5
		ELA2	12.3			ELA2	47.0
		ELA3	24.4			ELA3	56.9
15	Dhungegadhi	Base	27.7	33	Turwang	Base	45.1
		ELA1	25.0			ELA1	45.1
		ELA2	30.0			ELA2	45.8
		ELA3	39.8			ELA3	51.9
16	Gothiwang	Base	19.7	34	Tusara	Base	37.9
		ELA1	19.7			ELA1	38.0
		ELA2	21.6			ELA2	39.4
		ELA3	38.3			ELA3	49.2
17	Hansapur	Base	7.3	35	Bangemaroth	Base	31.0
		ELA1	7.4			ELA1	31.1
		ELA2	9.7			ELA2	32.5
		ELA3	23.6			ELA3	50.3
18	Jumrikanda	Base	10.3				
		ELA1	10.4				
		ELA2	13.6				
		ELA3	29.0				

ELA = energy access case, NRs = Nepalese Rupees, S.No. = serial number.
Source: Authors.

Table A44: Total Electricity Supply Cost in 2017 for Completely Electrified Village Development Committees (Grid)

(million NRs)

S.No.	Village Development Committee	Case	Technology Grid
1	Bijuli	Base	35.8
		ELA1	35.8
		ELA2	35.8
		ELA3	40.4
2	Dakhakwadi	Base	63.9
		ELA1	63.9
		ELA2	64.0
		ELA3	70.0
3	Khaira	Base	31.0
		ELA1	31.0
		ELA2	31.0
		ELA3	36.8
4	Okherkot	Base	49.6
		ELA1	49.6
		ELA2	49.7
		ELA3	55.4
5	Pakala	Base	25.6
		ELA1	25.6
		ELA2	25.6
		ELA3	31.7
6	Ramdi	Base	11.8
		ELA1	11.8
		ELA2	11.8
		ELA3	16.8
7	Raspurkot	Base	27.0
		ELA1	27.0
		ELA2	27.2
		ELA3	31.9

ELA = energy access case, NRs = Nepalese Rupees, S.No. = serial number.
Source: Authors.

Table A45: Summary of Total Electricity Supply Cost in 2017
(million NRs)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified Village Development Committees (Off-grid)					
Base	15.6	14.2	26.4	0.0	56.2
ELA1	12.0	22.0	54.8	65.6	154.4
ELA2	13.4	25.8	66.0	66.9	172.1
ELA3	43.4	31.7	113.9	152.0	341.0
Partially Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	1,155.5	1,155.5
ELA1	0.0	0.0	0.0	1,155.2	1,155.2
ELA2	0.0	0.0	0.0	1,223.4	1,223.4
ELA3	0.0	0.0	0.0	1,625.1	1,625.1
Completely Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	244.7	244.7
ELA1	0.0	0.0	0.0	244.8	244.8
ELA2	0.0	0.0	0.0	245.1	245.1
ELA3	0.0	0.0	0.0	283.0	283.0
Total (ALL)					
Base	15.6	14.2	26.4	1,400.3	1,456.4
ELA1	12.0	22.0	54.8	1,465.6	1,554.4
ELA2	13.4	25.8	66.0	1,535.4	1,640.6
ELA3	43.4	31.7	113.9	2,060.0	2,249.1

BMG = biomass based power plant, ELA = energy access case, NRs = Nepalese Rupees, PV = solar photovoltaic.
Source: Authors.

Appendix 25

Total Electricity Supply Cost in 2022 by Village Development Committee Considering Light Emitting Diode Equivalent Lamps for Lighting

Table A46: Total Electricity Supply Cost in 2022 for Partially Electrified Village Development Committees (Off-grid)

(million NRs)

Village Development Committee	Case	Technology				
		PV	Microhydro	BMG	Grid	Total
Arkha	Base	0.0	10.1	0.0	0.0	10.1
	ELA1	0.0	12.0	0.0	0.0	12.0
	ELA2	0.0	0.0	0.0	70.9	70.9
	ELA3	0.0	0.0	0.0	10.0	10.0
Damri	Base	0.0	6.5	0.0	0.0	6.5
	ELA1	1.6	13.2	0.0	0.0	14.8
	ELA2	0.0	0.0	0.0	41.6	41.6
	ELA3	0.0	0.0	0.0	151.4	151.4
Khawang	Base	0.0	0.0	13.3	0.0	13.3
	ELA1	0.0	0.0	0.0	38.6	38.6
	ELA2	0.0	0.0	0.0	51.5	51.5
	ELA3	0.0	0.0	0.0	194.3	194.3
Khung	Base	7.7	0.0	0.0	0.0	7.7
	ELA1	0.0	0.0	0.0	40.6	40.6
	ELA2	0.0	0.0	0.0	46.0	46.0
	ELA3	0.0	0.0	0.0	127.6	127.6
Kochiwang	Base	7.0	0.0	0.0	0.0	7.0
	ELA1	0.0	0.0	0.0	28.2	28.2
	ELA2	0.0	0.0	0.0	40.4	40.4
	ELA3	0.0	0.0	0.0	141.2	141.2
Ligha	Base	3.2	0.0	0.0	0.0	3.2
	ELA1	3.1	0.0	14.3	0.0	17.5
	ELA2	4.8	0.0	25.8	0.0	30.5
	ELA3	0.0	0.0	0.0	120.5	120.5
Syauliwang	Base	0.0	0.0	25.7	0.0	25.7
	ELA1	0.0	0.0	26.8	0.0	26.8
	ELA2	0.0	0.0	0.0	75.1	75.1
	ELA3	0.0	0.0	0.0	205.2	205.2

BMG = biomass based power plant, ELA = energy access case, NRs = Nepalese Rupees, PV = solar photovoltaic.
Source: Authors.

Table A47: Total Electricity Supply Cost in 2022 for Partially Electrified Village Development Committees (Grid)

(million NRs)

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
1	Badikot	Base	46.3	19	Liwang	Base	17.2
		ELA1	47.7			ELA1	18.6
		ELA2	60.0			ELA2	33.3
		ELA3	186.1			ELA3	147.6
2	Bangesal	Base	21.5	20	Lung	Base	24.5
		ELA1	24.6			ELA1	26.9
		ELA2	41.5			ELA2	39.9
		ELA3	161.0			ELA3	160.0
3	Baraula	Base	43.3	21	Majhakot	Base	24.5
		ELA1	44.4			ELA1	26.3
		ELA2	51.4			ELA2	33.5
		ELA3	149.0			ELA3	110.2
4	Barjiwang	Base	23.8	22	Maranthana	Base	56.7
		ELA1	24.1			ELA1	60.2
		ELA2	27.0			ELA2	74.0
		ELA3	92.6			ELA3	228.4
5	Belbas	Base	40.9	23	Markhawang	Base	31.7
		ELA1	43.9			ELA1	32.8
		ELA2	61.7			ELA2	36.4
		ELA3	212.0			ELA3	96.3
6	Bhingri	Base	71.3	24	Narikot	Base	16.0
		ELA1	72.2			ELA1	17.6
		ELA2	77.1			ELA2	27.0
		ELA3	204.4			ELA3	111.8
7	Bijayanagar	Base	35.4	25	Nayagaon	Base	73.1
		ELA1	36.8			ELA1	73.3
		ELA2	44.5			ELA2	75.0
		ELA3	146.1			ELA3	133.9
8	Bijuwar	Base	114.1	26	Phopli	Base	53.2
		ELA1	117.3			ELA1	58.3
		ELA2	129.2			ELA2	79.0
		ELA3	289.6			ELA3	244.5
9	Chuja	Base	17.3	27	Puja	Base	34.3
		ELA1	23.1			ELA1	38.3
		ELA2	47.5			ELA2	57.5
		ELA3	199.5			ELA3	190.7

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
10	Dangwang	Base	21.2	28	Khalanga	Base	136.0
		ELA1	24.0			ELA1	137.9
		ELA2	35.6			ELA2	144.7
		ELA3	134.8			ELA3	258.7
11	Dharampani	Base	21.8	29	Rajbara	Base	17.1
		ELA1	23.4			ELA1	20.6
		ELA2	29.9			ELA2	28.8
		ELA3	111.3			ELA3	144.4
12	Dharmawoti	Base	104.6	30	Saari	Base	28.7
		ELA1	106.5			ELA1	29.6
		ELA2	113.2			ELA2	37.1
		ELA3	187.0			ELA3	132.7
13	Udayapurkot	Base	12.5	31	Swargadwari Khaal	Base	20.6
		ELA1	14.9			ELA1	22.7
		ELA2	24.0			ELA2	36.1
		ELA3	96.9			ELA3	111.8
14	Dhuwang	Base	12.0	32	Tiram	Base	56.7
		ELA1	13.9			ELA1	58.5
		ELA2	26.3			ELA2	67.9
		ELA3	114.0			ELA3	182.1
15	Dhungegadhi	Base	33.6	33	Turwang	Base	56.8
		ELA1	35.2			ELA1	57.5
		ELA2	46.2			ELA2	63.1
		ELA3	128.1			ELA3	149.7
16	Gothiwang	Base	24.1	34	Tusara	Base	47.7
		ELA1	25.5			ELA1	49.3
		ELA2	42.9			ELA2	58.4
		ELA3	186.7			ELA3	187.0
17	Hansapur	Base	8.2	35	Bangemaroth	Base	38.5
		ELA1	10.8			ELA1	40.0
		ELA2	25.4			ELA2	57.6
		ELA3	115.5			ELA3	207.7
18	Jumrikanda	Base	12.5				
		ELA1	15.0				
		ELA2	32.2				
		ELA3	140.9				

ELA = energy access case, NRs = Nepalese Rupees, S.No. = serial number.
Source: Authors.

Table A48: Total Electricity Supply Cost in 2022 for Completely Electrified Village Development Committees (Grid)

(million NRs)

S.No.	Village Development Committee	Case	Technology Grid
1	Bijuli	Base	45.2
		ELA1	45.2
		ELA2	48.4
		ELA3	145.1
2	Dakhakwadi	Base	80.6
		ELA1	80.6
		ELA2	85.3
		ELA3	221.7
3	Khaira	Base	39.2
		ELA1	39.2
		ELA2	43.7
		ELA3	143.0
4	Okherkot	Base	62.6
		ELA1	62.7
		ELA2	67.5
		ELA3	190.5
5	Pakala	Base	32.3
		ELA1	32.3
		ELA2	37.2
		ELA3	144.7
6	Ramdi	Base	14.9
		ELA1	14.9
		ELA2	19.1
		ELA3	81.1
7	Raspurkot	Base	34.1
		ELA1	34.2
		ELA2	38.3
		ELA3	121.5

ELA = energy access case, NRs = Nepalese Rupees, S.No. = serial number.
Source: Authors.

Table A49: Summary of Total Electricity Supply Cost in 2022
(million NRs)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified Village Development Committees (Off-grid)					
Base	17.9	16.7	39.0	0.0	73.5
ELA1	4.7	25.2	41.1	107.3	178.4
ELA2	4.8	0.0	25.8	325.6	356.1
ELA3	0.0	0.0	0.0	950.3	950.3
Partially Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	1,397.8	1,397.8
ELA1	0.0	0.0	0.0	1,471.7	1,471.7
ELA2	0.0	0.0	0.0	1,864.8	1,864.8
ELA3	0.0	0.0	0.0	5,653.2	5,653.2
Completely Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	308.9	308.9
ELA1	0.0	0.0	0.0	309.1	309.1
ELA2	0.0	0.0	0.0	339.6	339.6
ELA3	0.0	0.0	0.0	1,047.6	1,047.6
Total (ALL)					
Base	17.9	16.7	39.0	1,706.7	1,780.2
ELA1	4.7	25.2	41.1	1,888.1	1,959.2
ELA2	4.8	0.0	25.8	2,530.0	2,560.5
ELA3	0.0	0.0	0.0	7,651.1	7,651.1

BMG = biomass based power plant, ELA = energy access case, NRs = Nepalese Rupees, PV = solar photovoltaic.
Source: Authors.

Appendix 26

Total Electricity Supply Cost by Village Development Committee in 2030 Considering Light Emitting Diode Equivalent Lamps for Lighting

Table A50: Total Electricity Supply Cost in 2030 for Partially Electrified Village Development Committees (Off-grid)

(million NRs)

Village Development Committee	Case	Technology				
		PV	Microhydro	BMG	Grid	Total
Arkha	Base	0.0	11.1	0.0	0.0	11.1
	ELA1	19.5	18.5	52.4	0.0	90.5
	ELA2	0.0	0.0	0.0	96.8	96.8
	ELA3	0.0	0.0	0.0	111.8	111.8
Damri	Base	0.0	7.0	0.0	0.0	7.0
	ELA1	0.0	0.0	0.0	45.5	45.5
	ELA2	0.0	0.0	0.0	167.6	167.6
	ELA3	0.0	0.0	0.0	251.3	251.3
Khawang	Base	0.0	0.0	13.7	0.0	13.7
	ELA1	0.0	0.0	0.0	56.6	56.6
	ELA2	0.0	0.0	0.0	220.5	220.5
	ELA3	0.0	0.0	0.0	332.1	332.1
Khung	Base	12.4	0.0	0.0	0.0	12.4
	ELA1	0.0	0.0	0.0	49.0	49.0
	ELA2	0.0	0.0	0.0	142.5	142.5
	ELA3	0.0	0.0	0.0	206.2	206.2
Kochiwang	Base	7.7	0.0	0.0	0.0	7.7
	ELA1	0.0	0.0	0.0	43.5	43.5
	ELA2	0.0	0.0	0.0	144.4	144.4
	ELA3	0.0	0.0	0.0	213.1	213.1
Ligha	Base	3.6	0.0	0.0	0.0	3.6
	ELA1	0.0	0.0	34.5	0.0	34.5
	ELA2	0.0	0.0	0.0	133.9	133.9
	ELA3	0.0	0.0	0.0	191.1	191.1
Syauliwang	Base	0.0	0.0	32.9	0.0	32.9
	ELA1	0.0	0.0	0.0	81.4	81.4
	ELA2	0.0	0.0	0.0	229.2	229.2
	ELA3	0.0	0.0	0.0	332.3	332.3

BMG = biomass based power plant, ELA = energy access case, NRs = Nepalese Rupees, PV = solar photovoltaic.
Source: Authors.

Table A51: Total Electricity Supply Cost in 2030 for Partially Electrified Village Development Committees (Grid)

(million NRs)

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
1	Badikot	Base	66.0	19	Liwang	Base	23.5
		ELA1	79.7			ELA1	39.0
		ELA2	216.5			ELA2	168.9
		ELA3	325.0			ELA3	259.6
2	Bangesal	Base	28.6	20	Lung	Base	34.5
		ELA1	49.2			ELA1	49.8
		ELA2	183.8			ELA2	183.2
		ELA3	281.5			ELA3	282.3
3	Baraula	Base	62.1	21	Majhakot	Base	34.5
		ELA1	68.4			ELA1	43.7
		ELA2	176.8			ELA2	126.0
		ELA3	257.1			ELA3	193.9
4	Barjiwang	Base	34.3	22	Maranthana	Base	80.7
		ELA1	36.5			ELA1	96.9
		ELA2	106.1			ELA2	261.5
		ELA3	164.1			ELA3	403.1
5	Belbas	Base	57.3	23	Markhawang	Base	45.5
		ELA1	76.8			ELA1	50.7
		ELA2	246.1			ELA2	111.4
		ELA3	369.1			ELA3	169.0
6	Bhingri	Base	103.2	24	Narikot	Base	22.0
		ELA1	108.0			ELA1	32.8
		ELA2	236.6			ELA2	127.9
		ELA3	360.3			ELA3	196.5
7	Bijayanagar	Base	50.8	25	Nayagaon	Base	105.9
		ELA1	58.8			ELA1	107.3
		ELA2	167.5			ELA2	164.2
		ELA3	258.7			ELA3	226.5
8	Bijuwar	Base	165.3	26	Phopli	Base	75.1
		ELA1	181.3			ELA1	102.4
		ELA2	334.7			ELA2	281.9
		ELA3	511.3			ELA3	428.7
9	Chuja	Base	21.0	27	Puja	Base	39.5
		ELA1	53.8			ELA1	65.6
		ELA2	227.6			ELA2	215.5
		ELA3	347.5			ELA3	321.2

continued on next page

Table *continued*

S.No.	Village Development Committee	Case	Technology Grid	S.No.	Village Development Committee	Case	Technology Grid
10	Dangwang	Base	28.3	28	Khalanga	Base	197.0
		ELA1	43.0			ELA1	206.8
		ELA2	153.9			ELA2	311.0
		ELA3	235.4			ELA3	443.5
11	Dharampani	Base	31.0	29	Rajbara	Base	18.6
		ELA1	39.3			ELA1	43.0
		ELA2	127.5			ELA2	102.4
		ELA3	196.5			ELA3	245.9
12	Dharmawoti	Base	151.3	30	Saari	Base	41.0
		ELA1	161.1			ELA1	48.6
		ELA2	224.0			ELA2	152.0
		ELA3	321.4			ELA3	234.7
13	Udayapurkot	Base	16.6	31	Swargadwari Khaal	Base	23.8
		ELA1	29.3			ELA1	41.0
		ELA2	110.7			ELA2	126.3
		ELA3	169.4			ELA3	188.2
14	Dhuwang	Base	15.4	32	Tiram	Base	81.3
		ELA1	20.7			ELA1	91.2
		ELA2	130.1			ELA2	213.7
		ELA3	199.0			ELA3	316.3
15	Dhungegadhi	Base	46.5	33	Turwang	Base	82.2
		ELA1	54.6			ELA1	87.5
		ELA2	149.3			ELA2	175.4
		ELA3	220.5			ELA3	261.8
16	Gothiwang	Base	33.8	34	Tusara	Base	68.9
		ELA1	40.6			ELA1	77.6
		ELA2	213.8			ELA2	216.4
		ELA3	329.6			ELA3	329.8
17	Hansapur	Base	10.3	35	Bangemaroth	Base	54.7
		ELA1	23.1			ELA1	72.5
		ELA2	132.0			ELA2	239.7
		ELA3	202.5			ELA3	365.4
18	Jumrikanda	Base	17.2				
		ELA1	29.4				
		ELA2	161.3				
		ELA3	248.7				

ELA = energy access case, NRs = Nepalese Rupees, S.No. = number.
Source: Authors.

Table A52: Total Electricity Supply Cost in 2030 for Completely Electrified Village Development Committees (Grid)
(million NRs)

S.No.	Village Development Committee Name	Case	Technology Grid
1	Bijuli	Base	65.6
		ELA1	65.6
		ELA2	168.5
		ELA3	255.7
2	Dakhakwadi	Base	117.0
		ELA1	117.0
		ELA2	254.3
		ELA3	393.8
3	Khaira	Base	65.9
		ELA1	65.9
		ELA2	165.4
		ELA3	252.6
4	Okherkot	Base	90.9
		ELA1	93.3
		ELA2	222.1
		ELA3	334.6
5	Pakala	Base	46.9
		ELA1	48.5
		ELA2	166.0
		ELA3	257.1
6	Ramdi	Base	21.6
		ELA1	23.8
		ELA2	93.1
		ELA3	144.2
7	Raspurkot	Base	49.5
		ELA1	51.7
		ELA2	140.6
		ELA3	214.7

ELA = energy access case, NRs = Nepalese Rupees, S.No. = number.
Source: Authors.

Table A53: Summary of Total Electricity Supply Cost in 2030
(million NRs)

Electrification Type	Technology				
	PV	Microhydro	BMG	Grid	Total
Partially Electrified Village Development Committees (Off-grid)					
Base	23.6	18.1	46.7	0.0	88.4
ELA1	19.5	18.5	87.0	276.0	401.1
ELA2	0.0	0.0	0.0	1,134.8	1,134.8
ELA3	0.0	0.0	0.0	1,637.9	1,637.9
Partially Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	1,967.9	1,967.9
ELA1	0.0	0.0	0.0	2,410.1	2,410.1
ELA2	0.0	0.0	0.0	6,475.7	6,475.7
ELA3	0.0	0.0	0.0	9,864.3	9,864.3
Completely Electrified Village Development Committees (Grid)					
Base	0.0	0.0	0.0	457.5	457.5
ELA1	0.0	0.0	0.0	465.9	465.9
ELA2	0.0	0.0	0.0	1,210.1	1,210.1
ELA3	0.0	0.0	0.0	1,852.7	1,852.7
Total (ALL)					
Base	23.6	18.1	46.7	2,425.4	2,513.8
ELA1	19.5	18.5	87.0	3,152.0	3,277.0
ELA2	0.0	0.0	0.0	8,820.7	8,820.7
ELA3	0.0	0.0	0.0	13,354.9	13,354.9

BMG = biomass based power plant, ELA = energy access case, NRs = Nepalese Rupees, PV = solar photovoltaic.
Source: Authors.

Appendix 27

Table A54: Emission Factors by Fuel Used for Lighting

Fuel Type	PM (mg/kgoe)	CO (mg/kgoe)	NO_X (mg/kgoe)	BC (mg/kgoe)	CO_2 (gm/kgoe)
Biogas[a]	1,099.0	7.8	3.7	0.0	6.2
LPG[a]	475.0	3.4	1.6	0.0	2.7
Kerosene[b]	8.2	0.5	1.0	67.8	2.8
Candle[c]	0.9	0.3	1.1	0.0	0.0
Jharro[a]	14.3	150.5	1.5	0.3	2.0

BC =black carbon, CO = carbon monoxide, CO_2 = carbon dioxide, gm = gram, kgoe = kilogram of oil equivalent, LPG = liquefied petroleum gas, mg = milligram, NO_x = nitrous oxide, PM = particulate matter.
Source: [a] Shrestha et al. (2013); [b] Tedsen E. (2013); [c] Ongwandee and Pipithakul (2010).

Appendix 28

Table A55: Emission Factors by Cooking Stoves

kg/kgoe

Technology Type	PM_{10}	SO_2	CO	NO_X	BC
Traditional Cookstove	0.02776	0.0007	0.2586	0.0024	0.0022
Improved Cookstove	0.00897	0.00002	0.1987	0.0003	0.0005
Biogas	0.00054	0.0007	0.0078	0.0037	0.00002
LPG	0.00023	0.0003	0.0033	0.0015	0.00001

BC =black carbon, CO = carbon monoxide, kg = kilogram, kgoe = kilogram of oil equivalent, LPG = liquefied petroleum gas, NO_x = nitrous oxide, PM = particulate matter, SO_2 = sulfur dioxide.
Source: Derived based on Shrestha et al. (2013) and WECS (2010).

Appendix 29

Indoor Air Pollutants and CO_2 Emissions from Nonelectric Source of Lighting Under the Base Case

Table A56: PM_{10} Emissions Under the Base Case
(kg)

Village Development Committee	2014	2017	2022	2030
Badikot	56.2	59.2	67.9	89.4
Bangemaroth	10.3	10.8	12.4	16.3
Bangesal	32.9	34.6	39.7	52.3
Baraula	33.2	34.9	40.1	52.8
Barjiwang	7.8	8.2	9.4	12.4
Belbas	7.2	7.6	8.7	11.4
Bhingri	550.3	579.4	664.8	875.1
Bijayanagar	31.2	32.9	37.7	49.6
Bijuli	32.9	34.6	39.7	52.3
Bijuwar	47.5	50.1	57.4	75.6
Chuja	77.4	81.5	93.5	123.1
Dakhakwadi	7.1	7.5	8.6	11.3
Damri	803.7	846.3	971.0	1,278.2
Dangwang	172.6	181.7	208.5	274.4
Dharampani	53.7	56.6	64.9	85.4
Dharmawoti	27.1	28.6	32.8	43.2
Dhuwang	921.1	969.8	1,112.7	1,464.8
Gothiwang	103.9	109.4	125.5	165.2
Hansapur	24.4	25.7	29.5	38.8
Jumrikanda	639.2	673.1	772.2	1,016.6
Khaira	9.6	10.1	11.6	15.2
Khalanga	33.5	35.3	40.5	53.3
Khawang	1.7	1.8	2.1	2.7
Kochiwang	333.7	351.3	403.1	530.6
Ligha	3.0	3.1	3.6	4.7
Liwang	3.2	3.3	3.8	5.0
Lung	13.6	14.3	16.4	21.6
Majhakot	24.2	25.4	29.2	38.4
Maranthana	125.0	131.6	151.0	198.8
Markawang	39.4	41.5	47.6	62.7
Narikot	7.4	7.8	8.9	11.8
Nayagaon	10.7	11.2	12.9	17.0
Okherkot	24.7	26.0	29.8	39.3

continued on next page

Table *continued*

Village Development Committee	2014	2017	2022	2030
Pakala	12.8	13.5	15.5	20.4
Phopli	18.1	19.1	21.9	28.8
Rajbara	5.6	5.9	6.8	8.9
Ramdi	7.9	8.4	9.6	12.6
Raspurkot	10.5	11.1	12.7	16.8
Saari	10.6	11.2	12.8	16.8
Swargadwari Khaal	11.7	12.4	14.2	18.7
Syauliwang	0.6	0.7	0.8	1.0
Tiram	4.0	4.2	4.9	6.4
Turwang	28.1	29.6	34.0	44.7
Tusara	63.9	67.2	77.2	101.6
Udayapurkot	157.7	166.0	190.5	250.8
Total Pyuthan	**4,601.0**	**4,844.4**	**5,558.2**	**7,317.0**

kg = kilogram, PM = particulate matter.
Source: Authors.

Table A57: CO Emissions Under the Base Case
(kg)

Village Development Committee	2014	2017	2022	2030
Badikot	46.3	48.8	56.0	73.7
Bangemart	9.0	9.5	10.9	14.3
Bangesal	279.4	294.2	337.5	444.3
Baraula	45.6	48.0	55.0	72.5
Barjiwang	9.9	10.4	12.0	15.8
Belbas	5.9	6.2	7.1	9.3
Bhingri	851.6	896.6	1,028.8	1,354.3
Bijayanagar	50.8	53.5	61.4	80.8
Bijuli	26.9	28.3	32.5	42.7
Bijuwar	38.9	40.9	46.9	61.8
Chuja	64.4	67.8	77.8	102.4
Dakhakwadi	5.8	6.1	7.0	9.2
Damri	1,290.5	1,358.7	1,559.0	2,052.2
Dangwang	226.6	238.6	273.7	360.3
Dharampani	43.9	46.2	53.1	69.9
Dharmawoti	22.2	23.4	26.8	35.3
Dhuwang	1,451.2	1,528.0	1,753.2	2,307.9
Gothiwang	156.0	164.2	188.4	248.1
Hansapur	177.8	187.2	214.7	282.7
Jumrikanda	1,057.2	1,113.1	1,277.1	1,681.2
Khaira	7.8	8.2	9.5	12.4
Khalanga	27.4	28.9	33.1	43.6
Khawang	14.6	15.4	17.6	23.2
Kochiwang	536.1	564.5	647.6	852.6
Ligha	9.1	9.6	11.0	14.5
Liwang	2.8	3.0	3.4	4.5
Lung	46.9	49.4	56.7	74.6
Majhakot	36.1	38.0	43.6	57.4
Maranthana	166.9	175.7	201.6	265.4
Markawang	78.9	83.0	95.3	125.4
Narikot	6.0	6.4	7.3	9.6
Nayagaon	8.7	9.2	10.6	13.9
Okherkot	20.2	21.3	24.4	32.1
Pakala	10.5	11.0	12.7	16.7
Phopli	28.7	30.2	34.6	45.6
Rajbara	47.7	50.2	57.6	75.8
Ramdi	6.5	6.8	7.8	10.3
Raspurkot	8.6	9.1	10.4	13.7

continued on next page

Table *continued*

Village Development Committee	2014	2017	2022	2030
Saari	8.7	9.1	10.5	13.8
Swargadwari Khaal	51.0	53.7	61.7	81.2
Syauliwang	5.3	5.6	6.4	8.4
Tiram	3.5	3.6	4.2	5.5
Turwang	24.3	25.6	29.4	38.7
Tusara	68.4	72.1	82.7	108.8
Udayapurkot	272.9	287.4	329.7	434.1
Total Pyuthan	**7,357.5**	**7,746.7**	**8,888.2**	**11,700.6**

CO = carbon monoxide, kg = kilogram.
Source: Authors.

Table A58: NO_x Emissions under the Base Case
(kg)

Village Development Committee	2014	2017	2022	2030
Badikot	6.9	7.3	8.3	11.0
Bangemart	1.2	1.3	1.5	2.0
Bangesal	41.6	43.8	50.2	66.1
Baraula	3.9	4.1	4.7	6.2
Barjiwang	1.2	1.2	1.4	1.8
Belbas	0.9	0.9	1.1	1.4
Bhingri	60.0	63.1	72.4	95.4
Bijayanagar	5.6	5.9	6.8	8.9
Bijuli	4.0	4.2	4.8	6.4
Bijuwar	5.8	6.1	7.0	9.2
Chuja	9.6	10.1	11.6	15.2
Dakhakwadi	0.9	0.9	1.0	1.4
Damri	90.6	95.4	109.5	144.1
Dangwang	20.0	21.1	24.2	31.8
Dharampani	6.5	6.9	7.9	10.4
Dharmawoti	3.3	3.5	4.0	5.3
Dhuwang	100.4	105.7	121.3	159.7
Gothiwang	11.4	12.0	13.8	18.1
Hansapur	25.9	27.3	31.3	41.2
Jumrikanda	82.8	87.2	100.0	131.6
Khaira	1.2	1.2	1.4	1.9
Khalanga	4.1	4.3	4.9	6.5
Khawang	2.2	2.3	2.6	3.5
Kochiwang	37.5	39.4	45.2	59.6
Ligha	1.4	1.4	1.6	2.2
Liwang	0.4	0.4	0.5	0.7
Lung	7.0	7.4	8.4	11.1
Majhakot	4.4	4.6	5.3	7.0
Maranthana	24.8	26.2	30.0	39.5
Markawang	7.2	7.6	8.7	11.4
Narikot	0.9	0.9	1.1	1.4
Nayagaon	1.3	1.4	1.6	2.1
Okherkot	3.0	3.2	3.6	4.8
Pakala	1.6	1.6	1.9	2.5
Phopli	2.0	2.1	2.4	3.1
Rajbara	7.1	7.5	8.6	11.3
Ramdi	1.0	1.0	1.2	1.5
Raspurkot	1.3	1.4	1.5	2.0

continued on next page

Table *continued*

Village Development Committee	2014	2017	2022	2030
Saari	1.3	1.4	1.6	2.1
Swargadwari Khaal	6.7	7.1	8.1	10.7
Syauliwang	0.8	0.8	1.0	1.3
Tiram	0.5	0.5	0.6	0.8
Turwang	3.4	3.6	4.1	5.4
Tusara	10.2	10.7	12.3	16.2
Udayapurkot	21.7	22.9	26.2	34.5
Total Pyuthan	**635.2**	**668.8**	**767.3**	**1,010.1**

kg = kilogram, NO = nitrous oxide.
Source: Authors.

Table A59: BC Emissions Under The Base Case
(kg)

Village Development Committee	2014	2017	2022	2030
Badikot	470.2	495.1	568.0	747.7
Bangemart	83.7	88.1	101.1	133.1
Bangesal	2,835.7	2,985.7	3,425.6	4,509.6
Baraula	238.5	251.2	288.2	379.4
Barjiwang	76.3	80.3	92.1	121.3
Belbas	59.6	62.8	72.0	94.8
Bhingri	3,492.1	3,676.8	4,218.6	5,553.4
Bijayanagar	365.7	385.1	441.8	581.6
Bijuli	272.7	287.1	329.5	433.7
Bijuwar	394.4	415.3	476.5	627.2
Chuja	653.8	688.3	789.8	1,039.7
Dakhakwadi	58.8	62.0	71.1	93.6
Damri	5,272.2	5,551.0	6,369.0	8,384.3
Dangwang	1,242.7	1,308.4	1501.2	1,976.2
Dharampani	445.8	469.4	538.5	708.9
Dharmawoti	225.1	237.0	272.0	358.0
Dhuwang	5,814.2	6,121.8	7,023.9	9,246.3
Gothiwang	671.7	707.2	811.4	1,068.2
Hansapur	1,762.3	1,855.5	2,129.0	2,802.6
Jumrikanda	4,978.1	5,241.4	6013.8	7,916.6
Khaira	79.4	83.6	96.0	126.3
Khalanga	278.3	293.0	336.2	442.6
Khawang	148.3	156.1	179.1	235.8
Kochiwang	2,175.7	2,290.8	2,628.3	3,460.0
Ligha	92.3	97.2	111.6	146.9
Liwang	28.6	30.2	34.6	45.6
Lung	476.0	501.2	575.0	757.0
Majhakot	292.0	307.4	352.7	464.3
Maranthana	1,693.5	1,783.1	2,045.8	2,693.2
Markawang	449.8	473.6	543.4	715.3
Narikot	61.4	64.6	74.1	97.6
Nayagaon	88.6	93.3	107.1	141.0
Okherkot	204.9	215.7	247.5	325.8
Pakala	106.4	112.0	128.5	169.2
Phopli	113.2	119.2	136.7	180.0
Rajbara	484.0	509.6	584.6	769.6
Ramdi	65.9	69.3	79.6	104.7
Raspurkot	87.5	92.1	105.6	139.1

continued on next page

Table *continued*

Village Development Committee	2014	2017	2022	2030
Saari	87.9	92.6	106.2	139.8
Swargadwari Khaal	448.8	472.5	542.1	713.7
Syauliwang	53.9	56.8	65.1	85.8
Tiram	35.2	37.0	42.5	55.9
Turwang	229.7	241.8	277.4	365.2
Tusara	694.6	731.4	839.1	1,104.6
Udayapurkot	1,311.9	1,381.3	1,584.9	2,086.4
Total Pyuthan	**39,201.1**	**41,274.8**	**47,356.8**	**62,341.5**

BC = black carbon, kg = kilogram.
Source: Authors.

Table A60: CO_2 Emissions Under the Base Case
(in kg)

Village Development Committee	2014	2017	2022	2030
Badikot	19,695.6	20,737.5	23,793.3	31,321.9
Bangemart	3,401.5	3,581.4	4,109.2	5,409.4
Bangesal	165,678.8	174,442.9	20,0147.8	263,478.6
Baraula	7,420.3	7,812.9	8,964.1	11,800.6
Barjiwang	3,196.2	3,365.2	3,861.1	5,082.8
Belbas	2,487.5	2,619.1	3,005.1	3,955.9
Bhingri	83,225.5	87,628.0	100,540.3	132,353.3
Bijayanagar	15,993.5	16,839.5	19,320.9	25,434.4
Bijuli	11,381.2	11,983.3	13,749.1	18,099.6
Bijuwar	16,459.7	17,330.4	19,884.1	26,175.9
Chuja	27,493.8	28,948.2	33,213.8	43,723.4
Dakhakwadi	2,455.9	2,585.8	2,966.8	3,905.6
Damri	129,397.0	136,242.0	156,317.7	205,779.9
Dangwang	39,613.6	41,709.1	47,855.1	62,997.5
Dharampani	18,604.0	19,588.1	22,474.5	29,585.8
Dharmawoti	9,395.1	9,892.0	11,349.7	14,940.9
Dhuwang	135,017.5	142,159.8	163,107.5	214,718.1
Gothiwang	16,970.7	17,868.5	20,501.4	26,988.5
Hansapur	102,014.9	107,411.4	123,238.9	162,234.2
Jumrikanda	154,085.3	162,236.1	186,142.2	245,041.5
Khaira	3,314.8	3,490.1	4,004.4	5,271.5
Khalanga	11,614.1	12,228.5	14,030.4	18,469.9
Khawang	8,662.1	9,120.3	10,464.2	13,775.3
Kochiwang	52,794.8	55,587.6	63,778.6	83,959.5
Ligha	5,105.3	5,375.4	6,167.4	8,118.9
Liwang	1,239.6	1,305.2	1,497.5	1,971.4
Lung	26,579.2	27,985.2	32,108.9	42,268.8
Majhakot	13,258.6	13,960.0	16,017.0	21,085.2
Maranthana	82,798.7	87,178.6	100,024.7	131,674.6
Markawang	18,131.7	19,090.9	21,904.0	28,834.8
Narikot	2,560.4	2,695.9	3093.1	4,071.9
Nayagaon	3,699.2	3,894.9	4468.8	5,882.9
Okherkot	8,550.9	9,003.2	10,329.9	13,598.4
Pakala	4,439.1	4,673.9	5,362.6	7,059.4
Phopli	2,565.4	2,701.1	3,099.1	4,079.7
Rajbara	28,275.9	29,771.6	34,158.6	44,967.0
Ramdi	2,748.2	2,893.6	3,320.0	4,370.5
Raspurkot	3,649.6	3,842.7	4,408.9	5,804.0

continued on next page

Table *continued*

Village Development Committee	2014	2017	2022	2030
Saari	3,668.4	3,862.4	4,431.6	5,833.8
Swargadwari Khaal	24,643.6	25,947.2	29,770.6	39,190.7
Syauliwang	3,150.5	3,317.1	3,805.9	5,010.2
Tiram	1,501.5	1,580.9	1,813.9	2,387.8
Turwang	9,373.0	9,868.8	11,323.0	14,905.9
Tusara	32,031.6	33,726.0	38,695.6	50,939.7
Udayapurkot	42,736.1	44,996.8	51,627.3	67,963.2
Total	**1,361,080.1**	**1,433,079.1**	**1,644,248.7**	**2,164,522.9**

CO_2 = carbon dioxide, kg = kilogram.
Source: Authors.

Sustainable Energy Access Planning
A Case Study

Ensuring access to affordable, reliable, and sustainable energy is one of the Sustainable Development Goals of the United Nations. Sustainable energy access planning (SEAP) plays a vital role when it comes to ensuring energy access for poor households particularly in Nepal's Pyuthan district. SEAP identifies the needed resources and investments for sustainable energy in the district. This case study, supported by the Asian Development Bank, presents the application of a SEAP framework for developing cost-effective energy plans for Pyuthan district. It also highlights the benefits of access to cleaner energy in terms of social well-being, reduction in the emission of local pollutants and greenhouse gas, and reducing energy inequality.

About the Asian Development Bank

ADB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. Established in 1966, it is owned by 67 members—48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

ADB

ASIAN DEVELOPMENT BANK
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org