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Renewable Energy and other Strategies for Mitigating the Energy Crisis in Nepal

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in fulfilment of the requirements
for the Degree of Doctor of Philosophy
College of Engineering

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Declaration / Statements

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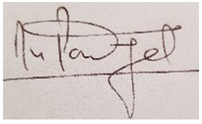

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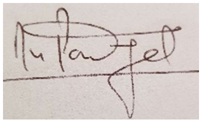

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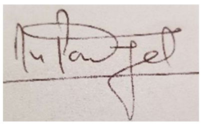

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Abstract

The overarching aim of this research is to carefully review Nepal's energy scenario from the technical and socio-economic perspective in order to determine the optimal near-term as well as long-term strategies to overcome the energy crisis. Renewable energy sources are pivotal to this research due to the abundant availability of these resources in Nepal. The long-term energy supply and demand forecast for Nepal over the next 30 years was obtained in Long-Range Energy Planning (LEAP) software. Other quantitative results were obtained using software packages, including PVsyst, Meteo, and HOMER. In many other cases, energy data collected from open literature, government and regulator reports were analysed. There are also several case studies considered in the thesis.

The PV rooftop energy systems for Nepalese town and rural households can minimise the energy trade deficit with neighbouring India, enhance energy security, and improve local employment opportunities as well as improve utilisation of the local resources. In particular, a 3kW PV rooftop system was designed and simulated in MATLAB/Simulink, and the corresponding PV and IV curves were obtained, including analysing the effects of environmental temperature and solar irradiation. The design was followed by techno-economic feasibility, assuming typical households in the Kathmandu valley. The study outcome is that the PV system for a residential building in Kathmandu is economically feasible, and it can provide nearly 6,000 kWh/year of energy.

The potential energy efficiency improvements in the cement industry were studied using data collected directly at one of the major cement plants in Nepal. The cement production processes are very energy-intensive, and they have not changed for years. Since the energy costs in Nepal are abnormally high, they represent over half of the cement production costs. It creates substantial pressure to conserve energy and materials while reducing the carbon footprint. Other important factors that must be considered apart from energy issues are production efficiency and sustainability, and how to exploit innovations and encourage investments.

The chaotic energy situation in Nepal is exacerbated by rather significant electricity distribution losses and frequent cases of electricity theft. These two issues are significant contributors to a widening gap between energy supply and demand.

Other such issues include overpriced and delayed hydropower projects, insufficient and outdated infrastructure, lack of energy conservation, deficient energy management, inadequately low efficiency of equipment, unsustainable energy pricing strategies, indecisive energy market regulations, reliance on energy imports, and especially inadequate exploitation of vast amounts of renewable energy resources. All these factors are also adversely affecting the geopolitical, environmental, and socio-economic situation in Nepal. The developments in the energy sector in Nepal are also discussed in light of the relevant energy policies which have been adopted by the government over the past two decades.

The results presented in the thesis can be used by the government regulators and energy policy planners, and possibly also by the public and private energy companies. It should be noted that the findings and observations in the thesis are also applicable to other countries with a similar development status and geography as Nepal.

Keywords

Renewable energy, Energy crisis, Energy planning, Rooftop PV system, Techno-economic feasibility, Energy Efficiency, Sustainable production, System loss, and Electricity theft.

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List of Acronyms

ADB	Asian Development Bank
ADB/N	Asian Development Bank/Nepal
$CaCO_3$	Calcium Carbonate
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSI	Cement Sustainability Initiative
CUF	Capacity Utilisation Factor
DoED	Department of Energy Development
DTU	Technical University of Denmark
EII	Energy Intensity Index
EMS	Energy Management System
FMCGs	Food Manufacturing Company Goods
GDP	Gross Domestic Production
GHG	Green House Gas
GHG	Green House Gas
GIZ	German Agency for International Cooperation
GJ	Giga Joule – 10^9 (billion) Joules
HCIL	Hetauda Cement Industries Limited
HDI	Human Development Index
HOMER	Hybrid Optimization of Multiple Electric Renewables
IEA	International Energy Agency
INPS	Integrated Nepal Power System
IPP	Independent Power Producer
KWh	Kilo Watt-hour
LCoE	Life Cost of Energy
LDC	Least Development Country
LEAP	Long-Range Energy Alternative and Planning
LPG	Liquefied Petroleum Gas
MDG	Millennium Development Goal
MJ	Million Joule – 10^6 (million Joules)
MT	Metric Ton

NEA	Nepal Electricity Authority
NEEP	Nepal Energy Efficiency Program
NIDC	Nepal Industrial Development Corporation
NOC	Nepal Oil Corporation
NO	Nitrogen oxide
NPC	National Planning Commission
NWTF	National Wind Task Force
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REN21	Renewable Energy Policy Network for the 21st Century
RET	Renewable Energy Technology
ROR	Run Off River
SAARC	South Asian Association for Regional Cooperation
SASEC	South Asia Sub-Regional Economic Cooperation
SDG	Sustainable Development Goal
SE4ALL	Sustainable Energy for All
SO_2	Sulphur dioxide
SO	Sulphur oxide
T&D	Transmission and Distribution
TCN	Timber Corporation of Nepal
Toe	Ton of oil equivalent
TPD	Ton per Day
UCIL	Udayapur Cement Industries Limited
UMN	United Mission to Nepal
UNDP	United Nation Development Bank
WECS	Water and Energy Commission Secretariat

Chapter 1
Introduction

This Chapter provides a general background of this thesis. It provides a comprehensive overview of Nepal's energy sector and identifies the challenges that will need to be met to achieve the country's energy requirements. Further, it discusses the changes in the energy landscape brought about by enduring energy transition and the importance of renewable energy adaptation. It also identifies energy efficiency measures and sustainable productions along with highlighting the inefficiency in the Nepalese power system of Nepal and illustrating the path to convenient means.

The general aim of this thesis is to review the energy situation of Nepal by data analysis of the country's renewable energy resources, policies of the government and to investigate the causes and solutions of the current energy crisis. After analysing the situation, with the use of Long-Range Energy Alternative Planning System (LEAP) the future energy demands of Nepal up to 2042 is predicted. Likewise, PV design and techno-economic feasibility of Solar Photovoltaic rooftop systems in the residential building of Kathmandu has been undertaken using MATLAB/Simulink, PVsyst, Meteonorm and HOMER software. In addition, energy efficiency improvement and sustainable production of the cement industry have been investigated through the case study of UCIL, Nepal. Lastly, the impact of electricity loss on power generation in Nepal and its minimising techniques have been studied.

Furthermore, this chapter introduces the motivation and the necessity of such research, the conceptual paradigm of the study followed by the research objectives, scope, research questions and the importance of the study. It concludes with the thesis structure, which outlines the five research chapters that are related to the energy optimisation problems within the energy systems of Nepal.

1.1 Background

Energy access is the "golden thread" that weaves together human development, economic growth and environmental sustainability [1]. The agreement of 17 new Sustainable Development Goals (SDGs) in 2015, which together make up the 2030 Agenda for Sustainable Development, underlines the significance of energy to development. UN member states from 193 countries, developed and developing alike, adopted the SDGs which include, for the first time, a target to ensure access to reliable, affordable, sustainable and modern energy for all [2]. It is an essential element for the process of improvement of socio-economic prospects of any nation – the better the availability of power, the higher the level of development and vice versa [3]. The worldwide demand for electricity is regularly growing with industrial development, technological innovation, and rising urbanisation. A substantial part of the future growth in energy demands will be in developing countries, for the improvement of people's living standards [4].

Energy is available in several forms that are classified as conventional and non-conventional sources, of which, the traditional fuels are rapidly diminishing. Rapid industrialisation and economic growth in developing nations are among the main factors that have caused depletion of conventional fuels leading to severe energy crises [5],[6].There is an urgent problem for every nation to manage the demands for energy without harming the economy and the environment. Increasing energy demands, energy security and climate change mitigation pose the most prominent environmental challenges for sustainable development worldwide [7].

The energy crisis is a clear indicator that the global energy demands on the limited natural resources are becoming scarcer, while the requirements are increasingly growing. World energy utilisation has been increasing at a concerning rate since the mid-1970s[8]. The dependence on oil and other fossil fuels presents a dilemma as the sources are finite and so the energy crisis worsens. While the rates of increase in energy use have been plummeting, the industrialisation, agricultural development, and speedily rising populations of developing countries will need much more energy. Nevertheless, to match developing countries' energy use, with that of industrialised countries by 2025, would mean an increase which compared to the present world's energy use by a factor of five. The environmental ecosystems would not be able to handle this if the rises were based on non-renewable fossil fuels. The current fear of global warming and acidification of the environment seeks to avoid even a doubling-up of energy use based on the present model of energy supply.

As part of the country is located within the Himalaya Mountains, Nepal has utilised its hydro renewable energy resource since the early 1960s, with the projects slowly increasing in number and capacity to become a vital source of off-grid electricity in rural Nepal [9]. However, like many other developing countries, Nepal is experiencing considerable challenges in providing energy services to its population of 30 million people. Nepal has experienced an energy crisis for more than a decade despite significant indigenous natural resources, and this is limiting economic development. Nepal endures as one of the deprived nations globally with an estimated GDP per capita of $1,003.64 as of July 2018 [10]. According to the annual energy outlook 2018 of Nepal, from 2017 to 2050, the projected growth domestic product (GDP) grows yearly at a rate of 2 per cent, while projected energy consumption grows at 0.4per cent per year, it will then surpass its 2007 peak by 2033 [11]. Existing power plants are unable to attain full production capacity due to seasonal flow as Nepal's electricity is based on run-off-river type hydropower.

Nepalese energy consumption by this source can be categorised as traditional, commercial, and renewable. The conventional source meets the bulk of total energy consumption of 78 per cent, followed by Petro-products 12 per cent, Coal 4 per cent, Grid electric 3 per cent and renewable energy 3 per cent as illustrated in Figure 1.1. Despite the enormous hydropower potential, utilisation of hydropower accounts for only 2 per cent of total potential and the vastness of Nepal's energy supplies come from traditional sources, mainly from firewood, agricultural residue and animal residue [12].

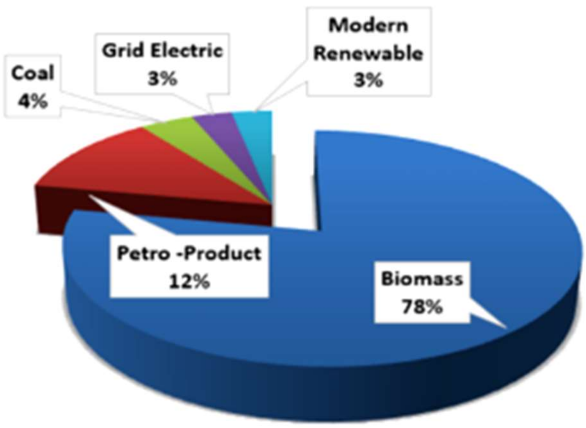

Figure 1.1 Energy review of Nepal [12]

The current level of energy consumption in Nepal combined with the poor harnessing of the indigenous renewable resources and the increasing dependence on imported fossil fuels is unsustainable and is contributing to the global Carbon dioxide

(CO_2) emissions. Inadequate domestic supplies of electricity and no proven source of petroleum, LPG and coal, mean that Nepal is highly dependent on imports. This costs Nepal considerably and bears a massive trade deficit of 36 per cent in total. CO_2 emissions per capita have recently increased, mostly because of the more substantial use of fossil fuels, particularly in the energy sector [13]**.** Furthermore, according to the report of the world's energy council Trilemma Index 2018, Nepal ranks 118 among 125 countries with a score of DDC for energy security, equity scores and environmental sustainability as illustrated in Figure 1.2 similarly, key metrics and energy profile are presented in Figure 1.3 [9].

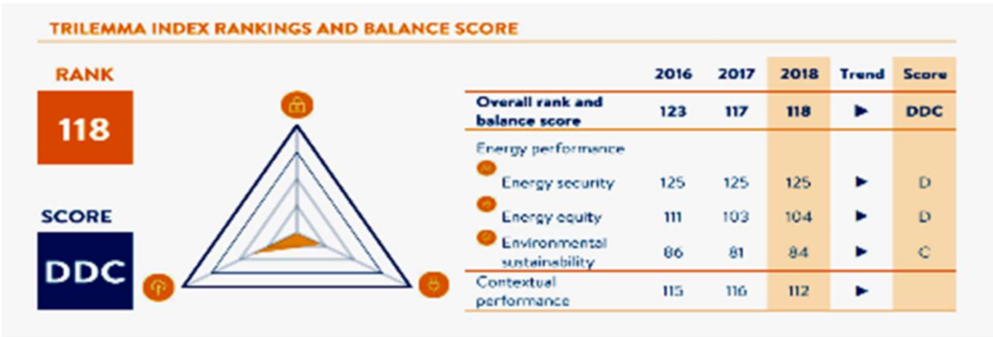

Figure 1.2 Key metrics of Nepal's energy sector [9]

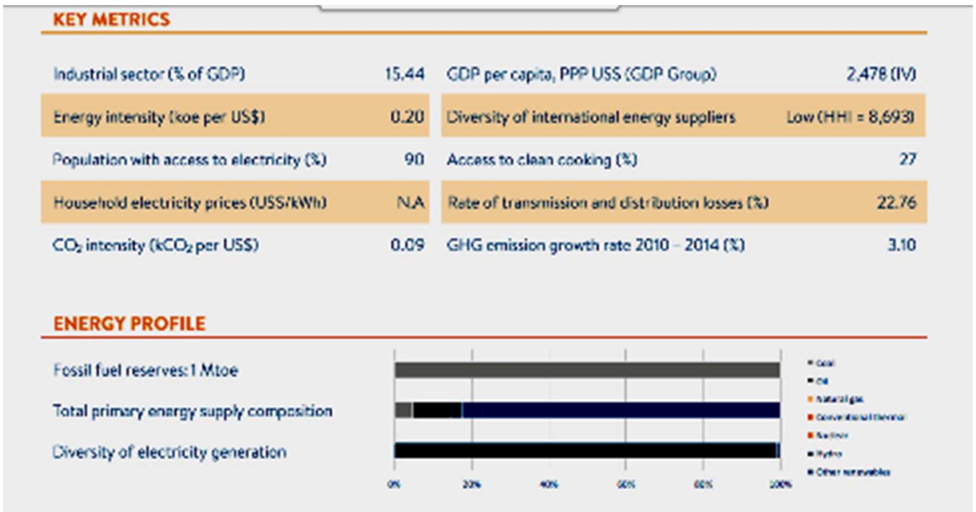

Figure 1.3 Energy profile of Nepal [9]

Nepal ranks 137th out of 147 countries in the quality of electricity supply [13]. At the moment, only 85 per cent of rural households and 90.7 per cent of the nation's total population has access to electricity [14]. However, even in urban areas, the electricity supply is inadequate for cooking purposes; Nepal spends 26 billion NPR annually for LPG. It is not surprising that Nepal has a deficient level of electricity consumption of 139.14 kWh per capita per year compared with the world average of 3,104 kWh per capita per year [15][16].

The critical challenges for Nepal are to improve access to modern energy in rural communities and to increase the electricity supply to provide reliable energy services to the population. The Government of Nepal has planned to build hydropower according to the country's demand, and the preceding program of the Government of Nepal shows the construction of medium to large hydropower projects as their priority rather than investing in the current international trend of energy mixes such as small hydro, solar PV, biomass and wind energy**.** It is the main bottleneck of Nepal's energy system where hydropower represents more than 90 per cent.

In Nepal, power generation has been centralized and then transmitted over long distances via electricity networks to local areas. There are many places where wired electricity networks are not available. In such regions, solar-powered standalone devices, SPV, can be used as solar energy can be generated and distributed locally, which can reduce the need to maintain expensive transmission lines and provide improved energy security. In Nepal, SPV can be the best alternative as Nepal has situations where electricity networks are not accessible due to power blackouts, grid infrastructure failures, economic reasons and remote geographical regions. This SPV can cover a wide range of sizes, from residential roofs with systems of a few kW to large-area commercial roofs.

To exacerbate the situation, Nepal has the highest power system loss in the region. Growing loads, increasing system loss and ageing infrastructures are stressing Nepal's Electric system and increasing the risk of widespread blackouts. The average yearly transmission loss in Nepal's electricity market is about 25.78 per cent according to NEA Annual Report 2015/16 [17]. In contrast, the average power loss among 134 countries (world average) that are in the World Bank's Database is 8.25 per cent, while Nepal has 32.21 per cent as of 2014 [18]. Notably, T&D losses in the range of 6–8 per cent of the energy generated is considered normal.

The largest energy consumers in Nepal are in the industrial, commercial and agricultural sectors. The industry sector plays a significant role in national consumption and contributes a large to enhance the national economy. The most energy-intensive industries are chemical (including refineries), metals and alloys, pulp and paper, and cement [19]. Each of these industries offers a substantial potential for energy efficiency improvements through the application of existing best practices around the world. The technical potential to reduce energy use at the global level is estimated to be 26 per cent in the pulp and paper industry, 21 per cent for iron and steel, 18 per cent in the cement industry, and 11 per cent for aluminium production [20]. Energy-intensive industries like cement are rapidly increasing in Nepal to meet the demand of about 5 million MT annually, of which 80 per cent is produced internally, and the remaining are imported from India. Reducing unnecessary energy and its economic losses by adopting proper energy efficiency measure is one of the significant challenges in Nepal. While Nepal is trying to be self-reliant in cement production, the Nepalese cement industry is affected by too high production cost. Due to the lack of energy efficiency measures and sustainable production, the cement industry faces an increasingly competitive global business environment. Cement plants can save a massive per cent of energy by applying energy efficiency measures.

Energy planning and infrastructure development in Nepal are inferior. The consistent, reliable demand projections of the energy are a vital pre-requisite for supply-side planning of the country. Given the challenges, we need to reduce energy consumption, increase renewable production, and provide solutions for matching demand and production. There are several different ways in which we can tackle the challenges.

1.2 Motivation of this study

The steady increase in energy consumption along with insufficient supply and environmental pollution, has motivated the researcher to study alternative and renewable energy solutions. Many countries in the world are continuously developing materials and methods for effectively utilizing the alternative fuel resources, energy-efficient technologies and renewable energy available in their region. However, Nepal is in the early stage. The design of the present study has, therefore, been initiated to find the solution of the deeply rooted energy crises in Nepal, as highlighted in section 1.1. Because of the power outages, the researcher has seen the society falling, the negative impacts on schools, healthcare and industries. Being an electrical engineer from Nepal, it is the solemn duty of the researcher to help and contribute towards the home country. Help not only the people, who are fellow friends and family but the country itself, which strives in renewable energy potential and enormous capability.

To understand the energy crises, the current energy scenario of the country has to be studied, the system loss has to be examined, and the potential of renewable energy has to be explored. Moreover, the energy planning for futures has to be examined as the reliable future demand projections of the fuels are vital pre-requisite requirements for supply-side planning of the country. Hence one of the motivational factors of this study is to find the answer about the total energy demand of the country along with various sectors up to the projection year 2042.

In Nepal, a high percentage of energy is lost during transmission and distribution of energy and is wastage in energy-intensive industries. These losses can be minimised without making radical changes. Hence another motivational factor of this study is to present a realistic view of the current trends of energy-efficiency improvement practices in transmission and distribution and in cement industries.

1.3 Gaps in literature

Based on the literature review, the following gaps are identified:

Comprehensive studies on the energy situation exist for many countries, including India[21], Pakistan [22], Bangladesh[23], and Nigeria[24]. However, similar studies about the energy crisis in Nepal are either very limited in their scope or outdated. For instance, they focus on specific regions in Nepal, or they have become obsolete as they do not include the current data on energy consumption and production [25]–[31]. Energy modelling with LEAP, MATLAB/Simulink, PVsyst, Meteonorm and HOMER have seldom discussed in one research at a place to mitigate the energy crisis of Nepal. It is an interest to compare the various software for this research with up to data analysis and relevant case studies.

During the site visit and interviews, the researcher found that most of the existing studies only involved in retrofitting rather than a new technology instalment for new industrial establishments. This study fills that gap by suggesting new technology-based permanent solution to enhance the efficiency of the cement industry.

1.4 Aims and objectives

One of the principal aims is to review the current energy situation in Nepal with a specific focus on renewable energy developments to assess whether it can meet Nepal's future energy demands. It also aims to understand the causes of the chaotic energy situation in Nepal, due to insufficient electricity production and lack of petroleum products and LPG (Liquefied Petroleum Gas) which fail to meet the country's energy demands. This study aims to provide an updated view of the current energy situation in Nepal. The potential and utilisation of renewable energy sources in Nepal, including the relevant energy policies and trends, are explored to respond to the ongoing energy crisis. The energy reforms that are currently underway are discussed, including changing roles of the state and the private sectors. The findings from the research can be used to identify and analyse the critical developmental issues which are impacted by inadequate energy supply.

This research also focused on a case study in the energy-intensive cement industry. This research tries to fill the gap in the literature provided and will encourage using alternative fuels and materials for a sustainable future. Moreover, the Nepalese government has limited data and acquisition capacity. Limitation of research around the international journal and no energy audit culture in the industry are significant barriers to the study of the cement industry and its sustainable production.

This thesis is further motivated as part of the recognition of the significant challenges of this approach to renewable energy transitions in order to sharpen the view of the research. The following are the aims and objectives of the thesis described the methods used for this study, drawing from renewable energy lens.

- Become familiar with the energy system of Nepal
- Identify information and data to be acquired for the research
- Analyse and interpret the data obtained from various sources
- Observe the areas of improvement, energy and material wastage
- How sustainable and efficiency measures help to optimise the cement industry
- System loss reductions and its minimisation technique
- Energy planning by LEAP model

The main research question is “What are the energy scenario of Nepal and its potential solutions? “This question cannot be answered without answering the following sub-questions that fall into five categories’:

1. What is the profile of NEA and NOC in terms of supply, demand and deficit to analyse the Renewable energy situation of Nepal?
2. What is the future supply-demand situation of Nepal up to 2042 after LEAP model analysis?
3. What is the techno-economic feasibility of Solar PV rooftop by MATLAB/ Simulink, PVsyst, Meteonorm, and HOMER system analysis in Nepal?
4. What is the situation of UCIL’s to maintain its energy efficiency measures and sustainable production?
5. What is the perception of NEA’s to prevent huge system loss?

1.5 Methodology outline

The researcher has framed a conceptual paradigm that serves as a guideline in the research process. This research shall use Figure1.4 as the operational paradigm, which shows the schematic relationship between the variables under investigation and the expected outcomes of the study.

There are five main boxes. The first box represents the review of the current energy issue in Nepal along with its supply, demand, and deficit that helps to understand Nepal’s energy scenario correctly. The second box represents the long-term forecast of Nepal’s energy supply and demand by LEAP software from 2012 to 2042. The third box represents the analysis of solar PV adaptation in the residential building in Kathmandu by MATLAB/Simulink, PVsyst, Meteonorm, and HOMER model. The fourth box represents energy efficiency measures in industry and sustainable production, with the case study of UCIL. Lastly, the fifth box represents the impacts of electricity loss on power generation (Technical and Non-Technical) and the reduction measures in Nepal.

The diverse nature of the problems discussed and analysed in each chapter of the study all have different approaches to their analysis. The initial phase was descriptive, which is why the document review was the primary research technique. The first and second phases of the research, on the analysis of the existing government policy and study barriers, are on the border between descriptive and explanatory research, with a combination of document review and informal interview being used. The research is mostly qualitative in nature, although some quantitative data was gathered to support the arguments. In addition, a more detailed methodology has been added in each chapter.

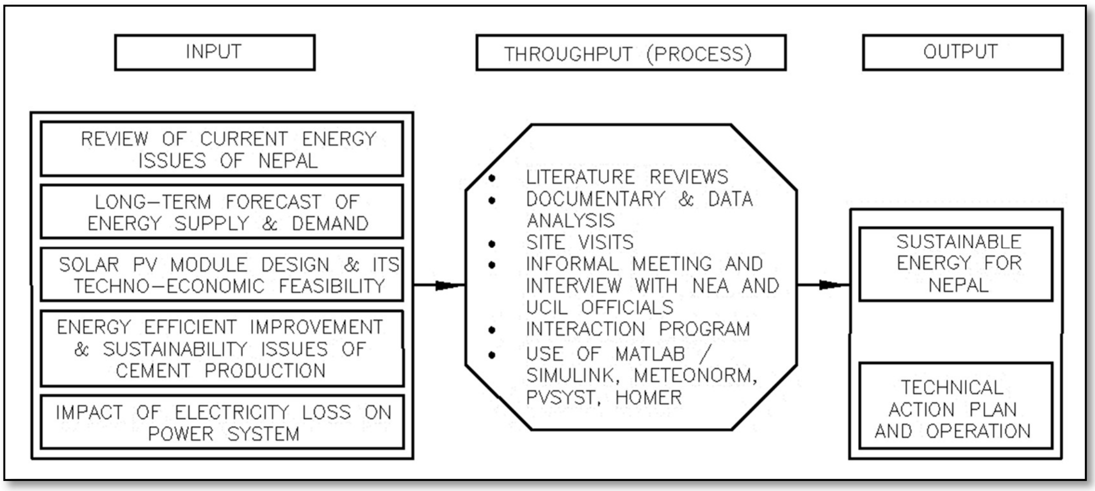

Figure 1.4 Schematic paradigm of the research with a detailed overview of the problems

1.5.1 Data collection

In this research, two techniques of data collection - qualitative and quantitative methods were used. The research started with a review of the documentary analysis of the energy system of Nepal. Document review and informal interviews were taken in this study. The study of the documents was an essential part of each phase of the study. In order to disclose the problems in more detail, informal conversations were used. Careful management of the information collected from the documents, informal discussions, and field notes were carried out, which is one of the vital ingredients of control of the research data. Informal focal group discussion, email, social media, were used as tools of communication with and among UCIL and NEA officials. News and media reports on the data collections and literature were also considered as a source of information. The informal focus group discussion questions set has been presented in Appendix A.

1.5.2 Interviews

Informal interviews (informal focus group discussions) were conducted mainly in the form of informal discussions with experts and stakeholders. The researcher had the opportunities to participate in several conferences, and talk programs on energy-related projects with various organizations, such as IEEE conference in Pattaya Thailand, NRNA Knowledge convention in Kathmandu, the conference on an investment opportunity in the energy sector in Nepal organised by London based Nepalese Embassy, SONE/UK's conferences, BNAC conferences and Nepal Engineers Association, Centre for Energy Studies. In addition, the researcher also had talk program and site visits to Udayapur Cement and Hetauda Cement Industries.

1.5.3 Document review

The study relies on extensive analysis of government documents, for example, various NEA annual Report, NOC annual report, white papers and Government act and policy. Similarly, annual report of different International Agency related to energy and Newspaper articles about the energy sector were also studied.

In order to gather a significant amount of data, the analysis started once the various data was obtained. Singleton and Straits (1999) recommend three stages in data analysis that were used in the study and included organizing information, developing ideas, and drawing and verifying conclusions to be used. [32].

For the validity of the information gathered, and the conclusion of the several approaches was used, as suggested by Singleton and Straits (1999). One of them was to look at the data from different perspectives like "data triangulation," which in the research was achieved by using various sources of data collection such as government documents, studies, and interviews. Rigorous desk review of relevant scientific literature such as articles; research reports; inventory reports and map-based energy mix inventory; relevant legislation, policies; rules and regulations on the energy efficiency improvement, the management were conducted. Annual reports of the UCIL, NEA, were also reviewed and analysed.

1.6 Limitations of the study

The limitation of the research is those restrictions and shortcomings of design or methodology that impacted the interpretation of the findings from the analysis [33]. Throughout the process of the study, the researcher had to deal with some complications and limitations. The first complication was an unstructured interview with the limited respondent of NEA and UCIL. Management was not friendly to answer real problems because of their jobs. The government did not allow them to disclose the actual data, especially in system loss cases. The second limitation was very poor data availability for the researcher and a handful of published articles in peer-reviewed international journals. As the researcher chose to work with the qualitative study, there were data deficiency, data differences, and minimal journal articles that have been published in the case of Nepal's power system. In addition, there was no official / published data available for the industrial sector's energy consumption. The researcher had to rely on the country's newspaper articles, annual reports, and reliance on verbal information provided by the company/plant manager.

1.7 Thesis contributions and impacts

The primary objective of the thesis is the development of strategies to mitigate the energy crisis in Nepal. These strategies exploit energy modelling and optimization with a focus on integrating various renewable energy sources and improving energy efficiency, energy infrastructure, and energy planning to predict and match the energy supply and demand. The research carried out and presented in the thesis consists of several interrelated research tasks. All these research tasks consider some energy issues in their focus.

Apart from traditional research, the motivation for the research in this thesis is to contribute national development of Nepal and to create a broader impact by providing unbiased scientific and technical views on the energy situation in Nepal. Many of the research outputs produced in this work were published in English and Nepali languages in the national newspapers and magazines published in Nepal. In addition, the researcher worked with the recently established National Innovation Centre in Kathmandu to contribute to the strategic planning of research & development projects, especially in the area of renewable energy systems.

- Energy data collection and evaluation

Energy data that are relevant to Nepal and up to date are critical for understanding the energy crisis. The data were collated from various government reports, white papers, Annual reports, and International reports of IRENA, IEA. The collected data allows for painting an accurate picture of overall energy supply and demand in the country and even understands how the energy is used in different sectors of the economy. Such a view on the today's energy situation in Nepal has not to be done for several years, despite many government energy programs adopted over the past decade, and rapid progress in renewable energy technologies and their decreasing prices. Moreover, the data can be used to determine an optimum energy mix for including renewable energy sources to the country's energy supply. The energy sources abundantly available in Nepal are hydropower, solar, wind, and biomass. Our framework of incorporating renewable energy sources and analysing the energy outlook is applicable to other similar (e.g., developing) countries. This work has appeared in the Journal of Renewable and Sustainable Energy Reviews [34] and already received several citations.

- Energy modelling and analysis in LEAP software

In order to assess the long-term energy outlook in Nepal, the commercial software LEAP was used to predict the energy supply and demand over the next 30 years. Understanding long-term energy prospects are vital for the country's economic and social developments. The inputs to configure energy models in LEAP were the previously collected energy data. Furthermore, the long-term energy projection is reviewed against the current government initiatives and policies which are affecting the future energy demands. The policymakers in Nepal should consider the long-term energy projections such as the one researcher has developed in this thesis to understand how to formulate resilient energy policies and strategies. Part of this work has appeared in the Journal of Renewable and Sustainable Energy Reviews [34] and already received several citations. The full analysis article is under review in the same Journal.

- Rooftop photovoltaic energy source design for Kathmandu

This task considers the design of a rooftop solar source with the photovoltaic panel to supply electricity for a typical household in Kathmandu, the capital of Nepal. The key design parameters which must be accounted for are solar radiation, sunshine hours, temperature, precipitation, and wind velocity. These parameters were obtained specifically for the case of Kathmandu. In addition to the technical design of the electrical circuit converting variable power from the PV panel to a steady fixed voltage source, an economic analysis of the whole solar system was carried out to understand whether it is economically viable. The results were compared with similar designs available in the literature. Our findings can be used by the city energy planners and policymakers to devise and allocate investments into renewable energy sources in the city. The results and findings were published in the SONE/UK conference proceeding in 2020 [35].

- Energy Efficiency for Sustainable Cement Production

The aim of this research task was to evaluate the energy economy of the cement production to gain an understanding if there is any room for improvement and how much the improvement in energy efficiency could be achieved. The reasons for choosing cement production are twofold. First, cement production is known to be one of the largest CO_2 polluters, and second, the researcher was able to approach the management of the UCIL cement plant in Nepal and obtain the relevant data. Hence, the study provides an excellent representative example of the energy-hungry production plant in Nepal. The findings from this study revealed that the current average capacity utilization of UCIL is only 36 per cent, and it operates with low energy efficiency under no energy audits. The finding further showed that the consumption of electrical and thermal energies is well above the national average, and the production cost per unit of energy is doubled compared to the international standard. The research findings can be used to enhance issues, including environmental impacts, adoption of new technology, proper maintenance, efficient utilization of fuels and materials, and development of proper energy and materials management.

- Impacts of Electricity loss on the power system in Nepal

Nepal is known to have the most significant system losses for electricity distribution among all countries in the same region. The study was carried out by collating relevant energy data form the literature and then evaluating the real system by a site visit and talk program with the concerned officials of NEA. The research finding indicated that factors contribute to increasing energy losses in distribution systems are vandalism, illegal connection to transmission/distribution lines tampering with or bypassing meters, often with the connivance of utility staff. Revenue leaks resulted from weaknesses in metering, billing and collection, internal control systems, and lack of enforcement of the disconnection policy, poor quality, use of wrong size conductors. The increase in electricity thefts changed the priority of the problems related to electricity losses.

The recommendations can be used by NEA and implement periodic field inspections, update mechanisms and technologies to avoid theft as well as technical loss, construction and regular updates of reliable databases based on field activities aimed at checking its consistency with physical reality, deploy modern infrastructure like smart meters, smart grid and adopt new energy management system to monitor such kind of irregularities. The data generated will be useful for system expansion planning, utilities desirous of minimizing power system losses, for policymakers wishing to formulate more effective policies, and for researchers pursuing relevant studies. The key contribution of this thesis is the development of a new optimization approach and models to mitigate the energy crisis of Nepal. Each of the research chapters contributes to informing further integration of various renewable energy sources and other strategies to improve energy efficiency, energy infrastructure, and better energy planning to predict the actual supply and demand.

Lastly, this study can be instrumental in further recommending the society towards integrated renewable energy adaptation in developing countries like Nepal and similarly in other parts of the world.

1.8 Thesis organisation

The work presented in this thesis is a collection of various papers. Most of these papers have been published or were accepted for publishing in journals or conference proceedings. It should be noted that since each chapter is an independently published paper, there is some overlap between sections. On the other hand, it is not required to read all branches, or it is not essential to understand different chapters in the order presented here. The questions addressed in section 1.4 above reflects the research, this dissertation is divided into five parts (in addition to this introduction and the conclusion part).

In Chapter 2, the current energy issues in Nepal has been reviewed. For this purpose, the existing profile of the state-owned company NEA and NOC who are responsible for supplying electricity, petroleum products, and LPG for the entire country are assessed. The renewable energy potential of Nepal is evaluated, focusing on hydropower, solar, wind, and biomass energy sources. This chapter further discussed the relevant energy policy of Nepal. The causes of energy problems have pinpointed, and approaches to mitigate the crisis have been discussed.

In chapter 3, the Long-term forecast of Nepal's energy supply and demand has been calculated by the LEAP (Long Range Energy Alternative and Planning System) software. The researcher has projected Nepal's energy demands over 30 years up to the year 2042. This chapter further reviewed the current initiatives and policies being developed by the Government of Nepal. The chapter ends with the discussion and conclusion.

In chapter 4, Solar PV system design in MATLAB/Simulink, and Techno-economic feasibility modelling in PVsyst and HOMER software have been done for the residential buildings of Kathmandu, Nepal.

In chapter 5, the current efficiency measures in Nepalese Industries, especially cement industries, were examined. The outcome of the case study, site visits, and the talk program in state-owned UCIL cement industries were discussed. Further to this, sustainable cement production, health, and safety issues of employees, conservation of energy, and the importance of alternative fuels and materials were also discussed. Finally, the possibility of a waste heat recovery system to generate electricity in the UCIL plant was advised.

In chapter 6, the electric system loss of NEA was examined. The technical and non-technical system losses were discussed. The effects of system loss were explained. Finally, recommendations to reduce both system losses were presented.

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Chapter 2
Review of current energy issues in Nepal

The aim of this chapter is summarized in both data and literature. It is the continuation of renewable energy and other strategies for mitigating the energy crisis in the Nepal concept introduces in chapter 1. This work has been published in Poudyal et al. (2017) [1] and Poudyal et al. (2019) [2].

2.1 Introduction

Energy is one of the basic requirements to sustain human societies, so its supply should be secured and abundant. It needs to be economically viable, environmentally friendly, and socially acceptable. In the 21st century, electrical energy plays a vital role in the development of nations. The energy consumption of 7.5billion (world population) represents a unique challenge, which is further aggravated by an ongoing climate change. Climate change significantly affects economic systems, ecological structures, and social development of countries [3]. The recently adopted 17 United Nations Sustainable Development Goals (SDGs) [4] aim to end poverty, protect the planet, and confirm the prosperity for all. SDG number 7 calls for access to affordable, reliable, and sustainable energy. However, at present, 1.2 billion people in the Least Developed Countries (LDCs) do not have access to energy, and 2.9 billion people cook with inefficient fuels that lead to pollution.

Providing energy security by relying on fossil fuels is problematic as a small number of nations mostly control oil and gas reserves. The energy consumption accounts for 60 per cent of the total Green House Gas (GHG) emissions [5]. It is estimated that every 1 USD of investment towards the zero-carbon infrastructure not spent before 2020 will require an additional 4.3 USD to be paid after 2020 to compensate for the increased GHG emissions [6]. Moreover, as our dependency on electricity increases and supply-demand management is more challenging, large-scale power outages became more frequent. The energy crisis stems from the rising demands, while the energy generation capacities are limited. It has direct adverse effects on state economies [7]. Other key factors contributing to the energy crises are[2]:

- Overconsumption: The overall energy demand is increasing faster with the growing population, while the energy is not utilised optimally, and its distribution is inefficient.
- Inadequate infrastructure: The infrastructure for power generation and distribution is ageing as it is too costly to maintain it.
- The imbalance between production and consumption: The energy supply does not keep up with the growing energy demand requiring complex energy management solutions.
- Insufficient exploitation of renewable energy sources: The vast renewable energy resources in many countries are still under-utilised, although the situation is slowly improving.
- Energy wastage: There is generally low awareness of the importance of conserving energy. A related issue is energy theft, which is widespread in some countries.
- Accidents and natural disasters: The pipeline bursts, cyber-attacks, and natural calamities such as floods, earthquakes, and hurricanes damage the power infrastructure, sometimes long term.
- Wars and civil unrests: Wars, political, and public disorders can significantly disrupt energy supplies.
- Lack of proper energy storage: The energy may need to be stored until it is required.

Likewise, the storage capacity must be increased continuously to match the demands. The general causes of energy problems in developing countries are summarised in Figure 2.1.

The World Energy Outlook 2016 by the International Energy Agency (IEA) links energy, air pollution, and health [6]. To reduce the atmospheric emissions, the IEA recommends avoiding traditional fuels, improving energy efficiency and conservation, transitioning towards renewable energy sources, and developing low-carbon and carbon-capture technologies [8]. The governments need to monitor the impacts of the transition to renewable energy sources, especially on the poorest, observe the behaviours of the largest energy consumers, and catalyse the private sector investments [6]. It is estimated that renewable energy can cover 10 per cent of the total energy consumption and provide 30 per cent of the world population with access to electricity in the next 20 years.

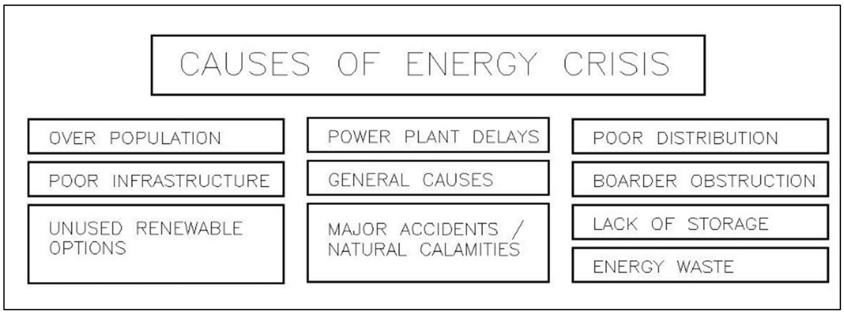


Figure 2.1 The general causes of energy problems in developing countries

Despite the tremendous renewable energy resources available worldwide, only about 27 per cent of the world population have access to electricity from clean, renewable energy [9]. The IEA predicts the rapid growth of renewable generation capacity worldwide using solar, wind, biomass, hydropower, municipal waste, geothermal sources, tidal, and wave sources. Many nations in the Asia Pacific region have potential energy sources in the form of millions of tons of rice husk, waste wood, coconut shells, horticulture and agricultural waste, palm oil waste, organic solids, and biogas which can be efficiently utilised in boilers to replace the traditional fossil fuels. Renewable energy already became an integral part of the national energy policies in many countries post the 1973 oil-shock [10]. However, the development of renewable energy solutions is constrained by various technical, economic, and political challenges. To improve the reliability of renewable power systems, different types of renewable sources can be combined and utilised with the energy storage devices and conventional generators to mitigate the power outages [11]. Renewable sources naturally support decentralisation as they are much more uniformly distributed and accessible also in remote areas. It reduces the need for electricity distribution since the electricity is mostly consumed where it is generated. The off-grid power systems (i.e., the systems which are not connected to the national electricity grids) can generate electricity both in rural and urban areas. Since the large scale, renewable projects have become economically competitive with new fossil-fuel technologies, the economic drivers of employing renewable energy sources are now as important as the previously considered environmental drivers.

Much of the growing energy demands in the global economy are driven by the emerging economies of China and India, the immediate neighbours of Nepal. These two countries already account for half of the world demand increases, and their consumption is expected to double by 2030[12], [13]. At the same time, these two countries also top renewable energy markets as the most attractive places for investment in renewable energy. China announced that it would spend 363 billion USD on expanding its renewable energy capacity by 2020. Half a million solar PV panels were installed every day, and two wind turbines were set up every hour in China in 2015, representing 153GW of the total installed capacity generating power from renewable[14]. The Indian government plan to produce 175GW of renewable energy by 2022. Subsidies per unit of new solar photovoltaic (PV)panels in China are predicted to drop by 75 per cent by 2025, while solar projects in India will be competitive without any financial support well before 2030 [13].

According to Jacobson et al. [15], hindering global warming from rising above 1.5^0C will require reaching 80 per cent zero-emissions energy by 2030 and 100 per cent by 2050, and much of this should be achieved through the increased use of renewable energy. This, in turn, motivates a steadily growing literature on a range of questions concerning the future of the transition to renewable energy.

Abandon literature has tackled the issue of determining how much renewable energy is potentially available in Europe. Past research in this field, initially activated by the setting of EU-2020 targets, addressed the question as to how much RES energy could be provided at what cost, given the existing technologies. An extensive example covering solar, wind, biomass is found in the study [16].

Comprehensive studies on the energy situation exist for many countries, including India [17], Pakistan [18], Bangladesh [19], and Nigeria [20], providing ample insight into the renewable energy. Withal, similar studies about the energy crisis in Nepal are either limited in their scope or outdated. For instance, they focus on specific regions in Nepal, or they have become obsolete as they do not include the current data on energy consumption and production [21]–[27]. It is essential to consider the recent rapid developments in the use of renewable energy sources, availability of new data, significant changes in the energy market dynamics, and energy pricing structures. Hence, one of our major aims is to review the current energy situation in Nepal with a specific focus on renewable energy developments to assess whether it can meet

Nepal's future energy demands. To understand the causes of a chaotic energy situation due to insufficient electricity production, and lack of petroleum products and LPG (Liquefied Petroleum Gas), which fail to meet the country's energy demands, this study aims to provide an updated view on the current energy situation in Nepal. The potential and utilisation of renewable energy sources, including the relevant energy policies and trends, are explored to respond to the ongoing energy crisis. The energy reforms that are currently underway are discussed, including changing roles of the state and the private sectors. The findings from the study can be used to identify and analyse the critical developmental issues which are impacted by insufficient energy supply.

This chapter reviews, systematic, and aggregates the existing research on renewable energy adaptation and the consequences of the transition to renewable energy in Nepal. For the purpose of this chapter, renewable energy adaptation broadly concerns the connection between geography, space and the power of nations, and the scope of the article is limited to the literature that deals explicitly with the consequences of the growing use of renewable energy for the power of states, international conflict or energy security. This research dealing with domestic issues and disputes related to renewable energy, or those that cover international relations but not power, conflict, or energy security, are outside the scope of this research.

2.2 Renewable energy prospects and opportunities in Nepal

Nepal encloses the rectangular area of 147,181 km^2 with the width and length of 193 km and 885 km, respectively[28]. The country falls in the subtropical monsoon climate and experiences all four seasons. There are tropical areas in the south and the alpine region in the north and the significant topographical variations in between. Nepal's territory contains hundreds of Himalaya fed rivers. Most of these are high-current Rivers flowing from extremely high altitudes above 8,800m to the low-level land areas as low as 70m. Although such geography is excellent for hydropower generation, it also presents many difficulties for electricity distribution, public transportation, and other services [29]. The challenging geography of Nepal poses a natural barrier to its development, even though the steady-state progress towards the poverty reduction over the past several years is impressive. An example of government energy planning to increase the energy generation capacity and improve energy services is provided in Table 2.1 [30]. The following hydropower plants are under operation and are licensed by NEA. The name of the project, capacity, and type are as illustrated in Tables 2.1 – 2.9.

Table 2.1 Large hydropower plants of Nepal

Name of the Project	Capacity in MW	Type
1 Kaligandaki 'A'	144 MW	Runoff River
2 Middle Marsyangdi	70 MW	Runoff River
3 Marsyangdi	69 MW	Runoff River
4 Kulekhani I	60 MW	Reservoir
5 Kulekhani II	32 MW	Reservoir
6 Trishuli	24 MW	Runoff River
7 Sunkoshi	10.05 MW	Runoff River
8 Gandak	15 MW	Runoff River
9 Devighat	14.10 MW	Runoff River
10 PuwaKhola	6.2 MW	Runoff River
11 Modi Khola	14.8 MW	Runoff River
12 Chamelia	30 MW	Runoff River
13 Upper Trisuli 3A HEP	60 MW	Runoff River
Sub Total	549.150 MW	Runoff River

Table 2.2 Small hydropower plants of Nepal

1 Sundarijal	640 KW	Runoff River
2 Panauti	2400 KW	Runoff River
3 Fewa	1000 KW	Runoff River
4 Seti (Pokhara)	1500 KW	Runoff River
5 Tatopani	2000 KW	Runoff River
6 Tinau	1024 KW	Runoff River
7 Pharping	500 KW	Runoff River
8 Chatara	3200 KW	Runoff River
9 Jomsom	200 KW	Runoff River
10 Baglung	200 KW	Runoff River
11 Khandbari	250 KW	Runoff River
12 Phidim	240 KW	Runoff River
13 Surnaiyagardh	200 KW	Runoff River
14 Doti	200 KW	Runoff River
15 Ramechhap	150 KW	Runoff River
16 Terathum	100 KW	Runoff River
17 Gamgadi	400 KW	Runoff River
Sub Total	14244 KW	

Table 2.3 Small hydropower plants (Isolated)

Name of the Project	Capacity in KW
1 Dhankuta	240
2 Jhupra (Surkhet)	345
3 Gorkhe (Ilam)	64
4 Jumla	200
5 Dhading	32
6 Syangja	80
7 Helambu	50
8 Darchula	300
9 Chame	45
10 Taplejung	125
11 Manang	80
12 Chaurjhari (Rukum)	150
13 Syaprudaha (Rukum)	200
14 Bhojpur	250
15 Bajura	200
16 Bajang	200
17 Arughat (Gorkha)	150
18 Okhaldhunga	100
19 Rupalgadh (Dadeldhura)	100
20 Achham	400
21 Dolpa	200
22 Kalikot	500
23 Heldung (Humla)	500
Total	4536

Table 2.4 Solar power station

1 Simikot	50 KW
2 Gamgadhi	50 KW
Total	100 KW

Table 2.5 Diesel power station

1 Hetauda	14,410 KW
2 Duhabi Multifuel	39,000 KW
Total	53,410 KW

Table 2.6 Total power system of Nepal

Total Major Hydro(NEA) – Grid Connected	**563.394 MW**
Total Small Hydro (NEA Isolated)	4.536 MW
Total Hydro (NEA)	567.930 MW
Total Hydro (IPP)	560. 775 MW
Total Hydro (Nepal)	1128. 705 MW
Total Thermal (NEA)	53.410 MW
Total Solar (NEA)	100 KW
Total Installed Capacity	1074.135 MW
Total installed capacity (NEA and IPP) Grid	1182. 215 MW

Table 2.7 Power projects under construction

Upper Tamakoshi	**456,000 KW**
1 Tanau	140,000 KW
2 Upper Tamakoshi	456,000 KW
3 Kulekhani No. 3	14,000 KW
4 Rahuganga HEP	40,000 KW
5 Upper Sanjen	14,600 KW
6 Sanjen	42,500 KW
7 Rasuwagadi	111,000 KW
8 Madhya Bhotekoshi	102,000 KW
9 Upper Trishuli 3B	37,000 KW
Total	957,100 KW

Table 2.8 Plan and proposed

1 Aadhikhola Storage HEP	**180,000 KW**
2 Upper Arun HEP	1061,000 KW
3 Upper Modi 'A' HEP	42,000 KW
4 Upper Modi HEP	18,200 KW
5 Dudkoshi Storage HEP	635,000 KW
6 Tamor Storage HEP	762,000 KW
7 Uttar Ganga Storage HEP	828,000 KW
8 Tamakoshi V HEP	95,000 KW
9 Chainpur Seti HEP	210,000 KW
10 Begnas Rupa Pump Storage HEP	150,000 KW
Total	2,285,200 KW

Table 2.9 Independent power producers (IPPs)

Name of the Project	Capacity	Remark
1 Khimti	60 MW	Runoff River
2 Bhotekoshi	36 MW	Runoff River
3 Chilime	22.1 MW	Runoff River
4 Jhimruk	12 MW	Runoff River
5 Indrawati	7.5 MW	Runoff River
6 Andhi khola	5.1 MW	Runoff River
7 Khudi	3.45 MW	Runoff River
8 Pilukhola	3.0 MW	Runoff River
9 Sunkoshi small Hydro	2.5 MW	Runoff River
10 Thoppal Khola	1700 KW	Runoff River
11 Chaku Khola	1.5 MW	Runoff River
12 Patikhola	996 KW	Runoff River
13 Pheme Khola	995 KW	Runoff River
14 Baramchi Khola	4200 KW	Runoff River
15 Seti II	979 KW	Runoff River
16 Sisne Khola Small Hydro	750 KW	Runoff River
17 Salinadi	750 KW	Runoff River
18 Synge	183 KW	Runoff River
19 MathilloHandi Khola	991 KW	Runoff River
20 Ridi Khola	2400 KW	Runoff River
21 Mardi Khola	3100 KW	Runoff River
22 Mai Khola	4455 KW	Runoff River
23 Indrawati	4500 KW	Runoff River
24 Siuri Khola	5,000 KW	Runoff River
25 Charnawati	3600 KW	Runoff River
26 Lower Modi	10 MW	Runoff River
27 Bijayapur	4.5 MW	Runoff River
28 Sipring	10 MW	Runoff River
Total	209.844MW	512.695 MW up to 2018

Nepal is amongst one of the world's least developed nations, with one of the lowest energy consumption per capita in the world, and further has no key reserves of coal, natural gas or oil [31], [21], [2]. The high magnitude earthquake in April 2015 worsened the condition of energy access as around 30 per cent of the power infrastructure of Nepal was severely damaged [33].

The Nepalese economy is dominated by agriculture. It provides a livelihood for over 67 per cent of its population and accounts for 33 per cent of the Gross Domestic Product (GDP) [34]. There is a strong correlation between the country's energy consumption and its GDP, so the lack of energy supply impedes economic growth [35]. The energy crisis has forced the manufacturing sector, the 3rd most significant contributor to the GDP, to operate far below its available capacity for the last three years, estimated presently to be at 58 per cent. The ongoing crisis in Nepal enforces the LDC status, although the Nepalese government recently formulated a long-term economic vision intending to raise Nepal to a middle-income country by 2030 [30]. The Vision 2030 calls for the transformation of the subsistence-based farming to a large-scale commercial agriculture country, and to completely upgrade the currently dismal industrial sector. The planned industrialisation is formulated in the Special Economic Zone Act, which provides attractive facilities and privileges to the export-oriented industries [36]. These initiatives will create additional demands for energy. Together with the currently unfulfilled energy demands in the domestic markets, it can be exploited as the incentive for potential investors to get involved in the energy sector, even if the energy export prospects are not considered. The investors eager to harness energy sources in Nepal are likely to be from the countries requiring large amounts of energy to support their economies. For instance, India and China have already made significant investments in Nepal through 898 and 629 energy projects, respectively as of 2017 [9].Nepal's enormous potential energy sources suit the needs of China and India very well [37].

Access to electricity in Nepal is difficult, mainly where the high mountains are situated, and where there is a lack of accessible roads. Despite having more than a century-long history of electricity generation, 6.6 million people in Nepal are still without electricity [38], and those who have access to electricity are experiencing long hours of load shedding, especially during the dry winter seasons. Only 58 per cent of Nepalese citizens or 2.79 out of 5.5 million households are connected to the national grid while the other 9 per cent rely on the off-grid renewable supplies [9]. Since access to the energy services plays the essential role in the social development, it is not surprising that the Human Development Index (HDI) of Nepal is only 0.548, ranking it the 145th country among 188 countries in the world [39]. About 80 per cent of the Nepal population lives in remote villages, far from the national electricity network.

Unfortunately, connecting the remote villages to the national grid would be too costly, so the rural communities are often left isolated, scattered, and with no or inadequate access to the public infrastructure and services. Half of these people live in the areas so remote that the nearest road and the national electricity grid is within a few days of walking through the mountains [40]. In these areas, providing the national electricity grid is costly both due to the geography and the sparse population density. Even when the national electricity grid is available, natural disasters such as earthquakes, hurricanes, storms, floods, and security breaches often lead to catastrophic power outages. The two devastating earthquakes in Nepal in 2015 damaged 14 hydropower dams, and the national grid lost more than 30 per cent of its generating capacity [29]. The United Nations Development Program (UNDP) estimates that Nepal is the 11th most earthquake-prone country in the world [41]. The flooding of 2017 in the southern part of Nepal caused 73 billion NPR of damages and disrupted the electricity and telecommunication infrastructure, which will require 242 million NPR of repair costs [42].

It is not surprising that Nepal has a low level of electricity consumption of 139.14 kWh per capita per year compared with the world average of 3,104 kWh per capita per year[43], [44]. The total energy consumption in Nepal in the 2014/15 fiscal year (FY) was 11,232 toe (tons of oil equivalent) [9]. Nepal relies heavily on traditional energy sources such as wood, as it has no significant deposits of fossil fuels. The conventional fuels represent 78 per cent of the total energy consumption, followed by12 per cent of petroleum products. The use of modern renewable energies and the on-grid electricity generation are each just 3 per cent. Moreover, the dependency on imports of electricity and fossil fuels is continuously growing year by year. The price of kerosene as the primary and only source of energy for many people in rural areas has increased by 216per cent over the past 17 years [45].

The sector-wise energy consumption in different economic sectors in Nepal is shown in Figure 2.2. The residential area represents 48 per cent of the total consumed energy, followed by the industrial sector with 38 per cent consumption. The agriculture accounts only for 2 per cent of the total demand, despite being the dominant economic sector in Nepal. The energy consumption of the transport sector is negligible, indicating that this sector is very underdeveloped and hinders any future economic development. Overall, Nepalese are mostly dependent on fossil fuels totalling 116.8

billion NPR (NRB, 2018). Nepal imports and consumption of petroleum, oil, and coal have been steadily increasing at an alarming rate of 10 per cent per annum [46], [47] (Table 2.10) [32]. To meet its energy needs, Nepal spends a large part of its GDP on the electricity imports, especially from India, to overcome the supply deficits during dry seasons. Further, the use of petroleum products, which constitute both oil and gas, not only creates a deficiency in the balance of trade and payment but also increases air pollution with the emission of short-lived climate pollutants.

Table 2.10 The average daily and monthly imports of petroleum products [32]

	2014/15		**2015/16**	
	Daily Avg.	Monthly Avg.	Daily Avg.	Monthly Avg.
Petrol	794.09	23,822.22	410.08	12,302.50
Diesel	2,553.00	76,590.08	1,270.80	38,124.00
Kerosene	55.01	1,650.42	23.75	712.58
Aviation fuel	394.82	11,644.67	131.94	3,958.17
Total (excl. LPG)	3,796.92	113,708.00	1,836.57	55,097.25
LPG (Mt)	717.42	21,522.63	365.63	10,960.58

Table 2.11 The storage capacity and sales volume of petroleum products in FY 2017/18[48]

Province	**Storage (%)**	**Sales (%)**
1	16.7	16.2
2	32.7	28.1
3	31.9	27.1
4	4.8	4.4
5	10	19.1
6	0.2	0.9
7	3.7	4.2
100% total (in kL)	71,707	1,712,477

Consequently, the electricity is priced at 0.90 USD/kWh for the end-users in 2018, which is among the highest in the world. Such high costs of energy faced by developing countries require financial subsidies. This situation is mostly the result of poor governance of state-owned utility companies. It often promotes corruption, system inefficiencies, overstaffing, weak standards, and puts the financial burden on the state. Indeed, Transparency International consistently ranks the petroleum and electricity sectors, where corruption is the most prevalent [49].

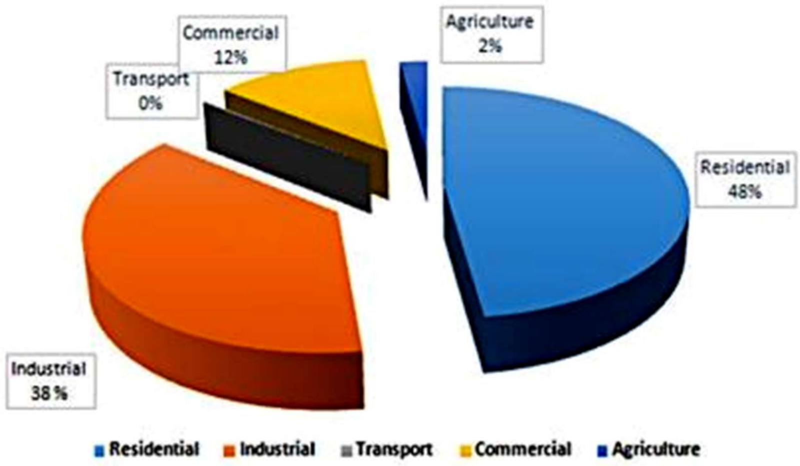


Figure 2.2 The sector-wise energy consumption within Nepal's national economy in 2018 [50]

The detailed view on the current energy situation of Nepal in FY 2017/18 is provided in Table 2.12. The data are presented in 6 sections: energy available, energy utilised, energy sales, energy revenues, energy expenditure, and energy consumer. It confirms the trends discussed previously. In particular, over 1/3 of electricity is purchased from India, most energy is utilised as internal sales while system losses are significant and as substantial as 20 per cent, the most massive sales of 44 per cent are to the households, and domestic consumers who represent 94 per cent of consumers and they generate the most considerable revenues, and 55 per cent of expenditures are used for power purchases. The energy trend data are presented in Table 2.10 [32], where it can observe that energy imports greatly exceed energy exports, the total energy consumption is on the rise, domestic use is higher than industrial consumption, and electricity losses are significant. Additional data can be found in [30].

Table 2.12 The energy data from NEA in 2017/18 [9]

Availability of energy		**Energy utilisation**		**Energy sales**	
Purchase from India	36.6%	Internal sales	78.7%	Domestic	43.5%
Hydro	32.7%	System loss	20.5%	Industrial	37.4%
Purchase in Nepal	30.7%	Self-consumption	0.8%	Others	8.4%
Thermal	0.0%	Export	0.1%	Commercial	7.4%
				Non-commercial	3.1%
				Export	0.1%
Energy revenue		Energy expenditures		Energy consumers	

Domestic	41.6%	Power purchase	55.6%	Domestic	93.8%
Industrial	36.0%	Depreciation	13.3%	Others	3.6%
Commercial	10.7%	Ops. & maintenance	9.3%	Industrial	1.4%
Others	6.9%	Interest	7.6%	Commercial	0.6%
Non-commercial	4.7%	Others	5.2%	Non-commercial	0.6%
Export	0.1%	Royalty	1.9%		

Table 2.13 The evolving energy situation in Nepal (in mil. kWh) over the past 7 years [9]

FY	Domestic	Industrial	Commercial	Other	Consume total	Electr. loss	Gener. & import	Energy trade	
								Import	Export
10/11	1143.2	1012.9	204.9	294.9	2687.0	1071.4	3758.4	94.1	31.1
11/12	1311.1	1192.1	227.1	384.5	3164.7	953.7	4119.0	800.0	50
12/13	1397.5	1141.1	237.9	379.6	3156.0	756.0	4220.2	790.1	0
13/14	1526.8	1246.7	285.2	385.6	3444.3	853.8	4681.1	1070.5	0
14/15	1688.5	1362.6	302.6	415.8	3772.6	1194.0	4966.7	1367.7	3.2
15/16	1799.6	1206.7	286.5	430.7	3789.0	1358.2	5077.2	1782.9	3.2
16/17	2150.2	1235.1	352.4	536.2	4776.5	966.5	5743.1	2175.0	2.7
17/18*	1397.6	1127.8	229.0	348.5	3104.7	511.3	3616.0	1413.8	1.75

*the first 8 months

About 78 per cent of the total energy demand in Nepal is supplied by the fuelwood and 12 per cent by the agricultural residues and animal dung [9]. Thus, the reliance on traditional biomass, as well as the consumption of kerosene and LPG in households, continues to be very high (Table 2.14) [45]. Burning low-quality or fossil fuels has severe adverse impacts on the health of people, especially in rural areas, leading to the death of more than 7,500 women and children each year due to indoor air pollution [51]. The children are also forced to devote plenty of their time to collect energy resources, so they are deprived of education. The depletion of the forest areas has prompted the environmentalist and energy planners to address the energy problems jointly.

Table 2.14 Monthly cooking costs in urban households in Nepal (in NPR) [45]

Year	Kerosene	LPG	Electricity
1997	180	350	605
2000	270	410	680
2003	340	510	790
2012	1640	1030 (with subsidy)	940

Table 2.15 The breakdown of energy consumption (in %)[48]

	2013/14	2014/15	2015/16	2016/17	2017/18
Traditional	77.6	78.4	72.4	74.5	68.9
Firewood	70.5	71.2	65.8	67.6	62.5
Agricultural residues	3.5	3.5	3.2	3.3	31
Cow dung	3.7	3.7	3.4	3.5	3.3
Coal	4	4.6	5.2	4	27.9
Petroleum products	12.5	10.8	16.2	13.8	18.7
Electricity	3.4	3.7	3.9	4.1	4
Renewables	2.5	2.5	2.3	3.5	3.2
100% total (in Mtoe)	11728	11768	12866	8257	9019

Nepal consumes 1.4 million tons of LPG every year, according to the Nepal Oil Corporation (NOC). A substantial part of this amount ends up in hotels and restaurants, which often consume several gas cylinders every day while most households maintain a stock of two or three cylinders. Although the urban families can still afford to pay the market prices for the gas, more impoverished communities in the valleys and across all nooks and corners of the country must rely on kerosene or fuelwood instead. The energy consumption for cooking has grown significantly in Kathmandu Valley. It is estimated to amount to 200 MW annually, and it is expected to rise further in the future[48]. For every 10 LPG cylinders delivered to Nepal, six are used in Kathmandu valley alone. The energy demand of the valley in 2014/15 stood at 1,300 GWh, and it has been increasing at the rate of more than 10 per cent a year. The price trends of petroleum products in Nepal over the past two decades, including prices of petrol, diesel, kerosene, aviation fuel, and LPG, are shown in Table 2.16 [52]. It indicates that the cost of kerosene has increased more than three-fold while the price of LPG increased more than two-fold.

Table 2.16 The development of petroleum products prices in Nepal since 2000[52]

	Petrol	**Diesel**	**Kerosene**	**Aviation fuel**	**LPG**
Year	NPR/Litre	NPR/Litre	NPR/Litre	USD/KL	NPR/Cyl
2003	54	31	24	360	700
2006	67.25	53.15	47.65	931.83	900
2009	77.5	58	58	750	1125
2012	125	99	99	1250	1470
2013	130	103	103	1300	1470
2014	140	109	109	1400	1470
2015	113.50	90	90	1400	1470
2016	101.50	77.50	77.50	750	1325
2017	100	76	76	750	1350
Rise (%)	85	145.16	216.66	108.33	92.85

2.3 Ongoing energy crisis

Nepal ranks 130th out of 190 nations in terms of infrastructure availability, the worst in South Asia. Two-thirds of Nepalese firms identified electricity as a critical constraint, much higher than the regional and world average. There are frequent power outages, and firms must rely on expensive diesel generators for up to 40 per cent of their electricity use. It increases costs and reduces competitiveness [34].

The ongoing energy crisis in Nepal has become a foremost public concern after the government declared a state of emergency due to the acute energy crisis in early 2008. The energy crisis threatens to undermine the social foundations of the country. It did not appear suddenly but is a direct consequence of chaotic energy policies over the past decades. It disrupts the everyday lives of individuals and businesses through frequent power outages. The Nepalese citizens are facing 12–14 hours of load shedding every day, especially during the winter months. The immediate solution is to resort to diesel power generators during the load shedding hours while many hospitals and healthcare clinics use the generators regularly. It creates environmental and indoor pollution. According to the Environmental Performance Index, Nepal stays 149 among 180 countries in terms of air quality [53].

Unplanned outages severely impact the national economy. Economic losses in the industrial sector due to power outages amount to 24.69 million USD a year, which is about 4 per cent of the total GDP produced by the industrial area [54]. Besides, the service-oriented industries cut their office hours to keep uniformity with other market participants. Manufacturing units are compelled to use diesel generators to maintain production, which increases the cost of finished products by a whopping 25 to 40 per cent. It has constrained many companies to either permanently shut down their operations or be forced to transform into trading more basic goods and products. Deferred investments in the electricity infrastructure also force the diesel generators. Particularly the manufacturers processing glass, textiles, chemicals, plastics, cement, and other similar materials cannot tolerate even short electricity disruptions, as it may take several hours to resume the production after the outage. The adverse impacts of load shedding for the delivery of different services are indicated in Figure 2.3. The economic costs of electricity disruptions are quantified in Table 2.17 [55]. The most substantial effects felt in providing education and water supply services, whereas the financial losses due to load shedding are the largest in materials processing industries and food production.

Table 2.17 The economic costs of electricity disruptions as 90% confidence intervals (in US$/KWh) [55]

Industry	Planned disruptions	Unplanned disruptions
Food, beverages, and tobacco	(0.00, 0.15)	(0.44, 1.13)
Chemical, petroleum, rubber	(0.00, 0.47)	(0.12, 0.73)
Textile and leather	(0.00, 0.74)	(0.71, 2.78)
Iron and steel	(0.00, 0.24)	(0.46, 2.31)
Hotels	(0.00, 0.24)	(0.00, 0.11)
Non-metallic and minerals	(0.00, 0.16)	(0.00, 0.05)
Miscellaneous	(0.00, 0.16)	(0.10, 0.38)
Industry sectors average	(0.03, 0.25)	(0.35, 0.62)

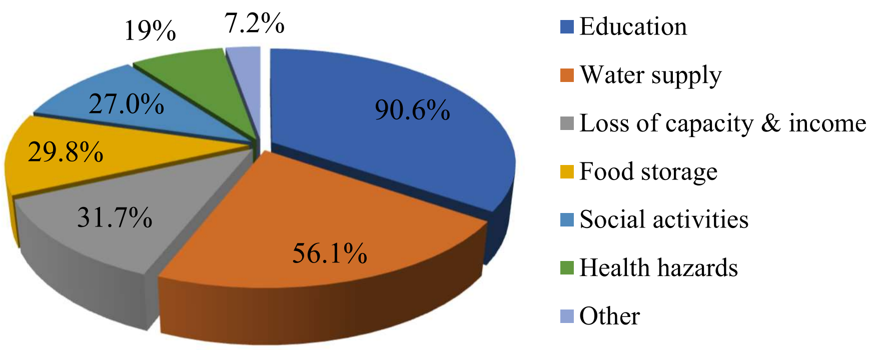


Figure 2.3 The impacts of load shedding [55]

To better understand the severity of the energy problems in Nepal today, it is sufficient to compare the overall electricity demands and supplies (cf. the supply-demand gaps in Figures 2.5 – 2.6) [48]. It is evident that the current attempts to close the supply-demand gap are not successful. The typical power load profile in 2018 is depicted in Figure 2.4 [50]. It shows that the energy demand is continuously decreasing from midnight overnight until about 4 pm the next day when the market starts abruptly rising. The peak demand occurs daily between 4 pm and 7 pm. This expected to increase from the current value of about 1,500 MW to 3,200 MW in 10 years [56]. More importantly, the peak demand of 1,500 MW, which is mostly driven by households, cannot be satisfied as only 1044.6MW of electricity, including imports, is available. The data in Table 2.10 [48] illustrates the extent of the current imports of electricity and petroleum products and how these imports are distributed among different provinces. Thus, hydropower-rich Nepal ironically imports 34 per cent (up from 27 per cent only a year earlier) or 345 MW of its electricity from India [50]. In 2015/16, Nepal paid to India 16 billion NPR for 2,175 GWh of electricity, 109 billion NPR for 1.3 million tons of refined fuels, and 17 billion NPR for 1.4 million tons of LPG [52]. Such large trade deficit has severe negative impacts on Nepal's economy, and the situation is worsening over the years [57]. The trend of electricity imports from India is contrasted with the volumes of electricity generation in Figure 2.8 [50] between the years 2010 and 2019.

Fortunately, Nepal is blessed with a substantial theoretical hydropower potential of 83,000 MW, out of which 45,000 MW is considered to be techno-economically feasible [58]. Nepal has almost 6,000 rivers with a total length of about 45,000 km and an annual discharge of 174 billion $m^3$of water. Nonetheless, until today, only 1,044.6 MW of hydropower is supplied to the peak load system representing 2 per cent of the total energy supply [59]. Also, the entire length of existing transmission lines is 3,496 km, and about the same distance under construction. However, the excessive reliance on hydropower means that the energy situation in Nepal rapidly deteriorates in dry seasons lasting from November to April when the water level in many rivers is significantly reduced while the situation improves during wet seasons from April to November each year. The data on demand and supply balance dependency on the wet and dry seasons projected over the next 5 years are shown in Table 2.18. The current information on energy use for years 2005 – 2015, as well as predicted data for years

2020 – 2030, is provided in Table 2.19. These data imply that the Nepalese Government expects that the energy consumption will substantially increase over the next decade.

Furthermore, even though the utilisation of renewable resources is projected to increase from today's 12 per cent to over 20 per cent in the next 10 years, the dependency on imported electricity is expected to rise to 34 per cent which negatively affects the country's economic independence. Some experts argue that Nepal's dependence on energy imports may not change its energy security significantly as long as the foreign supplies are reliable [60]. Though, the energy consumption data in Figures 2.4 – 2.6 and projections in Tables 2.18 - 2.19 indicate that Nepal's energy vulnerability is likely to worsen. What's more, Volatising nature of international energy markets aggravates the situation and makes the energy crisis more severe and even prominent [61], [62].

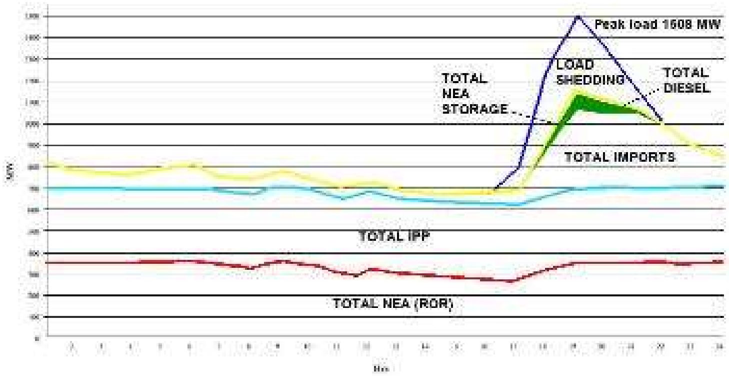
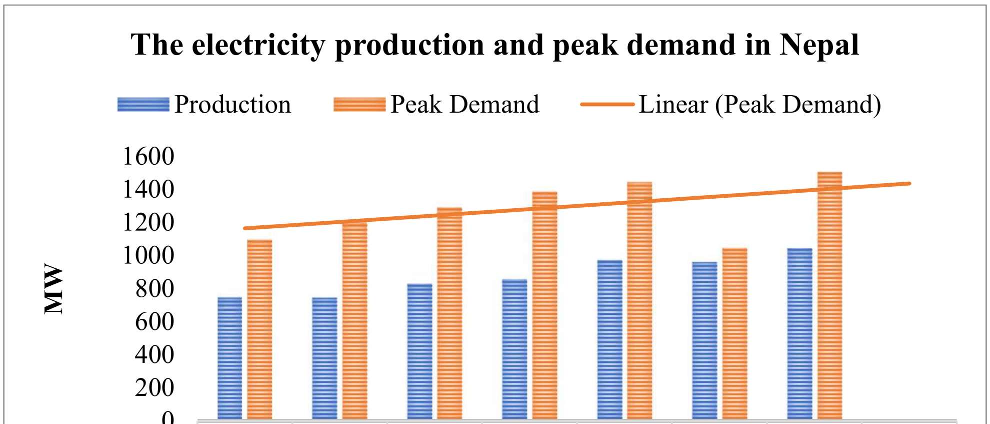


Figure 2.4 Typical daily power load profile in Nepal with a peak load in 2018[50]



	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Production	746	746	829.2	855.9	972.5	961.2	1044.6
Peak Demand	1094	1201	1291.1	1385	1444.1	1044.1	1508.2

Figure 2.5 The electricity production and peak demand in Nepal for over 2012 – 18 [50]

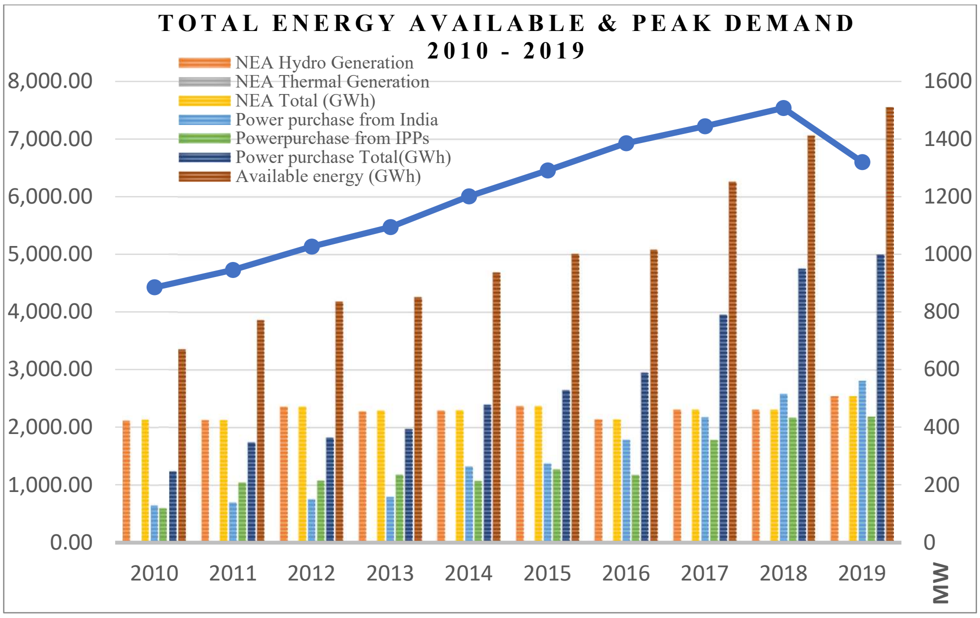


Figure 2.6 Total Energy available and peak demand 2010-2019

Table 2.18 The current and predicted electricity demand and supply (in MW) in the wet (April – November) and dry (November – April) seasons [48]

	FY	Demand	Supply	Balance
Wet seasons	2018/19	1841.13	2283.45	441.32
	2019/20	2225.65	2856.97	631.32
	2020/21	2638.29	3584.44	946.15
	2021/22	3062.87	3963.87	901
	2022/23	3365.97	4046.14	670.17
	2018/19	1841.13	1470	-372
Dry seasons	2019/20	2225.65	1686	-539
	2020/21	2638.29	1928	-709
	2021/22	3062.87	2055	-1007
	2022/23	3365.97	2079	-1283

Table 2.19 The current and predicted future energy use in Nepal [63]

Index	2005	2010	2015	2020	2025	2030
Per capita energy (GJ)	15	16	16	17	19	23
Per capita electricity (kWh)	67	80	124	231	496	1070
Household electricity use (%)	1	2	4	7	13	17
Energy per household (GJ)	76	79	78	78	13	17
Non-carbon elect. share (%)	1.7	1.9	2.8	4.8	9.3	16.5
Share of renewable (%)	11.7	11.9	11.2	12.3	15.4	22.1
Imported electricity (%)	10.6	13.4	18	23.4	29.9	34.8
Per capita GHG production (kg)	474	459	420	392	508	672

Table 2.20 The time and cost overruns of the hydropower and transmission line projects [32]

Project	Capacity	Due	Time overrun (months)	Cost overrun
Kulekhani I	60 MW		21	68– 123.6 million US$
Marsyangdi	69 MW		7	17 million US$
Kali Gandaki – A	144 MW		18	100 million US$
Middle Marsyangdi	70 MW		48	130 million US$
Chameliya	30 MW	2011	72	8.5 to 15.6 billion NPR
Raughat	40 MW	2014	84	827.4 million NPR
Upper Trisuli 3 A	60 MW	2013	72	125.8 million US$
Upper Tamakoshi	456 MW	2017	18	
Khimti – Dhalkebar	220 kV	2015	>120	
Dhalkebar – Muzaffarpur	400 kV		6	
Trisuli 3 A	37MW		26	
Kulekhani III	14 MW	2011	72	4.63 billionNPR
Chilime	22.1 MW		60	

Table 2.20 presents the time and cost overruns of the hydropower and transmission line projects. Almost all Nepalese hydropower projects have been delayed from 6 months to 12 years. The example of the most substantial cost overruns hydropower projects internationally are Three Gorges Dam in China US$47,6302 million, La Grande 2 in Canada US$17,460 million, Sanyo-Shushenskaya in Russia US$17,299 million, Tucurui Dam Stage 1 in Brazil US$7091 million, Sardar Sarover Dam India US$6773 million, Grand Coulee Dam II of the USA US$2306 million[64].

2.4 Approaches to mitigating energy crisis

The initial strategy to mitigate the present energy crisis can be concerned with identifying and reducing the transmission losses and improving the overall efficiency of energy systems and processes. It can be achieved without making more radical changes. Besides, the load/demand profile diagram can be used to devise efficient power management strategies and to understand the power supply-demand economics. The load profiles can be obtained for monthly, daily, and hourly timescales depending on the purpose of analysis and the application considered. An example of the hourly daily demand curve is shown in Figure 2.4. In particular, the lack of proper governance to overcome the widespread inefficiencies in energy systems is one of the key factors contributing to the energy crisis. For instance, the transmission and distribution (T&D)

losses exceed 34 per cent compared to the average losses of only 8 per cent worldwide. The most considerable T&D losses are observed in the South Asian Region [65]. Low-quality equipment and poor maintenance practices cause these losses. Besides, energy theft is estimated to represent 10 per cent of the overall losses, which are expected to reach more than 200 MW of electricity in Nepal, amounting to 75.47 million USD annually.

In addition, inadequate planning and investments in the generation, transmission, and distribution network due to lack of adequate legal and regulatory frameworks constitute another significant issue. For instance, about half a dozen transmissions line projects were put on hold due to the lack of proper policies. The NEA is unable to secure the rights of way from private landowners to be able to pass transmission lines over their land [66]. The rights of way and the forest clearance processes thus hamper the development of the critical energy infrastructure [21]. The appropriate regulatory policies can address these issues.

The government regulations and policies involving various financial and investment issues in the energy sector is the second effective strategy for mitigating the energy crisis. In this case, the Nepalese government drafted the 10 and 20 years of hydropower development programs along with the associated policies. The premise of these programs is to create more generation capacity to cover the expected demands. It has been projected that until 2030, an additional 20,354 MW of electricity generation capacity will be added to the integrated Nepal Power System (INPS), excluding already planned large hydropower projects [67]. In the last two decades, climate change has been reflected by some national energy policies. For example, Nepal's first energy policy statement appeared in its 5-Year Plan 1975 – 1980 [68] emphasising the need for increased utilisation of renewable energy sources while reducing dependence on the traditional energy sources and petroleum imports. Yet, despite many energy policies adopted by the Nepalese government, the implementation of these policies in real life is often lacking. The situation is further exacerbated by a high level of corruption, which leads to widespread institutional and governance failures[69].

One of the key policies is concerned with setting the proper energy pricing. The average cost of 1 kW of electricity in Nepal has doubled from 1,000 USD in the early 1980s to above 2,000 USD in the late 1990's[70]. The study [71] expects the average cost will rise to 2,500 USD/kW shortly, despite a wider adoption of renewable energy sources and the corresponding economies of scale [27]. The electricity prices in Nepal have now become one of the costliest tariffs in South Asia, even though the same pricing level was maintained for more than a decade. The 20 per cent price increase in August 2012 and the additional 18 per cent increase in July 2016 were adopted following the guidance of the Tariff Fixation Committee of Nepal.

On the other hand, the study [72]argues that electricity prices in Nepal are too low to cover all real costs, and the current rates are not based on the economic principles, but rather on the vested interests and political motives. The electricity is then supplied to end-users at highly subsidized prices distorting the market dynamics. It could be one of the key reasons why NEA suffers substantial financial losses, so it cannot afford to invest the required sums of money to costly infrastructure and hydropower projects. In the absence of cost-based tariff adjustments during the last three years, the financial health of NEA has deteriorated to the point that it is unable to finance in the new as well as existing infrastructure to respond to the energy crisis [1].

The third strategy important for mitigating the energy crisis in Nepal is to optimise the mix of energy sources used in the country. The immense hydropower potential is not exploited to satisfy its energy demands and to prevent the energy crisis for more than a decade. Nepal has also been facing uncertainties regarding the supply of petroleum products from India from time to time. Nepal's geographical position, its small size, and its economic dependency on other countries left Nepal to be vulnerable, especially at times of geopolitical crises [73]–[75]. For instance, after the Nepalese parliament passed a new constitution in 2015, it prompted India to halt its trucks carrying cooking LPG, gasoline, salt and other essential products at the borders to Nepal [76], [77]. This trade blockade lasting for two months caused acute shortages of gasoline, cooking gas, and medical supplies.

To boot, Nepal must focus on utilising its enormous renewable energy sources to establish the right energy mix for the country. If these resources are well utilised, they will also transform the whole economy. Nepal has enough renewable resources to generate electricity to satisfy its needs as well as to sell the excess electricity to the entire SAARC (South Asian Association for Regional Cooperation) region. The challenge is to make these opportunities commercially, economically, and politically viable. The Government set the goal of increasing the share of renewables less than 1 per cent to at least 10 per cent and to improve access to electricity from alternative sources from 10 per cent to 30 per cent within the next 20 years. The government plans to invest 1,076 million USD in renewables by 2020, targeting hydropower, solar, and biogas technologies [78], [79] primarily. Even small-scale renewable energy sources, including hydro, solar, wind, and biomass, can be utilised to mitigate the present energy crisis immediately. A typical case, providing each house with a renewable energy source (PV system), maybe a cost-effective solution independent of the existing electricity infrastructure, and it would empower people both economically and socially. Therefore, the development of the renewable energy sector has become a high priority for Nepal. Still, renewable power plants do not always operate at their full generation capacity, mainly due to weather conditions. To provide the reliability and quality of the power system by utilising the renewable, the energy storage device and conventional generators are used to mitigate the likely outages. The fourth strategy is to combine several renewable energy sources, which can significantly increase power system reliability [80]. There are many possibilities of a microgrid that could also be formed interconnecting MHPS with wind turbines or PV systems [81]. The data on the adoption of renewable energy sources in Nepal since FY 2012/13 are provided in Table 2.21.

Table 2.21 Adoption of alternative energy sources in Nepal [48]

Electricity generation	2012/13	2013/14	2014/15	2016/17	2016/17	2017/18
Small and micro-hydro (kW)	3366	3288	3346	1245	957	939.5
# household solar systems	96495	87038	103161	16084	9291	16572
# solar pumps	140	202	30	0	5	14
# bio-gas plants	17635	31512	30078	20536	15707	8346
# improved cook stoves	120364	140662	310281	60555	34767	10018

Another strategy that can significantly save energy is by implementing thermal and electric energy efficiency measures in energy-intensive industries such as cement, palm, and paper, steel, brick, and sugar industries. According to the energy efficiency program’s baseline study, Nepal cement industries has the highest energy-saving potential of around 20 per cent [82]. By adopting energy efficiency measures, the cement industries can reduce production costs and improve their sustainability outlooks.

2.5 The Renewable energy potential of Nepal

The seasonal nature of renewable energy sources is one of the main challenges hindering their efficient utilisation [83], [84]. The more profound understanding of these barriers is required to support their adoption. Occurrence, the study [83]showed that despite excellent support from the international community, funding for small-scale renewable energy projects is usually somewhat limited. However, the small projects are likely to play a vital role in the transition towards more sustainable energy systems. Unfortunately, most funds seem to be allocated primarily to large-scale energy projects, and the energy needs of the poorest are neglected. The ongoing energy crisis forced policymakers to consider various energy models to balance environmental and economic benefits. The estimated energy potential from renewable energy sources in Nepal is presented in Table 2.22. This data indicates that Nepal can exploit immense amounts of hydropower, solar energy, wind, and biofuels. In 2018, only 12 per cent of the Nepalese citizens had access to electricity from renewable energy sources providing 23 MW from micro-hydro plants, 12 KW from solar PV systems, and 12 kW from the windmills. For a large part of the rural population using low electrical energy, there is no viable alternative to solar electricity for rural electrification. The operation and maintenance cost of diesel generators is too high, biogas technology does not work satisfactorily on the cold high altitudes or in the mountains and would be difficult to achieve with roving herds of cattle [85]. Small hydro turbines need specific topographical conditions that are only found near a small percentage of users' dwellings. Solar electricity generating systems, which do not require fuel or expensive infrastructure, and it is easy and quick to install within a week to a month. It could be a very viable option in many locations in the country. Though it cannot be claimed that solar electricity can solve rural electrification issues completely. Solar power also has some intermittent characteristics and limitations. Some researchers argue that it can overcome with proper planning and integration with other renewable resources like small hydro, Wind turbine, and biogas. A hybrid system distributed generation system would be the perfect match for uninterrupted energy supply for Nepal. As well, using renewable energy sources to increase access to electricity would appear to be an example of the synergistic strategies, contributing to poverty reduction, climate change mitigation, and improved resilience [86].

Table 2.22 The estimated renewable energy potential of Nepal [87]

Technology	Potential	Comment
Mini/micro hydro	>100 MW	Possible in 55 districts of Nepal
Domestic biogas	1.1 million plants	For existing livestock population
Solar energy	2,100 MW	4.5KWh/m^2/day radiation and 2% country area
Imp. cooking stoves	>2.5 million	Assuming 75% of households eligible
Improved water mill	25 – 30,000 MW	-
Wind	3,000 MW	Assuming 10% area with more than 300W/m^2
Biofuel	100,000 tons	-

2.5.1 Hydropower

It is estimated that the Himalayan rivers flowing through Nepal have a hydropower potential of 83,000 MW, while in India, Bangladesh, and Pakistan, the approximated hydropower potential is about 70,000 MW, 1,772 MW, and 21,000 MW respectively. After having substantial water resources, very sadly, for decades, the SAARC region has been suffering from the degradation of its natural resources base and environmental pollution because of their overuse and often misuse of natural resources. The efficient use of natural resource base and ecological conservation should be given maximum priority by SAARC countries to meet their growing energy needs and alleviate the health risk to their vast population [88].

The water resources in Nepal are estimated at 225 billion m^3/km^2/year, which is four times higher than the world average [89]. The hydropower is often promoted as the most viable option for Nepal and its future economic developments[90]. Notwithstanding, despite such colossal potential, Nepal is currently utilising, only 2 per cent of this resource [91], and other renewable resources are largely ignored. Presently, there are 88 hydropower plants in operation in Nepal with a total generating capacity of 967.85 MW; 60 of those plants belong to Independent Power Producers (IPP), and their contribution amounts to 441 MW. There are 120 hydropower plants in the construction stage, with a total capacity of 3,090 MW. The key hydropower projects are listed in Table 2.23. Most of the existing hydropower stations are a run-of-river type, so any reduction in the water flow during the rainless months is immediately reflected in the falling production. The total generation capacity of the 30 most significant hydropower projects is 12,766 MW representing only 15 per cent of the full hydropower potential of the country. However, only Kulekhani I and II hydropower plants with combined 92 MW of generating power have water reservoirs, so that they can sustain fluctuations of river flows. During dry seasons, the production is reduced by as much as 35 per cent to only about 571 MW while the domestic hydropower electricity generation plunges by more than 30 per cent. These levels of electricity supply cannot satisfy the daily peak demand of 1,500 MW, which necessitates the increasing energy imports from India.

Table 2.23 The key hydropower projects in Nepal and their capacity (in MW) [50], [92]

Completed projects		**Largest projects**		**Projects under construction**		
Upper Mai C	5.1	West Seti	750	Kulekhani3rd	4	2018/19
Dhunge Jiri	0.6	Budhi Gandaki	1200	Upper Tamakoshi	56	2018/19
Sabha Khola	4.0	Kali Gandaki	600	Upper Trishuli 3A	0	2019/20
Puwa Khola	4.0	Aruns	643	Rahughat	0	2020/21
Fawa Khola	5.0	Karnalis	1380	Tanahun	40	2022/23
Thapa Khola	13.6	Pancheswor	6480	Total	10	
Sardi Khola	4.0	Dudh Kosi	30			
Chake Khola	2.8	Andhi Khola	180			
Midim Khola	3.0	Langtang	218			
SyouriBhumi	0.02	Upper Tamakoshi	309			
Chameliya	30.0					

Large hydropower projects often have notable environmental, social, cultural, technical, financial, and economic impacts. Without any mitigating measures, these impacts are unevenly distributed, facing the prospects of high rewards as well as high risks [93], [94]. The World Commission on Dams developed a set of guidelines to address the social and environmental impacts of damson natural habitats and the livelihoods of people [49]. Unfortunately, the production of large hydropower projects is very sluggish as most of these projects are experiencing considerable cost and time overruns, from 6 months up to 12 years [1] as shown in Table 2.20 [32]. Likewise, Figure 2.7 illustrated the list of major hydropower projects under development stages. The required investments into hydropower are the behemoth. Approximately 2 million USD/MW is needed to build a hydropower plant from a detailed survey to project completion, making it easier to underestimate these costs. According to the IRENA 2018, the global weighted average LCOE for recently commissioned projects was projected to be $ 0.05/kWh for hydropower, $ 0.06/kWh for onshore wind, 0.07/kWh for bioenergy and geothermal, and $ 0.10/kWh for solar PV. Some environmentalist argues by giving examples of the Three Gorges project in China has faced several criticisms over environmental impacts and the relocation of 1.4 million people [95]. The world's largest hydropower dam in terms of installed capacity, the Belo Monte dam's construction work had been halted many times because of a series of rallies opposed to relocation, environmental impact, and social impact [96]. The highly debatable Akosombo dam in Ghana had pushed the relocation of 80,000 people between 1962 and 1966 [97]. The Narmada valley Hydropower project in India is one of the most debated projects. Its biggest Sardar Sarovar dam is claimed to displace 200,000 people and protest was done through a social movement, the Narmada Bachao Andolan [64].

Other reasons behind the overruns are NEA's centralised and prolonged procurement processes, the NEA's weak project management capacity, the existence of ghost contractors leaving the work to be done by inexperienced and technically and financially incompetent local contractors, and low project readiness at the time of the project approval [21]. The start of some of the hydropower projects is often deliberately postponed with the intent to build "water grab" dams that endanger the Himalayas ecosystem. More than 400 hydroelectric schemes are planned in the mountain areas, which can be a disaster for the environment [98]. A rail link with China can help Nepal to balance its strong dependence on its southern neighbour [99]. Both India and China have funded several large hydropower projects in Nepal, as shown in Table 2.24.

Table 2.24 The hydropower projects in Nepal funded by India and China [50]

Project	Power	Funder	Originated	Comments
Arun 3	900	India	Nov 2014	Just started. Financial management problems.
Dudhkoshi 2	240	India	April 2015	Applied for the license.
Dudhkoshi 4	350	India	April 2015	Undecided.
Upper Karnali	900	India	Sept 2014	Land acquisition compensation and financial management problems.
Bheri 3 Storage	480	India	Oct 2012	Survey stage.
Western Seti	750	China	Feb 2012	PPA, Investment style not fixed yet.
Upper Marsyandi 2	600	India	2011	Equity and free electricity put on hold.
Upper Trisuli	102	China	May 2015	Applied for the license.
Pancheshwor Trishuli	6720	India	1995	DPR not yet read.

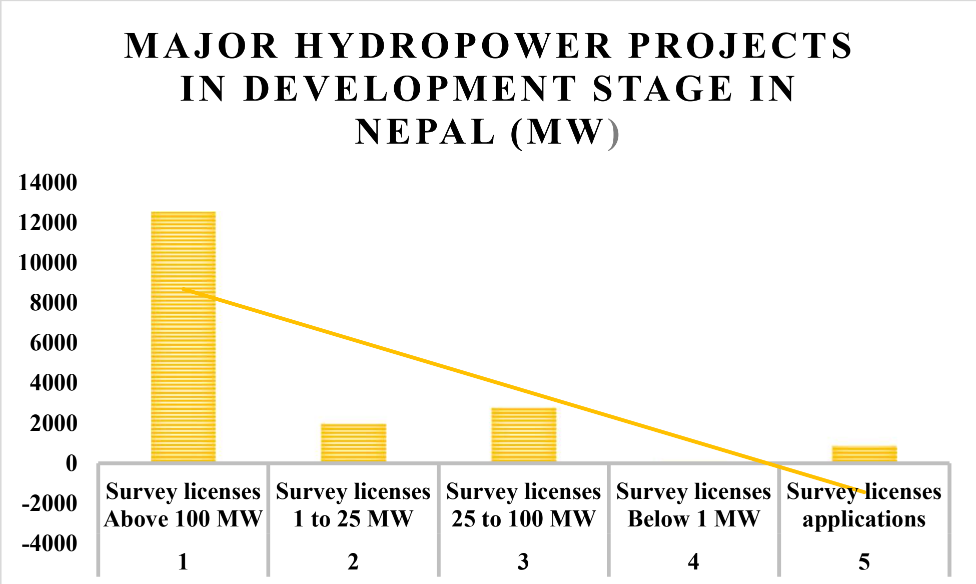


Figure 2.7 Major hydropower projects in the development stage in Nepal

Furthermore, political instability, labour actions, and power outages are the main obstacles for foreign companies to do business in Nepal according to the Enterprise Surveys for Nepal [100], which ranks Nepal to be 105^{th} worldwide in the 2014 Doing Business assessment. The "Water Resources and Public Investment" policy has been formulated to ensure participation of the general public and the Nepalese community abroad [101], aiming to develop sizeable reservoir-type hydropower projects by mobilising the capital scattered across the domestic markets and the local financial institutions.

Also, a small hydropower generation is now becoming very popular for the off-grid power supply in remote places [102]. According to the World Bank, over 400 micro-hydro power plants were built between 2007 and 2014 in Nepal, providing 150,000 rural households with access to reliable and clean power. Nepal generated 1,095 kW of electricity from the micro and small hydroelectricity plants in 2015 with 15 MW from mini-hydro projects. In 2016, 308 improved water mills were installed in Nepal [9]. The combined generation capacity of the existing domestic hydropower plants reached 961.2 MW [50]. Nevertheless, the current generation capacity of these plants is down to 617MW, which is a significant contributor to power cuts [103].

2.5.2 Solar

Among many available options for renewable energy, Solar PV is the best alternative for distributed energy generation, because of the quick decrease in cost along with advancement in technology [104]. The SPV has become so popular in the last decade that the global cumulative capacity of SPV generation globally has grown from 3 GW in 2003 to 219 GW in 2015 and reached 430 GW in 2018 [105]. The amount of solar energy incident on the Earth's surface is, on average, 1.5×10^{18} kWh/year. It is about 10,000 times the current annual energy consumption of the entire world [106].

Nepal lies between latitudes 26^0 and 31^0 N, and longitude 80^0 and 89^0 E. It is close to the tropic of cancer, so it experiences high solar irradiance. As a result, Nepal has abundant solar energy throughout the year with an annual average global solar radiation of Nepal varies from 3.6-6.2 kWh/m^2/day. Sunshine is about 300 days a year, the number of sunshine hours amounts almost 2100 hours per year and average insolation intensity about 4.7 kWhm^{2}day [107], [108]. Thus, Nepal is a favourable site for solar energy. The solar map of Nepal with average solar radiation intensities is shown in Figure2.8 [109].

Solar energy in Nepal has been used mainly for lighting in the communities not connected to the grid, but it is now spreading also to urban households and small to medium-size businesses. Harnessing solar power has helped several hospitals and medical clinics in rural Nepal to replace diesel generators [110]. If 0.25 per cent of Nepal is covered with the solar panels having 20 per cent efficiency, enough electricity would be generated to satisfy all of Nepal's demands [2]. The overall commercial potential of solar energy for the grid utilization in Nepal is estimated to be 2,100 MW, according to the 2008 AEPC report on the Solar and Wind Energy Resource Assessment. Nepal also received a credit from the World Bank towards the cost of the Grid Solar Energy and the Energy Efficiency Project (GSEEP) totalling 130 million USD [50].

In Nepal, 1.2 million people do not have access to electricity. Connecting every location through the national grid is neither possible nor technically feasible. Therefore, decentralised rooftop solar power supply for the people living in far remote areas is the best solution. Even so, the initial investment in decentralised rooftop solar power is enormous. Consequently, government policy, like affordable loans, the initial capital subsidy will play a very decisive role in attracting investors [111].

The Department of Electricity Development (DoED) classifies solar plants into several categories based on the installed capacity. Specifically, the stations with 500W to 10 kW are referred to as domestic producers, and the plants are producing 10 to 500kW are called organisational producers. The individuals are expected to cover their own needs mainly, whereas the solar plants with the installed capacity of more than 1MW will require a survey license to be issued for at least 25 years by the DoED. However, all producers, regardless of the generating power, will need to seek permission from the DoED before they can connect to the national grid. Small scale solar PV systems are used widely for lighting in a remote place of Khumbu (10 – 20 watts, 6 – 12 Volts, and 7 – 20 Ah battery capacity [85].

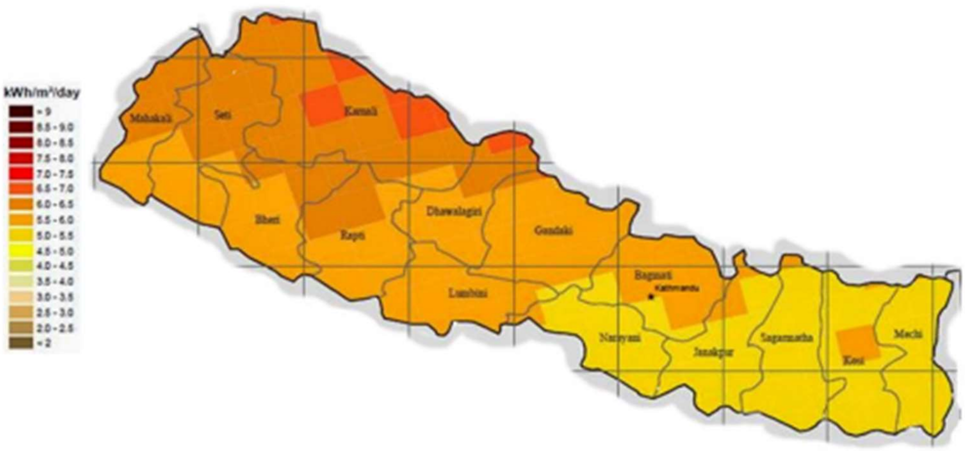


Figure 2.8 The solar map of Nepal [109]

The cost of solar PV panels is now half of what they used to be only seven years ago, and their prices are likely to fall by another 60 per cent over the next decade [112]. The solar PV panels are now viable without financial support, even in the regions with abundant fossil fuel resources [113]. At the same time, the prices of batteries and other electricity storage technologies have fallen as much as 80 per cent since 2010 [114].

2.5.3 Wind power

Wind power is one of the most widely used renewable energy sources around the world [115]. Nepal’s tall and windy mountains are very suitable for deploying wind turbines. The wind turbines are relatively quick to install, and they take much less space than large solar arrays. If the equipment is available and there are no political obstructions, a 100MW wind farm can be erected within 6 months. The more giant wind turbines have a much cheaper cost of electricity generation, but the primary concern is to have road access for their installation. The utilisation of wind energy is growing faster than the PV generation with annual increases in the capacity of around 20 per cent from 39 GW in 2003 to 318 GW in 2013, reaching 600 GW in 2018 [116]. Nevertheless, the wind electricity generation has to be backed by conventional generation capacity due to the wind intermittency [117]. Assuming the onshore wind turbines, China has the lowest weighted average Levelised Cost Of Electricity (LCOE) between 50 USD/MW to 72 USD/MW, whereas the Middle East and Africa; this cost is about 95USD/MW [112]. The wind industry has been able to prove its rising maturity, cost competitiveness, and efficiency by relying on one of the most critical measures (LCOE)in the energy industry. LCOE is the standard measure of defining the cost of wind energy and other energy sources for several years. Industry stakeholders and politicians are using LCOE to assess targets and support levels. The vital role of LCOE will not change and will continue to show how wind energy is progressing. LCOE of different renewable energy sources is compared in Figure 2.9 [118]. The result shows that the solar generation has the most significant decrease in LCOE over five years, while the hydropower remains the cheapest source. Therefore, the wind industry will need to continue playing its part using financial and technical innovation to drive costs down, improve project reliability and predictability, and to make it easier to integrate wind power into the power system. Further, by 2030, wind power could reach 2110 GW and supply up to 20 per cent of global electricity according to the Global Wind Report 2018. The wind sector once again grew strength. Wind energy is now one of the cheapest forms of electricity in many markets. Installations of wind capacity overtook new fossil fuel capacity in many mature and engineering markets for the first time. These are strong essentials for a now mainstream energy sources [119].

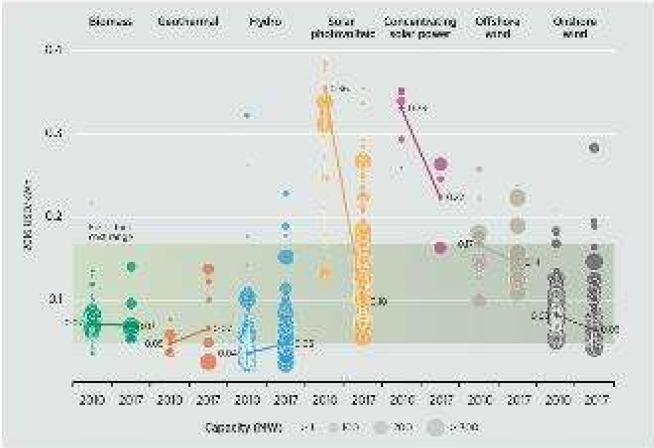


Figure 2.9 Global levelised cost of electricity from utility-scale renewable power generation technologies 2010 – 2017 (IRENA Renewable cost database)

The wind power potential in Nepal is estimated to be 3,000 MW, according to the World Bank[120]. Although, the current utilisation of wind power is negligible as the focus is almost exclusively on hydropower. The history of wind power started when the first wind turbine generator with 20 kW capacities was installed in Kagbeni of Mustang District in 1989, although within the first three months of operation, the blade and the tower got broken. Other wind turbines were installed in Chisapani of the Shivapuri National Park and Nagarkot, but they are not operational anymore. As part of the Asian Development Bank Renewable Village Program, two 5kW wind turbines in Dhaubadi village of Nawalparasi District were installed. As of 2018, the wind turbines installed in Nepal have a total generation capacity of 113.6 kW, comprising of 65 kW wind turbines provided by the Alternative Energy Promotion Centre (AEPC), and the private sector finances 45.1 MW wind turbines. A draft of the National Wind Policy for Nepal has been prepared by the National Wind Task Force (NWTF). The on-grid wind power purchases agreement provision was mentioned in Nepal's Energy Crisis Alleviation 10-Year Development Plan in February 2016. The South Asia Sub-regional Economic Cooperation (SASEC) project is funded by the Asian Development Bank (ADB). This project aims to review tariff regulations and norms, including designing tariff plans for the remote mini-grid connections. More importantly, all wind turbine projects in Nepal are tax exempt. The DoED now accepts applications for the on-grid wind power licenses consisting of the survey license and the generation license; though, so far, no project has been approved.

In spite of the fact that no comprehensive wind mapping of Nepal has been conducted yet, although saying that a relevant project is ongoing with the help of the Technical University of Denmark (DTU) and the 3E, a Belgian company, to identify the ideal sites for the wind farms in Nepal by producing 80 – 100 meters wind resolution map for 10 selected sites. The output of this 3-year project will be the Wind Atlas of Nepal [121]. A low-resolution wind map of Nepal, which is insufficient for planning the wind turbine deployment is shown in Figure 2.8 [122]. Besides, the wind mapping initiative of Nepal as part of the Energy Sector Management Assistance Program (ESMAP), and part of the Nepal Energy Sector Development Platform, the World Bank Group has designed a capacity development program for educating the policymakers, financiers, developers, and technical experts[120]. The World Bank intends to produce a public 200 meters resolution wind map of Nepal by 2018. This wind map project has been done so far. Figure 2.10 is obtained from the Global Wind Atlas online owned by the Technical University of Denmark.

A global atlas formulated by the World Bank illustrates that Mustang is an ideal place for wind energy development (See Figure 2.11). If only 2 per cent of the mustang's land area is covered by a solar and wind turbine, Mustang can generate 3,000 MW of solar power and 1,200 MW of wind power [123].

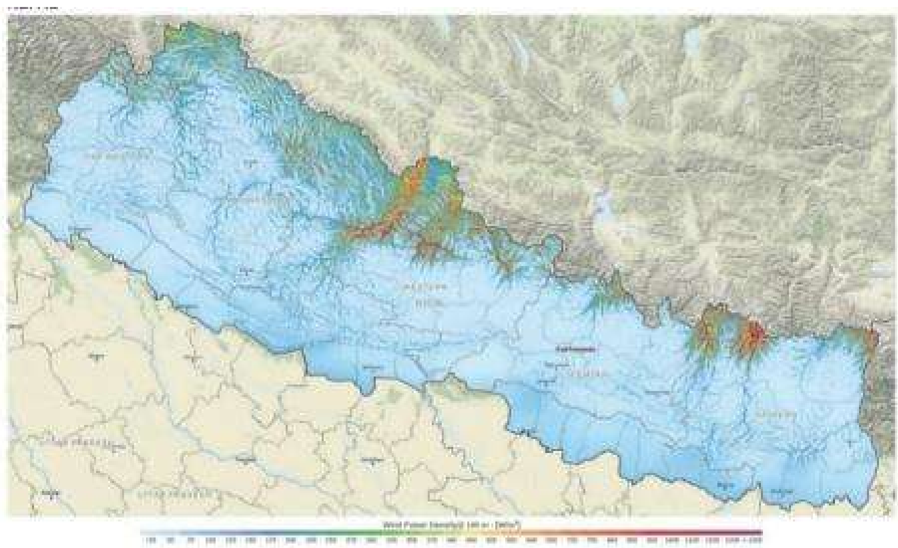


Figure 2.10 Global wind atlas mean wind power density map of Nepal [122]

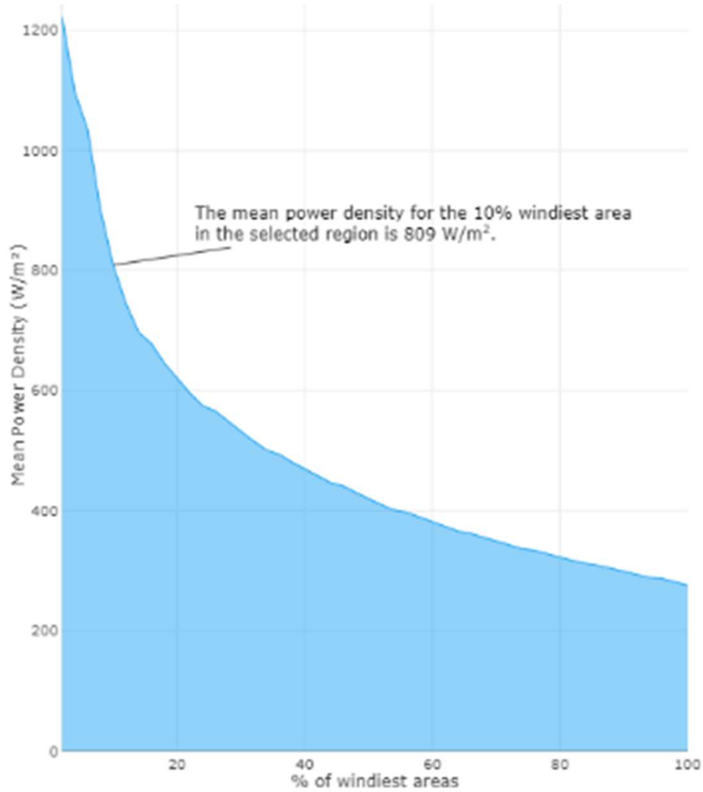


Figure 2.11 The mean power density for the 10% windiest area in the selected region of Nepal

2.5.4 Biomass

Traditional fossil fuels have dominated world energy supplies for decades. Biomass contributes some 9-14 per cent to the total energy supplies, but in developing countries like Nepal, this is as high as one-fifth to one-third [124]. Biomass is a significant source of energy for cooking and heating for more than 2 billion people, mostly from developing countries and Nepal, not being an exception. The residential sector in Nepal accounts for more than 80 per cent of energy consumption. The traditional biomass is the primary source of fuel and accounted for 95per cent of the total energy consumption in the residential sector. Fuelwood comprises 90per cent of the biomass, followed by animal dung 6per cent and agro-residues 4per cent [125].

Since Nepal is mostly an agricultural country, livestock and farming activities produce massive amounts of biomass in the form of crop residues and animal waste, including dung, bagasse, and rice husk. Regardless of how, the traditional use of millions of tons of biomass creates indoor air pollution, which diminishes the quality of life, especially for young children and women [126]. According to the World Health

Organisation [127], over four million people a year die worldwide due to illness caused by household air pollution from cooking with solid fuels such as wood, crops, and animal dung. Nepal census of 2001 proved that number one deaths due to asthma and bronchitis were 7,170 (6.71 per cent) annually, among which the deaths of infants had a shared of 23 per cent. PM10 (density, in the air, of particles lesser than 10-micron meter in diameter) measured at Nepal homes was 2,418 μg/m3, which was about three times heavier the case when LNG was burnt [128],[127]. Nepal's forest area has also been briskly declining because people tend to consume more wood.

As a solution to the above massive problems, improved biomass stoves have been developed and becoming famous. Biogas is a cleaner cooking option in rural households that have a minimum of two cattle or buffaloes. The dung of the livestock is the source of feed for biogas production. The beginning of the biogas exploitation in Nepal was the program by the United Mission to Nepal in 1974/75, whose objective was to make the biogas plants like those used in India. The Agricultural Development Bank of Nepal (ADB/N) assisted in financing these plants through credit frameworks. In 2014, a conservative forecast by Winrock International predicted that the remaining technical potential of biogas is about 0.9–1.3 million plants [129]. Although there is no estimate of how many of those can become large commercial systems, at present, there are 365,000 household biogas systems and ten community and 370 institutional larger biogas systems in operation according to the World Bank. From the technical and financial help from various national and international agencies, has been able to install over 3,30,000 biogas digesters all over the country [125].

Nepal has a target to meet 100per cent electrification rate by 2030, out of which 75per cent would be grid supply, and 25per cent would be off-grid supply. Nepal has also committed to reducing its GHG emissions in future; however, the reduction target has not been quantified. Moreover, the Nepal government has promised to disseminate biogas stoves and improved cooking stoves in order to reduce forest degradation and GHG emission [125]. There are numerous studies carried out using integrated energy models in the case of Nepal. The studies have assessed the implications of the carbon tax, transport electrification, and low carbon development on energy and GHG emissions [130].

Table 2.24 Global renewable power generation costs in 2018

	Global Weighted Average Cost of electricity (US$/kWh) 2018	Cost of electricity: 5th and 9th percentiles (US$/kWh) 2018	Change in the cost of electricity 2017-18
Bioenergy	0.062	0.048 - 0.243	-14%
Geothermal	0.072	0.060 - 0.143	-1%
Hydro	0.047	0.030 - 0.136	-11%
Solar PV	0.085	0.058 - 0.219	-13%
Concentrating Solar power	0.185	0.109 - 0.272	-26%
Offshore wind	0.127	0.102 - 0.198	-1%
Onshore wind	0.056	0.044 - 0.100	-13%

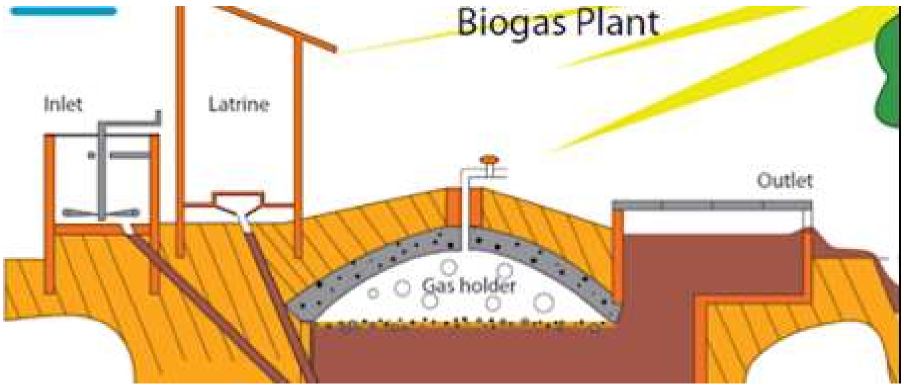


Figure 2.12 Biodigesters adopted from SNV Netherlands development organization

SNV is a not-for-profit organization aiming to make a lasting difference in the lives of people living in poverty, various developing countries like Nepal. Biogas can be generated from wastes, energy crops, human and animal faeces, as illustrated in Figure 2.12. Biogas constituents are primarily methane and CO_2 and are suitable for heat and power production [131],[132]. According to Bhattacharya et al.; Haryanto et al. [133], [134], agriculture residues such as livestock faeces, residues, and wastes from food industries are the most suitable substrates for biogas production. Table 2.25 presents the Cumulative achievement in technology promotion (AEPC annual report 2017/18). Similarly. Figure 2.13 shows the development of the biogas system in Nepal by illustrating the year wise installation of biogas plants 1992/93 – 2015/16.

Table 2.25 Cumulative achievement in technology promotion (AEPC annual report) [135]

Program	Unit	Achievements till FY 2017/18
Mud Improved Cooking stoves(ICS)	No.	1,423,242
Solar Home System	No.	850,643
Domestic Biogas	No.	416,060
Micro/Mini Hydro	kW	30,706
Institutional solar PV system	No.	1,752
Metallic Improved Cooking stoves(ICS)	No.	55,892
Improved water mill (IWM)	No.	10,857
Urban solar home system	No.	21,144
Solar drinking water and irrigation pump	No.	486
Solar/Wind mini-grid system	kW	413
Large Biogas Plant	No.	189

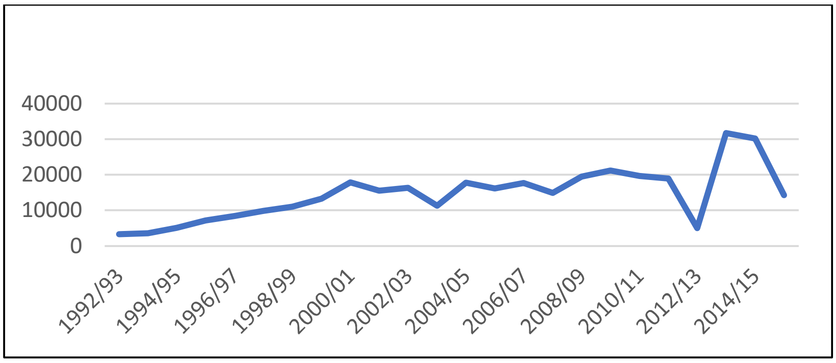


Figure 2.13 Year-wise installation of biogas plants 1992/93 – 2015/16 [136]

Table 2.26 Statistics on electricity access, and traditional use of Biomass for cooking [137]

Region/Country	Population Without Electricity (in Millions)	Electrification Rates (2013)			Population relying on biomass (2012)	
		National%	Urban%	Rural %	In Million	%
Rest of Developing Asia excluding China, India & South East Asia)	168	6%	86%	53%	328	72%
Nepal	7	76%	97%	72%	22	80%

Source: World Energy Outlook 2015, IEA

Table 2.26 illustrates that the Statistics on Electricity Access, and traditional use of Biomass for cooking. In August 2012, Nepal joined the UN Secretary General's

SE4ALL initiative, and in 2013, the National Planning Commission (NPC) published the Rapid Assessment and Gap Analysis Report. The Report illustrates that the progress but also several gaps, such as lack of an environment conducive to business and private sector entry, appropriate policies and regulations, and market-oriented tariff structure, amongst others.

2.6 Policies for renewable energy adoption

Given the integrated environment of South Asia, it is crucial for SAARC countries to think of strategies for environmental conservation collectively. This will require the South Asian Development Fund in order to provide financial support to regional renewable energy projects. Comparable to regulate energy projects and industries, the Government of Nepal has formulated and issued many relevant acts, rules, regulations, and policies. The country's substantial hydro, solar, wind, and biogas resources represent excellent opportunity to reconsider the current energy generation strategy and shift the attention from mainly hydropower thinking to other types of renewable sources. The policymakers in Nepal are presently exploring mixed energy models. To boot, it has been shown that including solar power into the energy mix can make a noticeable difference[138]. The energy mix of different renewable energy sources with suitable energy storage solutions can be beneficial to cope with daily and seasonal demand fluctuations [139]. Woefully, the adoption of renewable energy generation has been very slow so far. New measures to boost the utilisation of renewables are necessary for the form of policies, regulations, legislative frameworks, licensing arrangements for the private sector, decisions on tariffs, and defining renewable energy market rules. As long as Nepal can start implementing its energy policies and other measures beneficially, it can likely satisfy its current as well as future electricity demands [140]. More specifically, the following energy policies and acts were recently issued by the Government of Nepal: the Hydropower Development Policy(1992) [141]and (2001) [142], the Water Resource Act (1992) [143], the Electricity Act (1992) [144], the Forest Sector Policies and Forest Act (1993) [145], the Water Resource Strategy (2002) [146], the National Water Plan (2005) [147], the Rural Energy Policy (2006) [148], National Electricity Crisis Resolution Action Plan (2008), the 10 Years Hydro Power Development (2009), the Energy Sector Synopsis Report

(2010) [149], the Government of Nepal Scaling up Renewable Energy Program (2011) [78], and the National Energy Strategy of Nepal (2013) [150].The Rural Energy Policy (2006) [148] highlighting the opportunities for improving the living standards in rural communities by developing and exploiting sustainable, i.e., renewable energy sources. The main objectives of this policy are: (1) reduce the dependency on traditional energy sources and conserve the environment by increasing access to the clean and, cost-effective energy in rural areas, (2) increase the employment and productivity through the development of rural energy resources, and (3) improve the living standards in rural populations by integrating the energy with the social and economic events. More recent renewable energy policies and visions of the Nepalese government which are in effect from 2016 include: Renewable Energy Subsidy Policy(2013) [151],Renewable Energy Subsidy Delivery Mechanism(2013) [152], National Energy Crisis Mitigation and Energy Development Decade (2016) [153], and Renewable energy capacity needs assessment for Nepal (2016) [154].

In addition to these policies, the Ministry of Water Resources, the Ministry of Energy, Water and Energy Commission, Department of Electricity Development, and the Nepal Electricity Authority have the right to formulate different policies, administer the development of hydropower projects, and enter into the power purchase agreements (PPA). There are also tax exemptions for renewable energy systems and components, various guidelines for technology standardisation, quality assurance, and monitoring, and the carbon revenue utilisation. The assessment of climate and carbon activity impacts has been published in the government report [155]. Besides, Nepal is the signatory country of many bilateral and multilateral agreements with international partners to foster cooperative research and development. No matter how, these pacts are typically more ceremonial than actionable, so Nepal's international activities are of limited value, despite the enormous opportunities to participate in the growing global energy markets [156].

Moreover, Nepal is now undergoing a significant governance transition to a federal system consisting of 7 newly elected federal governments. It creates an opportunity to restructure its energy systems and address the energy crisis. In whatever way, due to the diversity in geography and development, there are some inequalities in terms of energy infrastructures among the federal states. The National Planning Commission (NPC) of Nepal drafted a proposal to produce 383MW of electricity from

277 of hydropower plants dispersed among all seven provinces with the generation capacity between 500 and 1000 kW as indicated in Table 2.27 [48]. This proposal also counts on the local exploitation of solar, wind, and biogas resources. The number of certificates and licenses issued for hydropower projects is summarised in Table 2.26 [48]. In January earlier this year, the Nepalese government requested that NEA starts promoting the use of renewables so that the alternative energy sources can reach at least 10 per cent of the total installed capacity soon. Also, the Ministry of Energy issued guidelines in February 2018 for connecting alternative energy sources to the national grid. These guidelines are intended for individuals, Organisations as well as large commercial producers. The NEA will subsidise all these producers at the rate of 7.30 NPR/kW with the priority being given to the solar energy.

Table 2.27 The3-year 13th government plan to increase energy generation in Nepal [30].

		End 2015	**13th Plan targets**
Per capita electricity (kWh)		132.65	140
Generation (MW)		829	1,358
Electricity access (%)		61.94	67
Houses (millions)	2.868	3.115	
Villages	2,892	3,000	
33 kV distribution lines (km)	4,011	4,000	
11 kV distribution lines (km)	28,824	25,500	
Distribution lines >66 kV (km)	2,848.86	2,958.86	

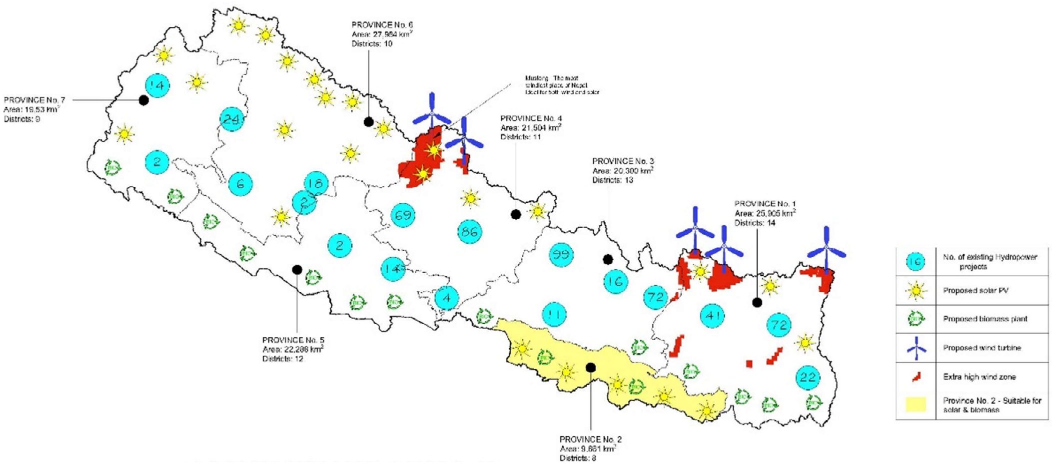


Figure 2.14 Energy mix map of Nepal

2.7 Key results from the data and literature

The continuing and even increasing dependency of modern societies on energy creates a complex web of challenging and interrelated issues. These issues are targeted by programs such as SDGs of the UN, and they have far-reaching impacts on social stability, quality of life, and the environment. The effect of insufficient energy production in developing countries such as Nepal is profound. Lack of energy creates daily nuisances such as long queues at gas stations and long hours of load shedding. However, the long-term impacts on the economic performance and development of Nepal are even more severe. Recently, the state-controlled NEA started to improve the dismal energy situation by adopting a series of policy and technological measures. A politically appointed position of the NEA director underlines the interdependence of energy and political matters. Some of the recent NEA achievements include expanding the electricity generation and distribution capacity and directing load shedding mainly to the most significant industrial consumers. NEA's management performance significantly improved, so it finally generates an operating surplus. Withal, the past poor performance of NEA contributed to the rise of IPP providers, which changed energy markets in the country. The power supplied by IPPs reached 80 per cent of the electricity annually imported from India. In absolute terms, the IPPs now produce almost 30 per cent of the total supply while the exports from India amounted to about 35 per cent. Regrettably, the electricity imported from India is mostly made by burning dirty coal. The problems in the energy sector, which Nepal is currently facing, are summarised in Figure 2.15.

Despite tremendous renewable resources, Nepal is facing many obstructions to meet its energy demands. The hydroelectricity represents more than 99 per cent of electricity in the national grid; although only about 2 per cent of the overall hydropower potential is utilised — diversification and increasing electricity production is an essential condition for improving the country's socio-economic development. There are many great opportunities to invest in renewable energy technologies to change the energy and economic situation in Nepal. Over and above that, harnessing renewable energy supports sustainability. It is essential to understand how investments in small and abundant renewable energy projects can affect the energy-dependent economy of Nepal, and how to establish the right mix of different renewable energy sources to suit the needs of people in cities and rural areas. Locally, smaller-scale renewable energy sources can be utilised to promote the economic activity and lifestyle of communities in remote areas. Yet, large hydro projects are necessary to secure industrial and agricultural production in the long run. While renewable energy generation is somewhat volatile due to varying weather and seasonal conditions, the promptly falling prices of renewable energy technologies can turn Nepal into a notable/high exporter of electricity to other countries.

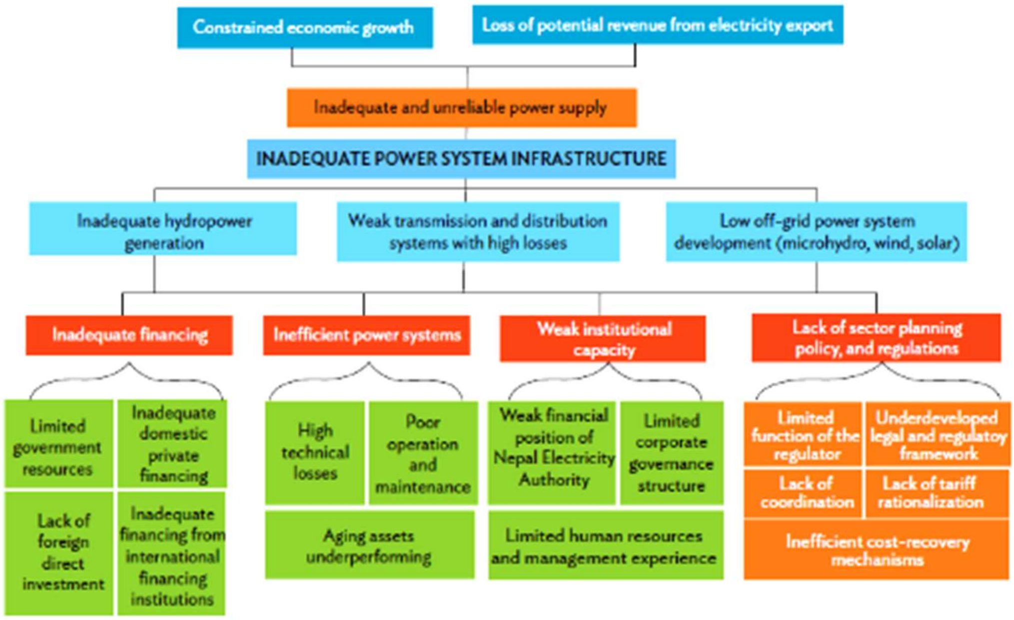


Figure 2.15 Overview of the problems in the energy sector in today's Nepal [157]

The current level of energy intake in Nepal, with the poor harnessing of its renewable resources and expanding dependence on imported fossil fuels, is unsustainable. The electrification rate of Nepal remains to be one of the lowest among the developing countries, while the electricity grid remains unreliable. Since developing the electric power grid and the power stations is hugely capital intensive, substantial funding and proper technical expertise both from private and public sectors are required. In order to break down policy barriers and to tackle persistent challenges of low investments and weak productivity, Nepal needs to dramatically restructure its public investment programs, intensify the level of competition in the domestic markets, especially in transport, logistics, and telecommunications, and reduce the costs of doing businesses, and open and steadily integrate its economy into the global world [29]. Renewable energy projects need to be promoted by the government to produce and sell electricity in the domestic and foreign markets. Nepal also needs significant investments in the modern infrastructure, mitigate the T&D losses, monitor and improve energy efficiency, and raise the overall industrial production. The digitalisation of electricity distribution networks enables automation and near real-time management of electricity demands and supply. These functions can be stimulated by international sharing of policies and best practices, including data collection strategies, and by achieving a society-wide focus on conserving energy. The plans which are suitable to tackle Nepal's energy problems are summarised in Figure 2.11. The short-term and long-term policies to provoke the national economic developments are discussed in detail in [100] where the recommendations are made for the countries facing different challenges: weak level of investment, tax competition, in the process of diversifying the economy and having a unique advantage such as large amounts of renewable means. It is clear that Nepal can be considered under all these 4 scenarios (Table 2.28) [100].

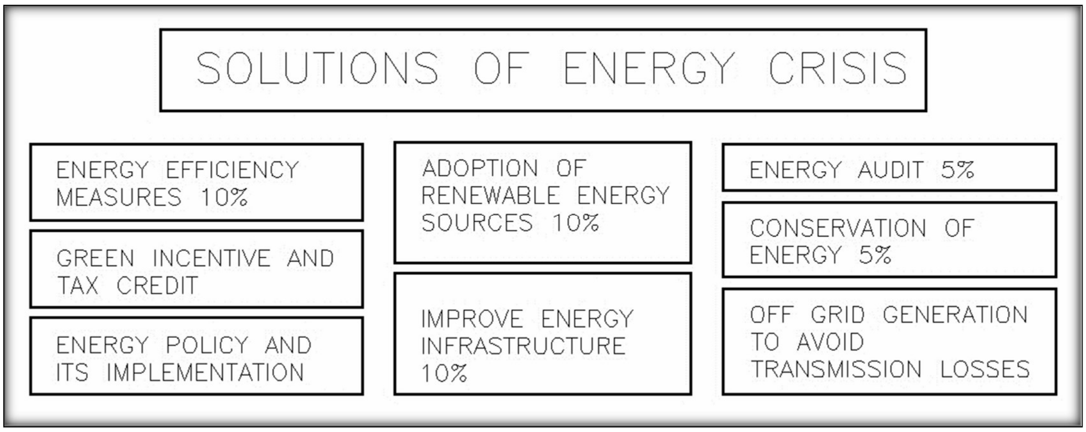


Figure 2.16 General strategies for solving the energy crisis in developing countries

Renewable energy sources abundantly present in Nepal are naturally the key potential solution to the energy crisis since they are both immediately available as well as sustainable in the long run. Creating the right energy mix for Nepal is still subject to debate. Hydropower plants will likely remain to be the dominant source of electricity. Regardless, the existing run-of-river hydropower systems may be improved by also considering peak-run-of-river and reservoir type of projects. Other renewable sources started to be recognised only recently. The solar, wind, and biomass (See Figure 2.14), should all be considered to increase energy security, reduce GHG emissions, and to lower the dependence on energy imports and fossil fuels. In particular, the use of PV rooftop panels and wind turbines is economical, provided that the required load is less than 75kWh/day, and the load point is more than 50 km away from the national grid. The pumped hydro storage systems can be the right solution for peak-hour load management and levelling the electricity demand more evenly over the day. The development of the hydropower-based electricity storage can significantly reduce the seasonal dependency for the flow-of-rive type hydropower systems. The energy consumption and energy efficiency must be monitored at different scales, preferably in real-time, to minimise the currently massive energy losses. These measures need to be adopted as soon as possible since their impact on the energy crisis is significant. It would also be instrumental to periodically report the energy-related data which can be subjected to international auditing.

Table 2.28 The recommended investment incentives and policies [100]

Scenario	Short – term policy	A long – term policy
Countries with the weak investment climate	Investment incentives are ineffective and the waste of tax revenues. The revenues should instead be used to provide public goods. Reforms should be introduced to streamline the taxes.	Such countries should reduce barriers to investment, for example, by simplifying investment procedures
Countries facing tax competition	Incentives can be used in the short term to ensure that the country is not a disadvantage relative to its neighbours.	Such countries should work on regional pacts to stop tax competition and promote their substantive differences (labour skills, infrastructure, and so on).
Countries seeking to diversify their economy	Such countries can use incentives linked to investment growth (investment allowances, accelerated depreciation), but for a limited period based on clear prioritisation of sectors in line with FDI competitiveness.	Broader industrial policy strategies have to be followed, including a focus on sector targeting and promotion to attract investments.
Countries with a unique advantage (natural beauty, natural resources)	General investment incentives to attract investments that exploit such advantages waste revenue unless they can start investments.	Barriers should be lowered for investments designed to exploit natural resources, e.g. by improving access to land.

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Chapter 3
Long-term forecast of Nepal's energy supply and demand

This chapter aims to analyse the electricity supply and demand by the Long-range Energy Alternative Planning System (LEAP) model. This chapter predicts the energy demand up to 2042. Part of this work has been published in Poudyal et al. 2019 [1], and a detailed analysis of the study is under review at separate submission in the same journal Renewable and Sustainable Energy Review Poudyal et al. 2019.

3.1 Introduction

Nepal is facing a chaotic energy crisis for a decade. The difference between demand and supply is widening quickly due to an increase in lifestyle, population growth, and industrial activities. While energy demand is increasing speedily, the generation side is sluggish. Nepal has a low level of electricity consumption of 139.14 kWh per capita per year compared with the world average of 3,104 kWh per capita annually [2], [3]. The rising demand for the total energy consumption in Nepal, in the 2014/15 fiscal year (FY), was 11,232 toe (tons of oil equivalent) [4]. Nepal relies heavily on traditional energy sources such as wood, as it has no significant deposits of fossil fuels. Equally, conventional fuels represent 78 per cent of the total energy consumption, followed by 12 per cent of petroleum products. The use of new renewable energies and the on-grid electricity generation are each just 3 per cent [4]. In addition, the dependency on imports of electricity and fossil fuels is continuously growing year by year. The price of kerosene as the primary and only source of energy for many people in rural areas has increased by 216.66 per cent over the past 17 years [1], [5], [6].

Around 85 per cent of households and 95.5 per cent of the population have access to electricity in Nepal, while the world average is 88.8 per cent [7]. On the contrary, according to the World energy council's Trilemma index, 2019, Nepal ranks 117 among 127 countries in terms of energy consumption [8],[9]. Sadly, Nepal ranks 137 among 147 nations on the quality electricity index [1]. This is the ill-lit picture of the quality power system of Nepal.

The resulting energy crises stem from the rising energy demands while the energy generation capacity is limited. This has direct adverse effects on state economies [10]. Emphasising, there is an urgent need to find out sector-wise energy demand of the country in terms of demanding fuels and need to examine the additional demand of clean energy resources. In connection to this, a proper combination of sectoral energy demand models of the country must be formulated for determining the national energy demand of the whole country.

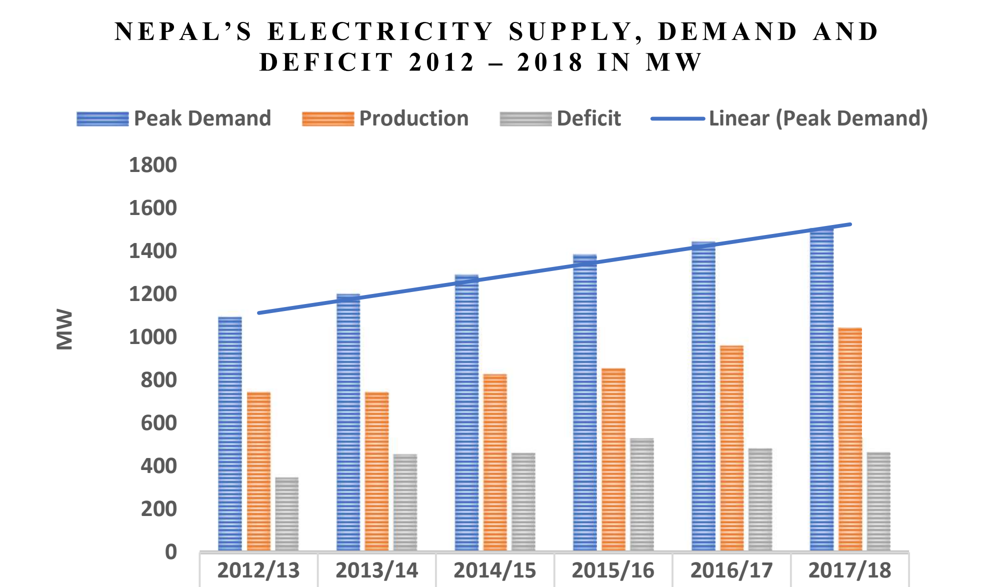
Numerous modelling tools are successfully implemented worldwide for devising energy policies. Various developing countries such as; India, Pakistan, Bangladesh, China, Ghana, Turkey, Nigeria have addressed critical energy issues by assisting effective energy policy formulation using these tools [11]. Likewise, few studies have been conducted to observe the relationship between energy consumption and economic growth [12],[13],[14],[15]. The overall findings prove that there is a strong relationship between energy consumption and economic growth [16]–[19].

Complementary to that, the primary aim of this study is to analyse the integrated energy resources planning for electricity generation. Future energy demand is analysed by using the LEAP model up to 2012 – 2042. LEAP software is an integrated modelling tool that can be used to track energy production, consumption, and resource extraction in all sectors of an economy. Additionally, to tracking Green House Gas (GHG), LEAP is used to examine emissions of local and regional air pollutants, making it well-suited to revises the climate co-benefits of local air pollution reduction [20],[21]. This study is also expected to contribute to filling the gap in Nepalese energy-related research.

It is concluded that the outcomes of the study will be helpful for formulating necessary policy measures for policymakers and concerning stakeholders in the sector. This study provides the possible structure of domestic energy demand with contributing demanding fuels. It also presents the necessary information on the energy demand inputs for the supply-side energy planning of the country. This helps to find the energy consumption trend, economic growth, and to obtain policy implementation from the results.

The remainder of this chapter is organised as follows: Sections 3.2 and 3.3 briefly review the supply, demand, and deficit of electricity and petroleum product. Section 3.4 discusses the research method used; Section 3.5 describes the long-term forecast of energy demand in Nepal and energy demand modelling. In this section, modelling is carried out for business as usual scenario and has Results and Discussion are outlined. Ultimately, section 3.6 concludes the research.

3.2 Supply, demand, and the deficit of electricity



	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Peak Demand	1094	1201	1291.1	1385	1444.1	1508.2
Production	746	746	829.2	855.9	961.2	1044.6
Deficit	348	455	461	529.1	482.9	463.6

Figure 3.1 Nepal's electricity supply, demand and deficit 2012 – 2018 in MW

The supply of electricity in Nepal is excessive reliance on hydropower plants, followed by diesel and solar. Existing hydropower plants are unable to attain full production capacity due to seasonal flow as most of the hydropower project is a run-of-river type. Figure 3.1 illustrates the supply, demand, and deficit from 2012 to 2018 in MW, where the massive difference in supply and demand is observed. This difference rises more in the dry seasons, and 70per cent is not obtainable [22]. Tables 3.1 and 3.2 show that the energy situation in Nepal rapidly deteriorates in dry seasons lasting from November to April when the water level in many rivers is significantly reduced while the situation improves during wet seasons from April to November each year.

Table 3.1 National planning's analysis in monsoon wet season (Apr/May – Nov/Dec)

Year	Electricity Demand in MW	Electricity supply in MW	Balance in MW
2018/19	1841.13	2283.45	441.32
2019/202.87	2225.65	2856.97	631.32
2020/21	2638.29	3584.44	946.15
2021/22	3062.87	3963.87	901
2022/23	3365.97	4046.14	670.17

Table 3.2 National planning's analysis in the dry season (Dec/Jan – Mar/Apr)

Year	Electricity Demand in MW	Electricity supply in MW	Balance in MW
2018/19	1841.13	1470	-372
2019/202.87	2225.65	1686	-539
2020/21	2638.29	1928	-709
2021/22	3062.87	2055	-1007
2022/23	3365.97	2079	-1283

3.3 Supply, demand and deficit of petroleum products

Nepal Oil Corporation Limited is a state-owned trading enterprise of Nepal that imports, stores, and distributes various petroleum products. All the petroleum products and LPG for cooking consumed in Nepal are procured and imported from India. The nearest seaport from Nepal is Haldia (Kolkata), which is about 900 Km from the nearest Indo-Nepal border. Unfortunately, the present storage capacity of NOC is 71,622 Kl is just enough for 15 days [23]. This is the biggest bottleneck of the energy crisis in Nepal as a similar kind of storage capacity in other countries is about three months or more [1].

The petroleum sector in Nepal is a monopoly as the country's petroleum needs are satisfied by imports. Nepal imported 2.07 million kiloliters of petroleum in 2017/18 (see Table 3.3), and demand has been rocketing at the rate of 13.8 per cent annually. It is projected to exceed 13 million kiloliters in the next three years [24]. The private sector only has gas storage facilities of about 6,000 tons of LPG.

Diesel petrol and LPG are skyrocketing every year. In 2035, the LPG demand for cooking is projected to be 26.5 million GJ, 16.3 million GJ, 45.2 million GJ and 58.2

million GJ for business as usual (BAU), Low growth rate(LGR), medium growth rate(MGR) and Higher growth rate(HGR) scenarios, respectively. Similarly, to substitute LPG with electricity in the cooking sector by 2035, an additional 1207 MW, 734 MW, 2055 MW, and 2626 MW hydropower installation is required for BAU, LGR, MGR, and HGR scenarios, respectively. In the MGR scenario, substituting LPG with electricity could save from $21.8 million (2016) to $70.8 million (2035) each year, which could be used to develop large-scale hydropower projects in the long term [25].

Table 3.3 Gasoline consumption of Nepal in Kiloliters from 2013/14 to 2017/18

Year	Petrol	High-Speed Diesel	Aircraft Oil
2013/14	251,451	811,100	123,527
2014/15	283,567	901,393	139,404
2015/16	238,578	782,658	80,119
2016/17	402,278	1,297,066	164,299
2017/18	484,781	1,597,551	194,358

3.4 Research methods

The energy demand forecast is essential for the future of the energy planning of the country. As energy planning is not a one-stop activity, it needs a regular update. Every country is trying to devise the proper strategies to balance energy resources and increasing demand. The long term forecasting of energy demand and supply is vital in Nepal due to the steady increase in energy necessity, the non-availability of petroleum products and LPG, the high dependence on imported fossil fuels to meet the requirements, and the universal concerns over the energy-induced environmental issues. This chapter is concerned with modelling possible outlook paths for Nepal's energy future and the related emissions. Future energy demand is forecasted based on socio-economic variables such as per capita income, GDP, population growth, and urbanisation trend.

Energy management software such as LEAP, MARKAL, and TIMES are the most prominent tools for developing energy models and forecasting various energy requirements [26]. This study is exploratory and limited to Nepal's electricity generation. In this chapter, LEAP is utilised for supply and demand analysis of current and forecasted energy, assessment of environmental emissions, and cost-benefit ratios. Data for the period 2011/2012 was used to calibrate the model parameters. A scenario for the period of 2011/2012 – 2041/2042 were undertaken, which is business-as-usual (BAU) scenarios.

As discussed in the previous chapter, the largest energy consumers in Nepal are the industrial, commercial, and agricultural sectors. Our prediction methodology extrapolates the energy consumption data available for FYs 2011/12 until 2016/17. The energy forecast assumes an optimistic BAU scenario since other scenarios may require detailed long-term analysis of the anticipated societal, economic, and technology trends, which is beyond the scope of this chapter. For instance, future energy systems will involve increasing electrification and the share of variable renewable sources. Representing the short-term variability in the long-term studies and incorporating the effects of climate change to ensure openness and transparency in modelling is difficult [27].

The annual compound growth rate for fuels is used for supply and demand forecasting. Environmental emissions are calculated according to the intergovernmental Panel on Climate Change (IPCC) calculations. The benefits that have bought LEAP in selection for this work include:

- Low initial data requirements
- Easily adjustable time frame
- Integrated planning
- Multiple modelling methodologies
- User-friendly interface

The study also provides some policy insights and recognises synergies and trade-offs relating to the potential of energy policy to promote universal energy access, to enable a transition to renewable energy, and to mitigate climate change for sustainable development.

3.4.1 Developing energy demand model in LEAP

The LEAP adopts a bottom-up accounting framework that is used for energy modelling and forecasting [28]. The modelling relies on the existing data of electricity consumption, and it also incorporates information related to population, settlement patterns, and other macroeconomic factors. The integrated modelling is used to track the energy demand, energy production, and utilisation of resources across all sectors of the economy. The energy model accounts for all sources of Green House Gas emissions, and it also enables the assessment of air pollutants and air pollution.

There is a wide range of energy models and methodologies. For instance, on the demand side, there are bottom-up, end-use accounting, and top-down macroeconomic approaches. The energy models can be mixed and incorporate data from other, more specialised models. The main advantage of LEAP is its low requirements for supplying the input data since the models follow relatively simple accounting principles, while many other modelling aspects are optional. For example, the energy and environmental forecasts can be obtained before any costing data are considered. The time increments can be adjusted for annual and seasonal data down to the intra-day data, although the forecasted period is usually assumed for 10's of years ahead.

Most energy studies generally include a historical period known as the current accounts where the model can be tested to be able to replicate known data, and one or more forward-looking periods depending on the scenarios considered. The base year energy consumption, as well as the future energy demands at the national level, is calculated by incorporating the energy intensity values into the model of the current accounts. The techno-economic evaluation of various hybrid models to assess the energy demands in individual sectors is determined from the load demand, and the input data provided. These energy scenarios are self-contained, and they are used to predict how energy systems may evolve. The policy analysis tool is used to compare alternative scenarios in terms of their energy requirements, social costs, overall benefits, and environmental impacts. The scenario manager describes the individual policy measures which can be combined to produce alternative integrated scenarios. It allows the policymakers to assess the marginal effects of each policy and to identify the interactions which occur when multiple strategies are combined. For example, the benefits of energy efficiency standards combined with the portfolio of renewable energy standards may be smaller than the sum of these two measures considered separately.

3.4.2 The algorithm of the LEAP model

LEAP model uses a framework for measuring energy utilisation, transformation (electricity generation, oil refinery, charcoal production, and coal mining), and carbon emissions. The values are imputed into the LEAP model based on the required data which are available to the user. In the sequel of this subsection, mathematical expressions that were used in our LEAP analysis are outlined, including the definitions of all quantities used.

- **Energy consumption**

The total final energy consumption is calculated as follows [29],[30].

$$EC_n = \sum_i \sum_j AL_{n,j,i} \times EI_{n,j,i} \quad (1)$$

Where,

EC= the aggregate energy consumption of a given sector

AL= the Activity level and is a measure of the social or economic activity for which energy is consumed. It is measured for each year as the scale of units per household or tonnes for the industry.

The net energy consumption for transformation is calculated as follows:

$$ET_s = \sum_m \sum_t ETP_{t,m} \times \left(\frac{1}{f_{t,m,s}} - 1\right) \quad (2)$$

Where,

$ET = Netenergyconsumptionfortransformation$

$ETP = Energytransformationproduct$

$f = Energytransformationefficiency$

$m = Equipment$

$t = Typeofsecondaryenergy$

$$EV_n = \sum_c s \times \frac{m}{f_e} \quad (3)$$

Where,

$EV = Energyconsumptioninthetransport$ sector

$s = numberofvehicles\ (stock)$

$m = vehicledistance$

$fe = fueleconomy$

$n = fueltype$

$c = vehicletype$

- **Transformation**

The transmission and distribution module measures the domestic fuel requirement faced by the module and maps those corresponding to the output fuels, directly to them**.** The total local requirements are then decreased by the outputs of the module and increases by the inputs to the module [31],[30].

For each process p:

$$OUTPUT_P = \frac{INPUT_P}{EFFICIENCY_P} \quad (4)$$

- **For a transmission and distribution module**

$$EFFICIENCY_P = 1 - LOSSES_P \quad (5)$$

Where,

INPUT = Fuel or feedstock,

OUTPUT = Electricity generated or the refinery/production output,

EFFICIENCY = Efficiency of the power plants or refinery plants.

- **Carbon emission**

The carbon emission from final energy consumption is measured as follows [29], [30].

$$CEC = \sum_i \sum_j \sum_n AL_{n,j,i} \times EF_{n,j,i} \quad (6)$$

Where,

CEC = Carbon emission,

AL = Activity level,

EI = Energy intensity and is the carbon emission factor from fuel type *n* for equipment *j* from sector *i*.

The carbon emission from energy transformation is calculated as follows:

$$CET = \sum_s \sum_m \sum_t ETP_{t,m} \times \frac{1}{f_{t,m,s}} \times Ef_{t,m,s} \quad (7)$$

Where,

CET = Carbon emission

ETP = Energy transformation product

f = Energy transformation efficiency and is the emission factor from one unit of primary fuel types consumed for producing secondary fuel type t through equipment m.

- **Costs**

The total cost of the sector is measured [32], [30].

$$C = \sum_i \sum_j f_{(x)} = \{[\sum_n (e_{n,j,k} ep_n)] + \sum_n (m_{k,j,i} mp_k) + fc_{j,i}] pj_i\} \quad (8)$$

Where,

C = Total cost of the sector including equipment fixed costs and variable costs for raw materials and fuels

ep_n = Unit price of fuel type n

$m_{k,j,i}$= Demand for raw material k per unit of production used in equipment j within the production process i

mp_k = Unit price of raw material k

fcj,i = the fixed cost per unit production through equipment j (within production process i)

3.4.3 Protocols used in LEAP model

The first task for modelling is to evaluate the energy demands in different economic sectors assuming the base year 2011/12. The BAU scenario requires knowledge about the existing energy production and supply systems, which may occasionally incorporate other renewable energy sources. The LEAP energy model contains various modules with assumptions about energy resources, demands, and transformations. The key assumptions module used to define parameters are national GDP, total population, and others.

The future energy demands are then estimated, assuming the following model settings: General system parameters: standard energy unit GWh standard currency unit

(USD), base year (2011- 2012), baseline reference years (2011–2017), and the end year for the forecast (2041-2042). The Protocols used in the LEAP model is illustrated in Table 3.4.

Table 3.4 Protocols used in LEAP model

1. General Basic Parameters	
Standard Energy Unit	GJ (Giga Joule)
Standard Currency Unit	$ (US Dollar)
Base Year, Scenario Year and End Year	2011-2012, 2011-2017 and 2041-2042
2. Demand Analysis	
Energy Consuming Sector	Residential, Industrial, Transport, Agriculture, Commercial,
By Fuel Types	Fuelwood, Agriculture Residues, Animal Dung, Coal, Electricity, Petroleum
3. Data Structure	
Tree Structure	Bottom-up approach
Analysis	Technology, policy and alternatives
4. Current Accounts	
Current Year Inputs	End-use energy intensity & activity data
5. Reference Scenario	
Business As Usual	Average growth electricity customers with respect to electricity user penetration.
Clean Energy Technology	Optimised use of diesel and renewable energy technology (RETs) adoption.

Reference scenario and key assumptions regarding the available data and official sources were considered. These assumptions take averages energy consumption per year by different energy technologies according to their corresponding availability. Table 3.5 shows the average final energy consumption pattern.

Table 3.5 Average final energy consumption pattern (*could vary according to use*)

Grid Electricity	**1.2kW x 12hrs/day x 330days**
Diesel Generator	3litre/hr x 6hrs/day x 350days
Solar Energy	4kW x 5hrs/day x 315days
Wind Energy	1kW x 6hrs/day x 315days

By utilizing the energy intensity values into the current account of the LEAP model, the result reveals the base year energy consumption and future energy demand at the national level. More intensely, energy consumption by diesel is analysed critically, which in turn regards as the carbon footprint of such energy sectors in Nepal. This forwards the necessity of reducing fossil fuels consumptions like diesel for environmental benefits. Since no actual growth rate of each sector is available or cannot be precisely drawn, the assumption is made by the annual report and contemporary articles from different sources. This generates some best line linearity assumption in the growth of such sectors with some fundamental assumptions. For this, the researcher has assumed the national population growth rate to be 1.35 per cent annually, and the national GDP to optimistically grow at 4.3 per cent each year as shown in Table 3.6.

Table 3.6 Growth scenario of Nepal

Growth Scenario (have to find according to national data)	
Agriculture	
Commercial	
Industrial	
Residential	
Transport	
Key Assumptions	
National Population	Growth (1.35%)/Year
National GDP	Growth (4.3%)/Year

3.5 Long term forecast of energy demand in Nepal and modelling

Addressing the present energy crisis is essential, but not enough. It is equally significant to understand how energy demands are going to evolve in the years to come. Energy demand management engages effective utilisation of the energy resources, reliability in, competent management of energy resources, energy conservation, combined heat and power systems, renewable energy systems, integrated energy systems, independent power delivery systems. Demand management consists of planning, implementing, and monitoring activities of energy utilisation that are designed to persuade consumers to modify their level and pattern of energy usage [33].

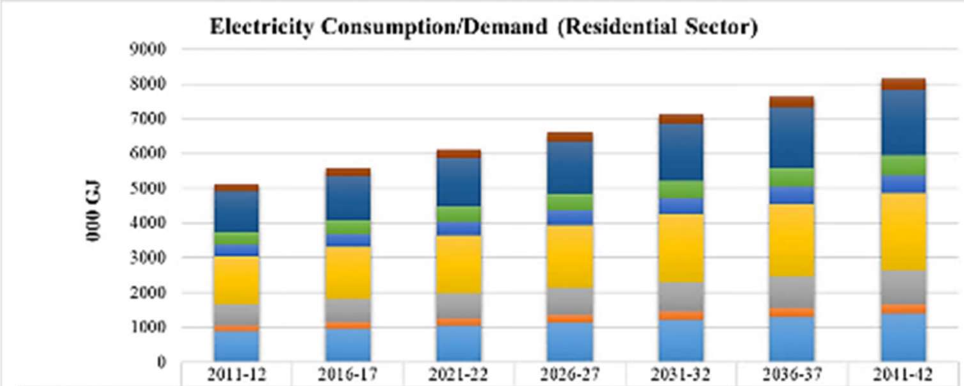
Hence, the likely energy demands in Nepal to be projected over the next 30 years using energy modelling in LEAP. Such analysis is vital for formulating the long-term integrated energy policies, and planning the expansion of energy generation and distribution systems and other infrastructure to fulfil the demands and tackle the energy crisis [33]. Likewise, it is shown that massive scale adoption of renewable energy sources must become an integral part of any future energy planning policies.

3.5.1 Business As Usual (BAU) scenario

The model data, including the growth rates in all economic sectors, are mostly obtained from various annual reports and other literature. In particular, the national population growth rate is assumed to be 1.35 per cent annually, and the national GDP is assumed to grow at 4.3per cent each year optimistically. The primary energy demand of Nepal is expected to grow at a rate of 2.73 per cent per year along with the electrical energy demands to grow by 8.8per cent per year [35]. The global primary energy demand is projected to increase on average by 1.46 per cent per year between 2009 and 2035 [36]. The same demographic characteristics are assumed throughout the whole evaluation period. The base year demographics and the energy data were obtained from the Water and Energy Commission Secretariat (WECS) [37], National Planning Commission [37], Central Bureau of Statistics of Nepal [38], National Population and Housing Census (2011)[39], Economic Survey by the Ministry of Energy [40], and the data from the Ministry of Finance [41], Nepal Oil Corporation[34] and NEA [42].

- **Residential sector Energy Demand**

The residential sector is the dominant electricity consumer under the BAU scenario (See Figure 3.2). This sector consumes 48per cent of the total electricity produced. At the end of the reference year 2017, the residential energy consumption was calculated to be 5.6 million GJ, which is then projected up to 8.14 million GJ at the end of the year 2042. Indoor lighting and the use of electric appliances constitute the most substantial portion of residential electricity consumption. It is followed by the consumption required for cooking and cooling.

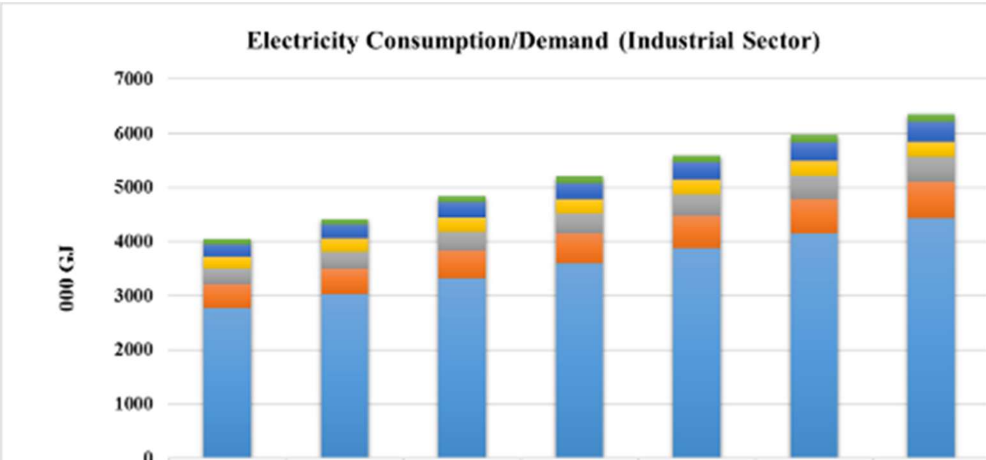


	2011-12	2016-17	2021-22	2026-27	2031-32	2036-37	2041-42
Other Uses	199.200	217.100	238.200	257.167	277.556	296.996	317.069
Electric Appliances	1173.100	1279.100	1403.200	1515.233	1635.311	1750.026	1868.316
Water Pumping	365.000	397.900	436.500	471.300	508.633	544.278	581.048
Water Boiling	326.500	355.900	390.500	421.633	455.078	486.981	519.912
Lighting	1390.700	1516.200	1663.300	1796.000	1938.300	2074.200	2214.367
Cooling	609.400	664.400	728.900	787.067	849.456	909.030	970.480
Heating	174.200	190.000	208.400	225.067	242.889	259.911	277.506
Cooking	878.500	957.800	1050.700	1134.533	1224.411	1310.259	1398.794

Figure 3.2 Energy use in the residential sector in 000GJ

- **Industrial Sector Electricity Demand**

The industrial sector Figure 3.3 comes second with 38 per cent of the overall electricity consumption. It requires about 4.04 million GJ during 2014, while the demand in 2017 is 6.5 million GJ, which is projected to increase to 5.6 million GJ by 2030. The power motive runs are the most energy-intensive processes in the industry, but the industrial heating and cooling follow similar trends.

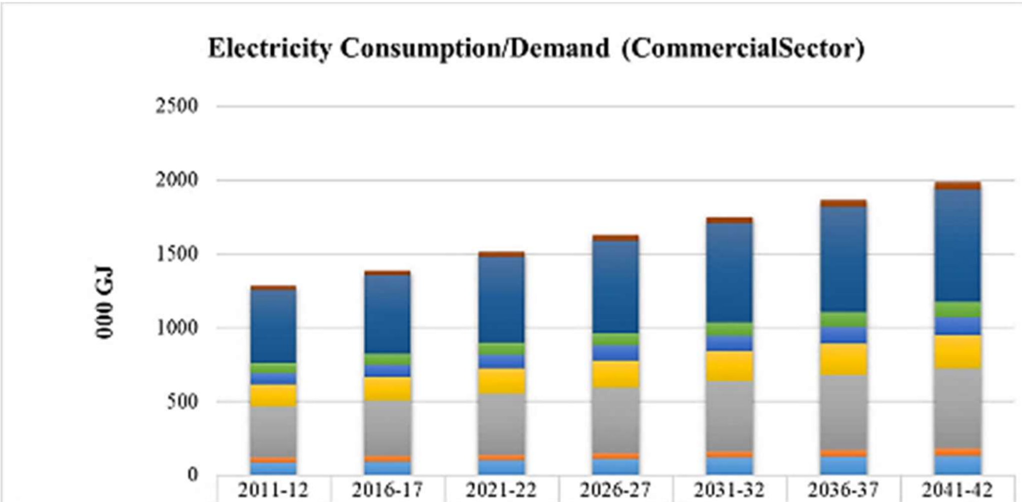


	2011-12	2016-17	2021-22	2026-27	2031-32	2036-37	2041-42
Others	91.890	100.190	109.910	118.683	128.088	137.071	146.336
Lighting	232.380	253.360	277.930	300.107	323.879	346.587	370.005
Boiler	228.080	248.670	272.790	272.202	276.320	275.535	276.352
Process Cooling	282.280	307.760	337.620	364.560	393.447	421.036	449.490
Process Heating	432.130	471.150	516.850	558.097	602.312	644.549	688.104
Power Motives	2779.410	3030.340	3324.310	3589.587	3873.992	4145.645	4425.800

Figure 3.3 Energy use in the industrial sector in 000GJ

- **Commercial Sector Electricity consumption Demand**

The commercial sector incorporates large electric appliances, so it contributes 12per cent to the overall electricity consumption. The baseline consumption was found to be between 1.3 and 1.4 million GJ between 2011 and 2017, which is projected to increase to 2.0 million GWh in the year 2042. Electric appliances seemed to be dominating all the sectors. The energy demand of 762. 299 thousand GJ is expected at the end of 2042 by the electric appliance. The need for cooling will also be rising considerably, which is 541. 275 thousand GJ at the end year 2042, as illustrated in Figure 3.4.



	2011-12	2016-17	2021-22	2026-27	2031-32	2036-37	2041-42
Other Uses	30.430	32.990	35.980	38.683	41.578	44.345	47.197
Electric Appliances	494.140	534.820	582.860	625.993	672.398	716.621	762.299
Water Pumping	67.320	72.860	79.410	85.287	91.612	97.639	103.864
Water Boiling	78.270	84.680	92.270	99.073	106.401	113.379	120.590
Lighting	146.760	158.770	173.000	185.750	199.487	212.566	226.083
Cooling	347.600	377.300	411.730	443.007	476.386	508.363	541.275
Heating	32.700	35.180	38.230	40.900	43.823	46.578	49.445
Cooking	86.720	93.840	102.250	109.800	117.923	125.664	133.660

Figure 3.4 Energy use in the commercial sector in 000GJ

- **Transport sector Electricity consumption Demand**

In the case of transportation, cable cars are still the primary means of transport in Nepal. Although they are electricity demanding, our projections show that transportation will reach only 0.04 million GJ at the end of the year 2042, as presented in Figure 3.5.

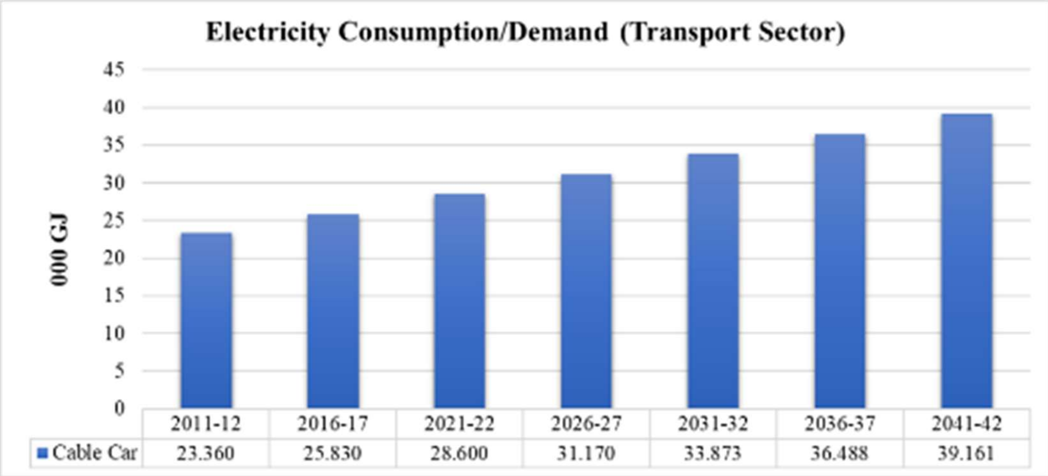


Figure 3.5 Electricity consumption/demand (Transport sector in 000 GJ)

- **Agriculture Sector Electricity Demand**

The use of electricity in the agriculture and transport sectors is much smaller since they constitute only 2 per cent of the total electricity consumed. For irrigation purposes, electricity is used mainly for water pumping and threshing. The overall electricity demand in the agricultural sector is projected up to 0.4 million GJ in 2042, up from 0.25 million GJ in 2017, as shown in Figure 3.6.

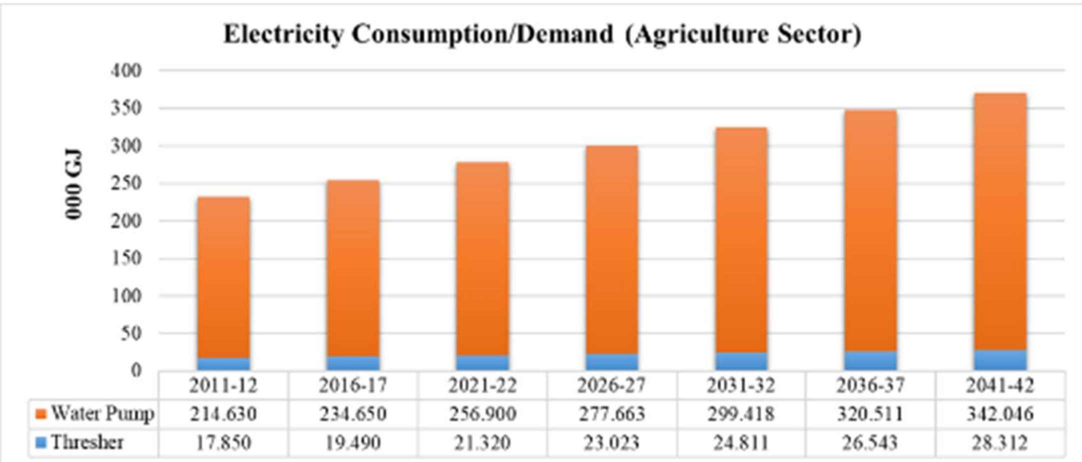
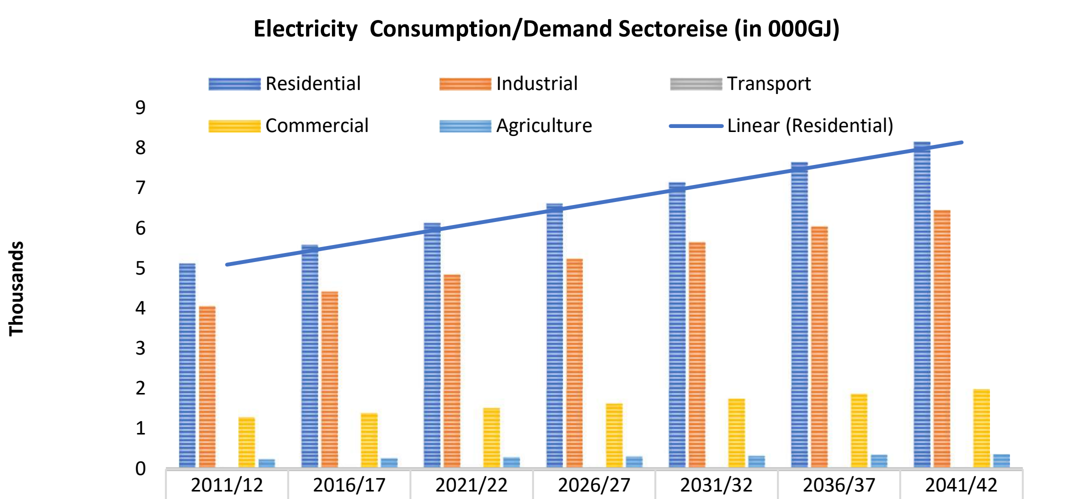


Figure 3.6 Electricity consumption / demand (Agriculture Sector, in 000GJ)

3.6 Results and discussion

The results of the projected energy demand up to FY 2041/42 are shown in Figures 3.2 -3.6 and summarised in Figure 3.7.

The energy demand projection in Figure 3.7 can be validated by considering the forecasts in other public literature. In particular, the long-term overall forecast by WECS [43] (see Figure 3.8), and Figures 3.9 shows the 2016 long-term forecast by NEA [34]. Note that neither [34] nor [43] considers the energy consumption in individual sectors. The curves in Figure 3.8 are parameterised by three different GDP growth models corresponding to the previous, base case, and the optimistic scenarios, respectively. The assumed GDP growth is one of the critical factors affecting the predicted energy demand. Comparing our forecasts in Figure 3.7 with the GDP growth rate of 4.3 per cent and the estimates in Figures 3.8 and 3.9 shows that our energy demand forecast is somewhat optimistic (i.e., smaller). One reason is the BAU scenario assumed in our analysis, and there may be other minor energy consumers not considered in our LEAP model.



	2011/12	2016/17	2021/22	2026/27	2031/32	2036/37	2041/42
Residential	5.117	5.578	6.12	6.608	7.13	7.632	8.147
Industrial	4.046	4.411	4.839	5.226	5.64	6.035	6.443
Transport	0.025	0.026	0.029	0.031	0.034	0.036	0.039
Commercial	1.284	1.39	1.516	1.628	1.75	1.865	1.984
Agriculture	0.233	0.254	0.278	0.301	0.324	0.347	0.37

Figure 3.7 Electricity consumption/demand sectorwise (in 000 GJ)

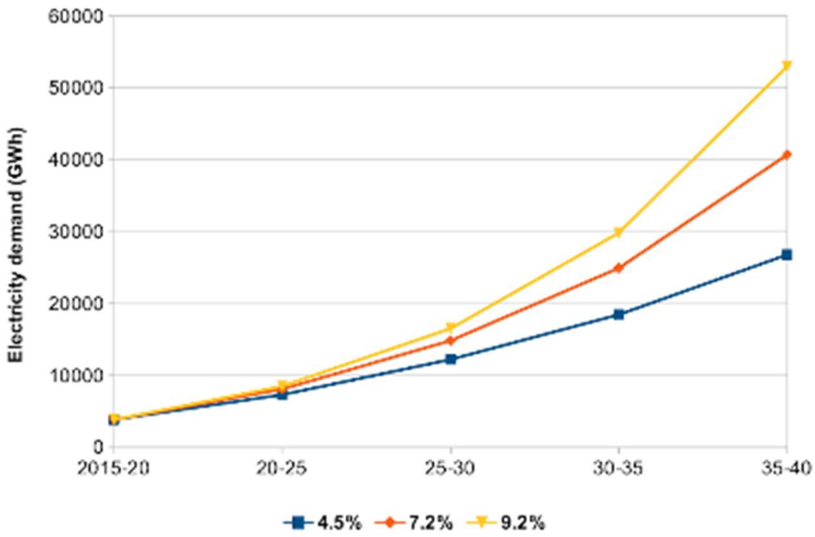


Figure 3.8 The overall projected electricity demand in Nepal by WECS assuming 3 different GDP growth models [43]

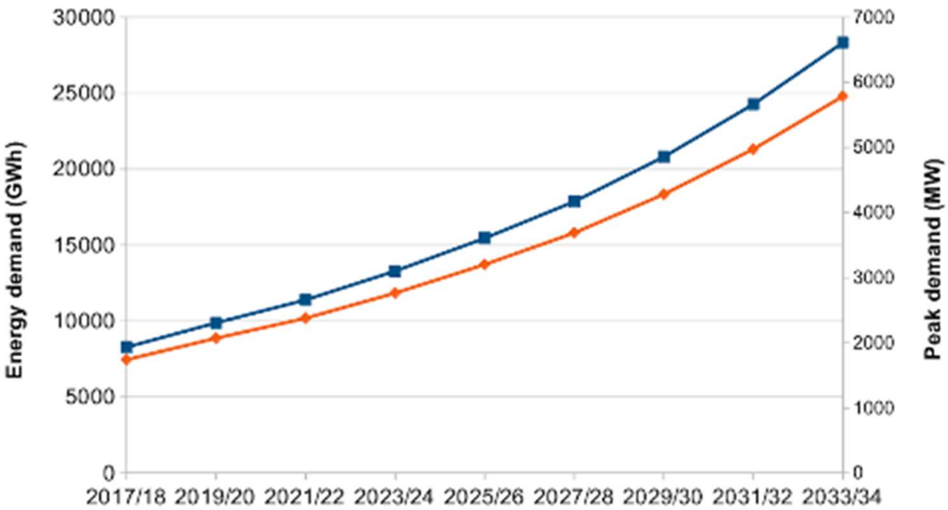


Figure 3.9 The long-term projected energy and peak demands in Nepal by NEA [34]

As discussed throughout this chapter, there are several models and data deficiencies inherent in this research. As for modelling limitations, LEAP does not provide hourly generation profiles, but somewhat annual generation profiles. As such, it is not possible to incorporate any correlation between weather patterns that impact wind, solar, and hydropower generation and demand curves. To overcome this limitation, a more sophisticated modelling platform would need to be developed.

The detailed forecasted results of electricity demand and generation capacity in Nepal for Base Line, scenarios are discussed in this section. The energy demand of all sectors, along with the non-energy requests, is measured. Interestingly, Nepal out of the five countries, Nepal is the closest to reaching 100 per cent electricity access with nearly 91 per cent access in this year's Trilemma Index. Nepal has seen a 24 per cent increase (from 67 per cent), which has improved its overall ranking by five places [9].

In 2017 Nepal was ranked as one of the top four recipient countries of private participation in electricity after Laos, Bangladesh, and Uganda with some significant investments from neighbouring China [9]. As Nepal pushes for 100 per cent electricity access, several schemes have been implemented. As part of the country is located within the Himalaya Mountains, Nepal has utilised its hydro renewable energy resource since the early 1960s, with the projects slowly increasing in number and capacity to become a significant source of off-grid electricity in rural Nepal [9].

In the early 2000s, with the long-term financial support of large institutional donors, the government initiated the Micro-Hydro Village Electrification (MHVE) programme. By 2014, more than 1,000 micro-hydro programmes with the total generation capacity of 22 MW had been developed, providing off-grid electricity access to 20 per cent of the population. The income of communities with micro-hydro units increased by 11 per cent, and the women and children from these communities suffered less from respiratory problems and disease, once again demonstrating the economic and social enabling capacity of cleaner and more sustainable energy systems. These micro-hydro units displace nearly 10 million kilograms of carbon dioxide each year [9].

Despite its unstable political environment, However, reports indicate that Nepal is on track to achieve 100 per cent electrification by 2030, and the rapid improvement in the Trilemma score for electricity access is a testament to this trend [9].

3.7 Conclusions

The principal idea of this research was to illustrate the energy situation of Nepal in the hope that it would enhance the understanding of energy scenarios, Renewable energy adaptation, and its long forecasting to help for future energy planning.

This research has investigated the forecasting and balancing electricity supply-demand situation of Nepal by considering the environmental and techno-economic parameters by the LEAP model. Supply- Demand-side scenarios are not merely a prediction; preferably, each of the two scenarios is one alternative picture of what the expectations can hold for Nepal's energy sector in terms of installed capacity, generation, CO_2 emissions, and cost perspective. The forecasted electricity demand for the study period is modest and comparable with other studies. The overall projected electricity demand in Nepal in 2042 has been forecasted to be 16. 983 GJ, which compared to only the 10.705 GJ in 2012. As such, the growth, which was 59 per cent higher than the base year 2011/2012, with a demand estimated annual average growth of 4.3per cent over the study period.

As per the result of this research, it is evident that following Nepal's current policies, Nepal will never become energy scare country in the future. Evidently, by following suggested measures, Nepal's energy sector should have to adapt energy mix policy, which can be turned into better energy security, thus reducing both the cost and emissions. In Nepal, Researchers are using the annual data based on 2011/2012 as a base year. Energy consumption could be thought of as a leading reason for increasing demand up to 2042. The enormous use of energy, mostly in the industry, commercial, and residential sectors, has directly pushed the economy. Production in industries such as construction, manufacturing, and transportation demands a substantial amount of energy.

In conclusion, for developing countries like Nepal, energy is an essential ingredient of economic development. Energy mix with renewable energy adaptation would reduce Nepal's vulnerability to fossil fuel price shocks and reduce global warming potential. In addition, it is expected that the current study will be beneficial for energy planners, policymakers, and government officials of other developing countries where there is insufficient knowledge of energy policy planning and energy management. Based on this research, the following technical recommendations are made.

- Energy modelling tools should be widely used for energy planning and forecasting.
- An active collaboration should be established between the government and academia to work together for better results.

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Chapter 4
Solar PV module designs and its techno-economic feasibility

This chapter aims to design the PV system and examine its techno-economic performance. The researcher also identifies enabling conditions and support systems required for their financial viability. This work has been published in Poudyal et al. 2020 [1], and detail analysis of the study is under submission in the journal Poudyal et al. 2020.

4.1 Introduction

Nepal has abundant availability of solar energy throughout the year, as illustrated in Figure 4.17. With the average solar radiation varies 3.6 – 6.2 kWh/m^2/day and 300 days of sunny weather, Nepal is an ideal place for solar energy [2]. Even so, Nepal's power system is mostly dominated by large hydropower only. This chapter advocates the necessity of energy mix through the solar PV rooftop system in Nepal as the fastest solution of energy crisis in compare with the long-delayed hydropower project [3], [4],[5],[6]. This has led to the origin of this chapter.

There is an acute shortage of energy and wasteful consumption of electricity, which has caused considerable worry in everyday life of Nepalese people. Hence the main objective of this chapter is to encourage Renewable Energy Technologies (RETs) that will allow the homeowners to produce their energy on the roof and make less dependent on electricity provided by NEA. In addition, this will help to reduce the load on the national grid, to reduce the CO_2 emissions, to create the net job as well as economic advantages resulting from fossil fuel savings and consequently reduce load shedding period.

Nepal's transmission network is outdated, and there is no position to accommodate large power generation that the government intends to accomplish in the next ten years. Stand-alone PV generation, therefore, has the capacity to not only lessen pressure on transmission and distribution system but also reduce power losses that occur upon using the obsolete infrastructure and colossal electricity theft [7]. In Nepal, a grid-connected solar system is in its emerging phase. The history of solar power has begun with the 1-MW system at Singha Durbar, 680 KW system at Sundharighat, 100 KW system at Kharipati, 65 KW at Nepal Telecom, and a 1KW test project at the centre for energy studies institute of Engineering, Pulchowk, Campus. However, the PV system is yet to gain momentum for the business scale. The government of Nepal has already formulated these policies for net metering and feed-in tariff (FIT), but its reluctance to implement them is causing a delay in its large-scale adaptation [7].

NEA has already issued licenses to various PV installers to produce more than 500 megawatts of solar energy. NEA plans to have an energy mix in which 85 per cent of the electricity is generated through hydropower and 15 per cent through solar power. So, NEA requires at least 200 megawatts of solar power at present to deliver the energy mix as the highest demand in the recent winter stood at 1,338 megawatts [8].

Many authors have explained the techno-economic feasibility analysis for a PV system in different regions and countries such as [9], [10], [11], [12], [13], [14], [15], [16], [17], [18]. A life cycle assessment of a 4.2kWp stand-alone PV system was performed in the South-east of Spain [19], which focuses on an energy payback period and CO_2 emission reduction. Similarly, A standalone lighting system generated by PV in Malaysia was assessed in [20], which employs the simulation tool PVsyst software for predicting energy output, instead of evaluating real-time operating data. The performance of a SAPV system in Saudi Arabia was analysed in [21], and a comparative study of grid-tied photovoltaic(PV) system in Kathmandu and Berlin were undertaken [22].

However, yet to the best of author's knowledge, very little has been done in the field of photovoltaic systems in the context of Nepal with up to date data.In addition, analytical work and empirical evidence on the socio-economic benefits of solar PV system topics remain relatively limited [23]. There is no discussion on how socio-economic and techno-economic feasibilities would influence the business scale adaptation of the rooftop PV system in Kathmandu, Nepal.

It is observed from the literature above that although several solar models for different locations around the world have been reported, the application of these models is limited in the case of Kathmandu, Nepal, since such models are locally defined. Thus, performance validation of available models for suitability of estimation in a climatic region needing to be established. This study, therefore, aims to fill a research gap by providing a techno-economic assessment of a standalone, grid-connected, and grid-connected with battery (hybrid) system to supply electricity for a residential home in Kathmandu, Nepal. This study will also fill the gaps in the current literature by analysing up-to-date data in the form of clearness index, tilting angle, meteo data, relative sunshine period, effects of temperatures, and irradiations on PV's output.

4.2 Methods and materials

This section presents the proposed system and the tool used for the study, including the simulation and optimization software, input data, design specifications, controller for the energy management, and mathematical model.

4.2.1 Simulation and optimization software

The simulation approach is used to design a 3kWp PV system. In the first part, the researcher has simulated the PV module in MATLAB/Simulink. The characteristics of PV cells that are affected by irradiation and temperature have been modelled by a single diode mathematical model. The values in the Simulink PV model have then been verified and compared with the datasheet of the chosen PV module. MATLAB is a programming platform explicitly designed for scientists and engineers. It is a matrix-based language allowing the most expression of computational mathematics. The language, apps, and built-in math functions enable the user to explore multiple approaches to arrive at a solution quickly.

In the second part, Meteonorm7.3 software has been used to collect the site metrological data such as daily and yearly solar irradiation levels, ambient temperatures, and wind speed. The Meteonorm software provides monthly meteorological data for any location on the earth. It has been around for more than 30 years and has become the standard meteorological database for solar energy simulations.

In the third part, PVsyst software and HOMER software have been used to simulate PV systems and to analyze technical and economic analysis. PVsyst software is a tool that allows its user to analyse different configurations accurately and to evaluate the results while identifying the best feasible solution. It helps to produce results both optimally and reliably. PVsyst allows for importing files provided by the Meteonorm software so that well-measured interpolated values can be taken graphically. PVsyst deals only with grid-connected, stand-alone, pumping, and DC-grid (public transportation) PV systems [20]. Hence for the hybrid system, HOMER software is used.

The HOMER is an optimization tool that allows its user to find optimized system configuration as it simplifies and finds the lowest cost system while also increasing the speed for finding the optimal system across a range of sensitivity values. It also makes it simple to identify and compare different systems designs. It attempts to simulate a viable method for all possible combinations of the equipment the users want to consider and filtered according to criteria that the users define, so the best possible solutions are seen [13]**.** In HOMER, the only optimal system is simulated; hence the result for stand-alone is not produced as the system was not viable. Hence to Simulink three systems, both PVsyst and HOMER software were used. The modelling details, key findings, and results are discussed in section 4.6.

4.2.2 Model inputs and assumptions

Various inputs have been used to operationalise the Solar PV model. The capital cost for the PV system is based on the quotation received from TANFON for both stand-alone PV system and grid-connected PV system, as presented in Tables 4.1 and 4.2. For both systems, a 330w mono panel has been used.

Table 4.1 Quotation from TANFON for standalone solar power supply system- SP 3000W

Product	Quantity	Unit price	Total price
330w Mono Panel	10pcs	$92.4	$924
H4T PV combiner	1pc	$117	$117
48V 60A charge controller	1pc	$98	$98
NW3000W solar inverter	1pc	$207	$207
200AH gel battery	4pcs	$200	$800
Solar panel bracket	1set	$450	$450
PV cable+ battery cable	1set	$185	$185
Total			$2841

Table 4.2 Quotation from TANFON for on-grid solar power supply system- SPB-3KW

Product	Quantity	Unit price	Total price
330w Mono Panel	10pcs	$92.4	$924
HBF 3KW on grid inverter	1pc	$340	$340
PV cable+ battery cable	1 set	$125	$125
Total			$1789

Similarly, a VAT rate of 15 per cent is added to the original quotation and shipping cost of $405 USD for a total volume of 1.2m^{3}and 360kg is added to the grid-connected system and shipping cost of $479 USD for the total volume of 1.96m^{3}and 537kg is added to the stand-alone system. Additional assumptions are made for the following: the O&M cost is taken as 3 per cent of the capital cost. The O&M cost is assumed to increase by 5 per cent per year. 1 per cent of the capital cost is taken as the cost of insurance for the plant per year. The output is assumed to de-rate 1 per cent per year, and life is taken as 25years. It is assumed that the technical and commercial loss in the system is 15 per cent, and the saleable output is obtained after deducting the energy lost in the system. Any available capital grant is applied first ($173 USD), and the grant amount reduces the capital investment requirement. The balance of capital is funded through loan and equity at an 80:20 ratio. Further, an inflation rate of 0.099 (9.9 per cent), the interest bank rate of 2.25 per cent for 15 years, 0.35 per cent administration charge of the bank, and a discount rate of 0.06 (6 per cent) are taken into consideration to calculate the real rate of interest. The fixed feed-in tariff rate of $0.063 USD/kWh is taken from the various sources such as [24], [25], [26], [27].

4.2.3 Load profile

The load profile is calculated to estimate the number and size of panels required for a project.

Table 4.3 Load profile of the average household in Kathmandu

Appliance/ Loads	Power (watts) (A)	Hours used in a day (B)	Days per week (C)	Watt-hours per week (A) x (B) x (C)
Lamp LED	15	7	7	735
TV	80	5	7	2800
Laptop	50	5	7	17500
Computer	80	5	7	2800
Fridge	58	24	7	9744
Fan	150	2	7	2100
Rice Cooker	1000	1	7	7000
Washing M/C	1000	1	2	2000
Microwave	1000	1	7	7000
Iron	1000	.5	5	2500
Dryer	1000	1	5	5000
Kettle	1200	0.75	7	6300
Well pump	750	1	4	3000
Smart Phone Recharge	6	3	7	126
Vacuum	1000	1	2	2000
Other	120	1	7	840
	Highest power used at one time		Total Power per week	55695 Wh/w

Load 55695 x 25 % (adding 25% more for system inefficiencies)

55695 x 1.25 = 69618.75 Wh/week = 9945.53 wh/day

Battery Bank Capacity

Watt-hours needed over day 9,945.53 wh/day = Approx. 10kWh/day

It is usually a good idea to round up, to help cover inverter inefficiencies, voltage drop, and other losses. Battery banks are typically wired for either 12 volts, 24 volts or 48volts depending on the size of the system,

For Lead Acid Battery Sizing - 10kWh/day x 2 (for 50% depth of battery discharge) x 1.2 (inefficiency factor) = 24 kWh

For Lithium Sizing - 10kWh/day x 1.2 (for 80% depth of batter discharge) x 1.05 (inefficiency factor) = 12.6 kWh

For Lead Acid, 24kWh is equal to:	For Lithium, 12.6 kWh is equal to:
2,000 amp hours at 12 volts	1,050 amp hours at 12 volts
1,000 amp hours at 24 volts	525 amp hours at 24 volts
500 amp hours at 48 volts	262.5 amp hours at 48 volts

4.2.4 Solar panel specification

Before starting to implement the calculations of the PV design, it is necessary to select the PV modules, which is going to be used during the process of computation. Furthermore, it is essential to obtain the technical specifications of these components since they are going to be used during calculations. The specification of the module is listed below:

Table 4.4 Module specification

Model	**Talesun - TP672M – 330**
Manufacturer	Zhongli Talesun Solar Co., Ltd.
Electrical Characteristics	
Maximum Power (Pmax)	330 W
Maximum Power Voltage (Vmp)	37.3V
Maximum Power Current (Imp)	8.85A
Short-circuit current (Isc)	9.19A
Open-circuit voltage (Voc)	46.1V
Module Efficiency	17%
Cell Size and series	Mono 156 x 156 - 72 pcs (6 x12)
Temperature coefficient of Pmax	-0.41%/^{0} C
Temperature coefficient of Voc	-0.31%/^{0} C
Temperature coefficient of Isc	+0.055%/^{0} C
Mechanical Characteristics	
Model Dimension	1960 x 992 x35mm
Frame	Anodized Aluminium Alloy
Glass	3.2mm, High Transmission, Tempered Glass
Junction box and Cable	IP65/ IP67
Weight	24.0 Kgs

The chosen PV technology is presented in Table 4.4. The household requirement is10kWh/day, which is 416.66Wh/hr. The average sunlight hour of Kathmandu is 7. Therefore, the required number of panels is

$$\frac{416.66 \text{ x } 7}{330} = 8.83 \text{ panels} = 9 \text{ panels}$$

4.3 PV array and PV modelling in MATLAB

A solar panel produces electricity using the photovoltaic effect, a phenomenon discovered in 1839 when Edmond Becquerel, a French Physicist, observed that certain materials produced an electric current when exposed to light. Two layers of a semi-conducting material are combined to establish this effect. One-layer must have a depleted number of electrons. When exposed to sunlight, the layers of material absorb the photons. This excites the electrons, causing some of them to ‘jump’ from one layer to the other, generating an electric charge.

The usual PV cell produces less than 3W of power at 0.5V DC; therefore, to increase their utility, several individual PV cells are interconnected together in a sealed, weatherproof package called a Panel (Module). Individual cells are typical 36, 60, and 72 connected in a series string to achieve the required output voltage.

Modules are wired in series and parallel into a PV Array to achieve the desired voltage and current. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical requirements. In series combination, the voltage across the terminal is the sum of all individual PV cells, and the current is the same across all the cells. In parallel connection of PV cells, the output voltage across each cell is the same, and the output current is the sum of each cell [28], [29].

If many cells are connected in series, shading of individual cells can lead to the destruction of the shaded cell or of the lamination material, so the Panel (Module) may blister and burst. To avoid such a sufficient condition, Bypass Diodes are connected anti-parallel to the solar cells, as in Figure 4.2. Therefore, more substantial voltage differences cannot arise in the reverse-current direction of the solar cells. In practice, it is enough to connect one bypass diode for every 15-20 cells. Bypass diodes also allow current to flow through the PV module when it is partially shaded, even if at a reduced voltage and power. Bypass diodes do not cause any losses, because, under regular operation, current does not flow through them.

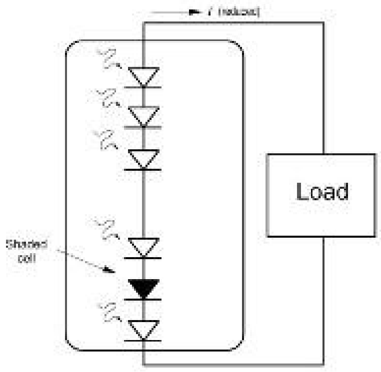


Figure 4.1 PV module cells without bypass diode

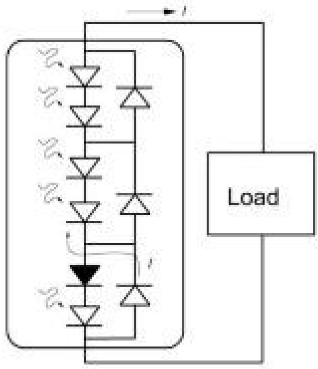


Figure 4.2 PV module cells with bypass diode

There are typically two types of photovoltaic (PV) systems: Stand-alone or off-grid or non-grid tied PV system and grid-connected or grid-tied PV system.

- ***Stand-alone system***

A Stand-alone system usually comprises of the solar modules, some power conditioning, and control units (converters: DC-DC, Inverter), some storage elements, and the load, as illustrated in Figure 4.3. In developing countries like Nepal, where 30 per cent of the total population mostly in remote villages, live in darkness [30], stand-alone systems will go a long way in rural electrification. They can also be used for mobile equipment and communication systems and water pumping systems.

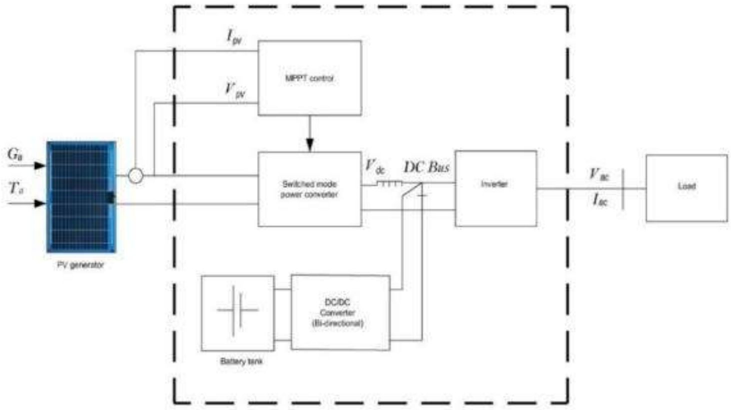


Figure 4.3 Stand-alone PV system

- ***Grid-connected PV system***

In this system, the PV modules are directly fed to an inverter; the inverter is connected to the grid so that the system can draw on the grid in times of need, and feed power back into the grid during times of excess production. The conventional setup is centralised technology, as presented in Figure 4.4, where a numeral amount of PV modules connected to the power grid via an inverter.

The string of PV modules is connected in parallel via protecting diode. Centralised technology is sensitive to mismatch losses and partial shading [31]. Each string of a PV module with a separate inverter is connected to the grid in parallel combination in string technology, as illustrated in Figure 4.5. It is less sensitive than DC power losses and partial shading, but it has the flexibility to add new strings to the system due to the smaller size of inverters in string technology the overall efficiency. The multi-string technology is a combination of both the centralised and string technology, as demonstrated in Figure 4.6. It has the advantage of both technologies. The system is modular, it is easy to add another string, and it has almost zero DC side loss. Each DC/DC converter implements the maximum power point tracking (MPPT) for the string. This configuration has a flexible design and improves overall PV system efficiency [31].

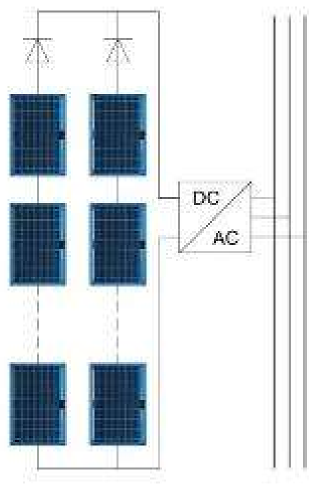


Figure 4.4 Centralized technology

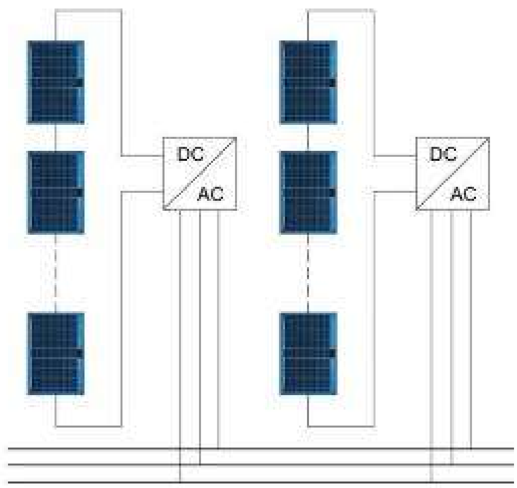


Figure 4.5 String technology

This configuration is primarily used in PV plants that have a nominal power rating higher than 10 kWp, where a high number of PV panels are connected in a series-parallel configuration. Each string has a blocking diode to prevent the energy reversion produced by the strings operating at different irradiance conditions, and by the existence of the energy storage system that operates during the night [31]**.** It is the simplified edition of the centralised configuration, where each string is connected to one DC/AC converter. If the string voltage does not have the appropriate value, a boost DC/DC converter or a step-up transformer is needed.

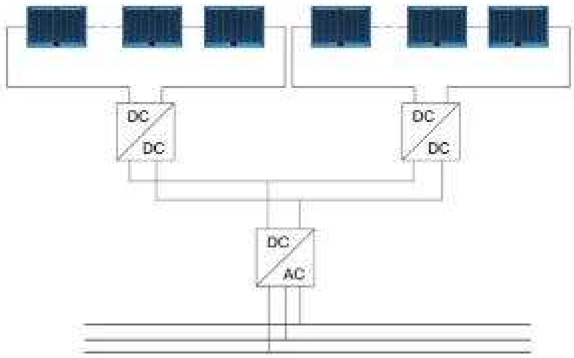


Figure 4.6 Different configurations of grid-connected PV generators

It is an evolution of the string configuration that unites the advantages of string and centralised configurations. Each DC/DC converter implements the Maximum Power Point Tracking (MPPT) for the string. This configuration has a flexible design and improves overall PV system efficiency [31]**.**

4.3.1 Mathematical modelling of PV in MATLAB

Any PV model is based on diode behaviour, which gives the PV cell its exponential characteristic. Single-diode and double-diode models are widely used to simulate PV characteristics. The single-diode model emulates the PV characteristics fairly and accurately [32]. Hence a single diode model is considered here.

The PV array block has a five parameter using a current source *IL* (light-generated current), the diode (I_0 and *nl* parameters), series resistance *Rs*, shunt resistance *Rsh* to represent the irradiance and temperature-dependent *I-V* characteristics of the *PV* module as presented in the Figures 4.7-4.8, respectively. Considering only a single diode solar cell, it can be modelled by utilising a current source, a diode, and two resistors.

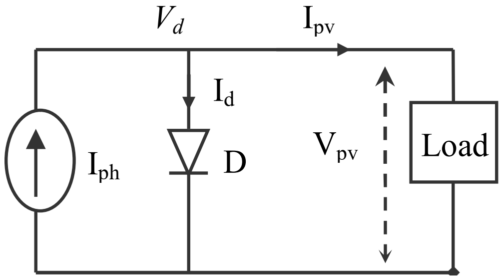


Figure 4.7 The single diode equivalent circuit model of PV cell

The equivalent circuit of the ideal PV panel is presented in figures 4.7 and 4.8. It contains the current source and the p-n junction diode connected in parallel. The inclusion of I_{ph} in the Shockley diode equation is due to the parallel connection of the current source and p-n junction diode in the equivalent circuit of the PV panel model.

$$Id = I_0[\exp\left(\frac{qv}{NsakT}\right] - 1] \quad (1)$$

Where,

I_0= diode reverse bias saturation current

q=charge of the electron

k=Boltzmann constant

a=diode ideality constant

T=operating temperature in Kelvin

Ns=Number of cells in series

V=Voltage of the PV panel

The output current of the ideal PV panel model is expressed in equation (2)

$$I_{PV} = I_{Ph} - I_d \quad (2)$$

Where,

I_{pv}= total output current of the PV panel

Now inserting the Shockley diode equation (2)

$$I_{pv} = I_{ph} - I_0[\exp\left(\frac{qv}{NsakT}\right] - 1] \quad (3)$$

It is clear from equation (3) that the ideal model of a PV panel involves only three parameters which need to be extracted. The unknown parameter which needs to be removed. The unknown parameters are diode ideality factor(a), the current generated by the incident light(I_{ph}) and diode reverse bias saturation current(I_0). The unknown parameters are required to obtain the *I-V* curve of the PV panel. Furthermore, I_{pv} is derived from the superposition of (I_{ph}) and I_d. The $I_d$the curve depicts the shape of the exponential *I-V* curve while the (I_{ph}) represents the vertical of the *I-V* curve, as explained by [33].

There are losses associated with the ideal PV panel model, which needs to be incorporated. The losses are due to the resistance in current flowing in the electrodes and silicon material. These losses can be illustrated as a series of resistance. After observing the series resistance, the output current of the PV panel is expressed as [34]–[36].

$$I_{pv} = I_{ph} - I_0[\exp\left(\frac{q(V+IR_s)}{NsakT}\right] - 1] \quad (4)$$

Where equation 4 does not take to report the temperature variation. Likewise, it is also necessary to incorporate the p-n junction leakage current, which can be illustrated by parallel resistance. Therefore, the model includes these losses, and its equivalent circuit consists of Rs and Rp, which is represented in figure 4.8. This model has five unknown parameters such asI_{ph}, I_0, a, R_s, and R_p.

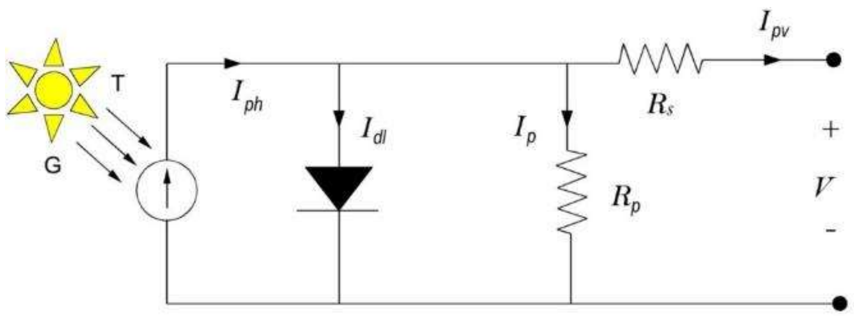


Figure 4.8 Single diode PV module with series and shunt resistances

The output current of the model is expressed in equation 5.

$$I_{pv} = I_{ph} - I_d - I_p \quad (5)$$

The current flowing through the parallel circuit is included in equation 5. The detailed equation of the model can be represented as [37].

$$I_{pv} = I_{ph} - I_0\left[\exp\left(\frac{q(V+IR_s)}{NsakT}\right] - 1\right] - \frac{V+IR_s}{R_p} \quad (6)$$

The model equation can also be written as:

$$I_{pv} = I_{ph} - I_0 \left[\exp\left(\frac{(V+IR_S)}{aV_T}\right] - 1\right] - \frac{V+IR_S}{R_p} \qquad (7)$$

Where, V_T = terminal voltage:

$$V_T = \frac{N_s k_T}{q} \qquad (8)$$

The complete equation of the model is shown in equation (7), which encloses the five unknown parameters of the model. The I-V and P-V curves can be obtained from the model equation at all operating conditions. Most of the time, the term '-1' in equation (7) is neglected in silicon devices as the dark saturation current is very tiny[38]. However, for achieving higher accuracy, it should be considered. The five unknown parameters of the model must be extracted in order to determine the voltage, current, and power at any operating conditions. The model can also be extended for the PV array by applying the method proposed by [39].

Short circuit point

Equation (7) can be expressed for short circuit condition as:

$$I_{sc} = I_{ph} - I_0 \left[\exp\left(\frac{(V_{sc}+I_{sc}R_S)}{aV_T}\right] - 1\right] - \frac{V_{sc}+I_{sc}R_S}{R_p} \qquad (9)$$

A short circuit point, V_{sc}=0. Therefore,

$$I_{sc} = I_{ph} - I_0 \left[\exp\left(\frac{I_{sc}R_S}{aV_T}\right) - 1\right] - \frac{I_{sc}R_S}{R_p} \qquad (10)$$

Open circuit point

The equation for open circuit point can be expressed as:

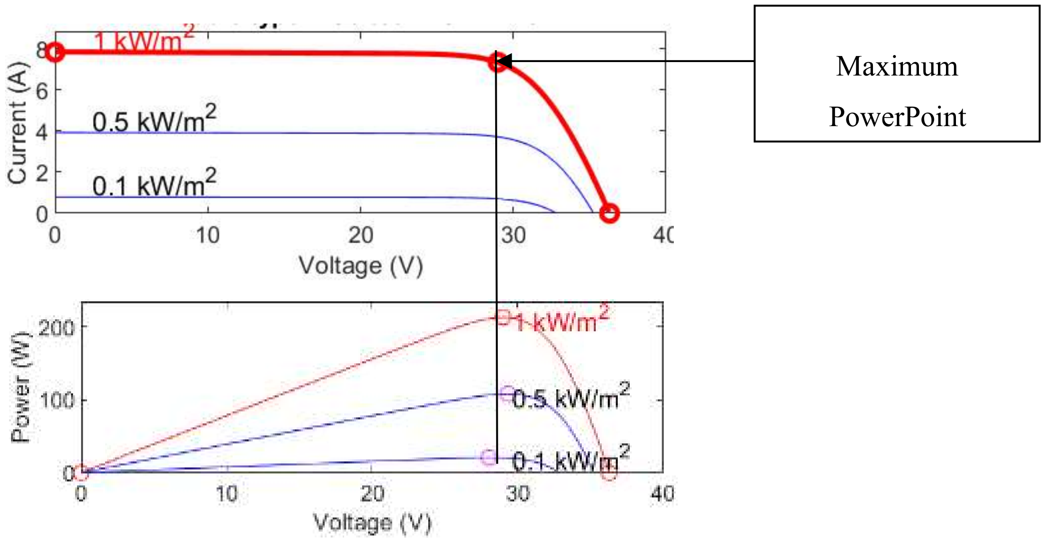
$$I_{oc} = I_{ph} - I_0 \left[\exp\left(\frac{(V_{oc}+I_{oc}R_S)}{aV_T}\right] - 1\right] - \frac{V_{oc}+I_{oc}R_S}{R_p} \qquad (11)$$

At open circuit I_{oc}=0. Therefore,

$$0 = I_{ph} - I_0 \left[\exp\left(\frac{V_{oc}}{aV_T}\right] - 1\right] - \frac{V_{oc}}{R_p} \qquad (12)$$

At maximum power point, $V = V_m$ and $I = I_m$. Therefore equation (4) can be expressed as:

$$I_m = I_{ph} - I_0 \left[\exp\left(\frac{V_{m+} I_m R_s}{aV_T}\right] - 1\right] - \frac{V_m + I_m R_s}{R_p} \qquad (13)$$



Figures 4.9 and 4.10 The typical *I-V* and *P-V* curve of PV cell indicating the Maximum PowerPoint

Changes in ambient situations such as temperature and irradiance have led to changes in the maximum power point (MPP) on the *P-V* curves illustrated in Figures 4.9–4.10, respectively. The maximum power point tracking device is required to track MPP changes on the *P-V* curves at all times above to ambient changes.

The shape and size of the solar cell are designed to maximise the absorbing surface and reduce the losses caused by contact resistance. The solar cell behaves as a p-n junction diode in the absence of solar irradiation [40]. The characteristics of the solar cell are determined by the Shockey diode equation [41], which expresses the diode current as equation 1 above.

$$PV\ Module\ Efficiency = \frac{V_{max} \times I_{max}}{Irradiance \times Module\ Area\ (m^2)} \times 100 (14)$$

$$Module\ Area\ (m^2) = 36\ \times Call\ Area\ (m^2) \qquad (15)$$

4.3.2 Cell characteristics

The effect of increasing temperature and irradiance on the typical PV module is observed under standard testing conditions (STC), i.e., irradiance 1000 W/m^2, module temperature 25^{0}C, and air mass of 1.5. The effect of increasing temperature on the PV module performance is illustrated in Table 4.5 and Figures 4.11 and 4.12. It is observed that the main effect of increasing temperature of the PV module from 25^{0}C to 75^{0}C have a significant effect on V_{oc} as this leads to a substantial reduction in V_{oc}. A slight effect is also noticed in I_{sc} with an increase in temperature. It is also observed that as the level of temperature increases, the output power generated by the module is substantially reduced. At a cooler temperature, the solar panel will generate more electricity, while at a warm temperature, the same solar panel will generate less.

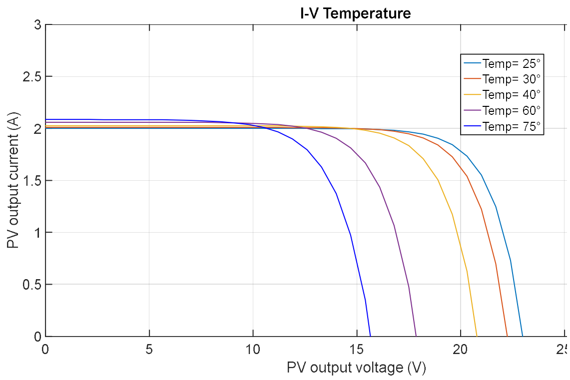


Figure 4.11 Photovoltaic output current versus output voltage (*I-V*) as a function of temperature

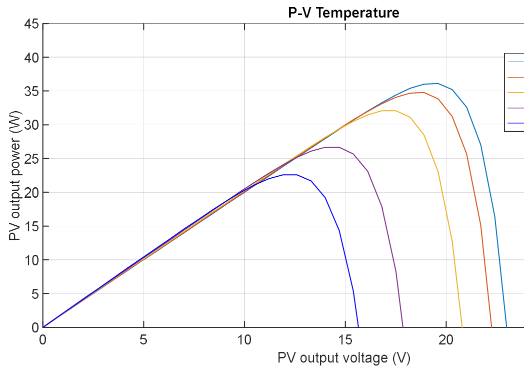


Figure 4.12 PV output power versus output voltage (P-V) as a function of temperature

Table 4.5 Temperature of PV module

Temperature (^{0}C)	I_{sc} (*A*)	V_{oc} (*V*)	V_{max} (*V*)	I_{max} (*A*)	P_{max} (W)	Efficiency (%)
75	2.085	15.7	12.6	1.793	22.6	9.098
60	2.059	17.9	14.0	1.905	26.67	10.737
40	2.026	20.8	17.5	1.833	32.08	12.91
30	2.009	22.3	18.9	1.839	34.76	13.99
25	2	22.9	19.6	1.842	36.1	14.53

Similarly, for different values of the irradiance, the values of the voltage, current, and power across the solar cell were observed. The increase in the value of irradiance indicates an increase in the intensity of solar energy. As the irradiance increases, the current and voltage also increase. This is illustrated in Table 4.6 and Figures 4.13 – 4.14. It is observed that reducing the level of irradiance from 1000 W/m^2 to 200 W/m^2 has a slight reduction in Voc but has a massive drop in I_{SC}.

Further, the amount of power produced by the module is substantially reduced due to the fall in the irradiance level. Similarly, a reduction in solar irradiance results in a drop in power at the maximum PowerPoint. The higher the irradiance, the better the performance of the PV module.

Changes in ambient situations such as temperature and irradiance lead to changes in the maximum power point (MPP) on the *P-V* curves illustrated in Figures 4.13 and 4.14, respectively. The maximum power point tracking device is always required to track MPP changes on the P-V curves above to ambient changes.

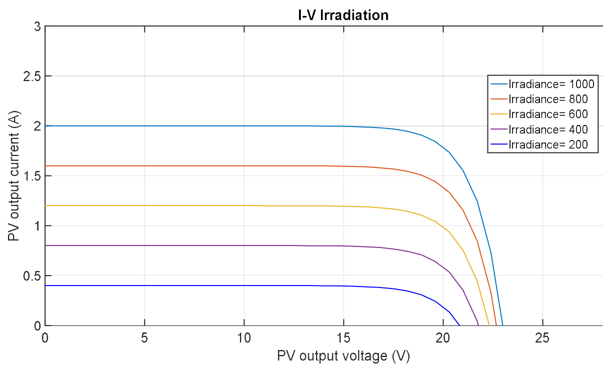


Figure 4.13 PV output current at various irradiance as a function of module current and output voltage

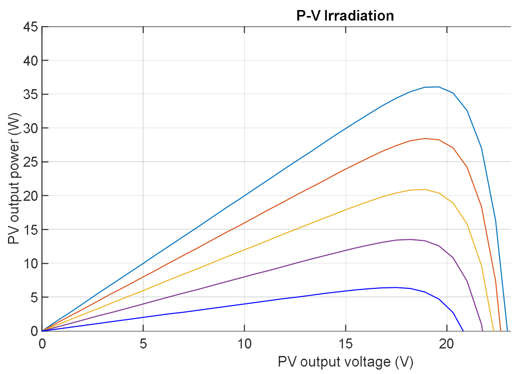


Figure 4.14 Photovoltaic output power at various irradiance as a function of module power and voltage

Table 4.6 Irradiation of PV module

Irradiation (W/m2)	I_{sc} **(A)**	V_{oc} **(V)**	V_{max} **(V)**	I_{max} **(A)**	P_{max} **(W)**	**Efficiency (%)**
1000	2	23	19.6	1.842	36.1	14.53
800	1.6	22.7	18.9	1.506	28.46	14.32
600	1.2	22.3	18.9	1.106	20.9	14.02
400	0.8	21.7	18.2	0.7442	13.54	13.63
200	0.4	20.9	17.5	0.3668	6.42	12.92

The above graphs show that temperature and irradiance have a direct effect on the maximum power point (MPP) on the *P-V* curves. The panel performance was noted to be best at 25^0C temperature and 1000 W/m^2 irradiance value. In the context of Nepal, the PV module is technically feasible as the average temperature is 25^0C, and the average solar irradiance is 1400 W/m^2.

4.3.3 PV modelling and simulations of I-V curves and P-V curves

A PV module is modelled by using Matlab Simulink. The parameters of the model are based on the equations mentioned above in section 4.3.1. The model is built by following the sequences until the final model is presented. Figures 4.15 and 4.16 show the purposed PV module and its output.

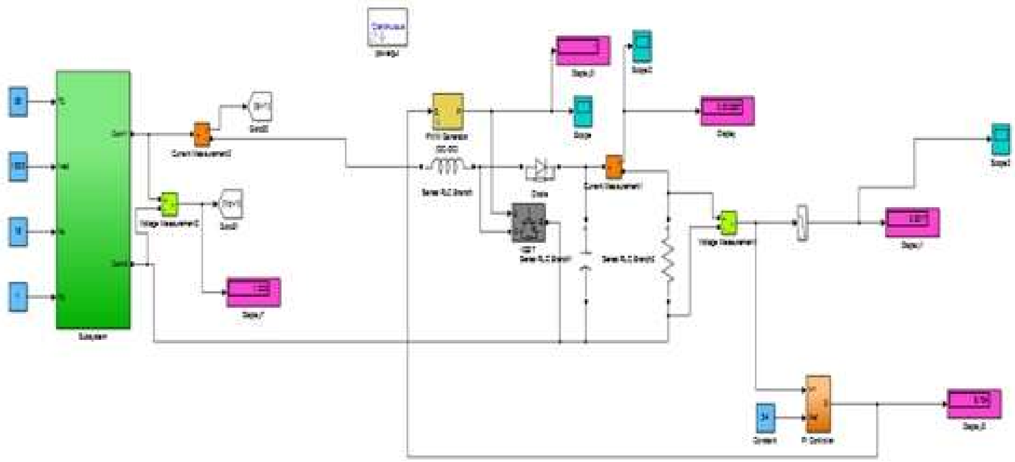


Figure 4.15 Purposed PV system module in Nepal

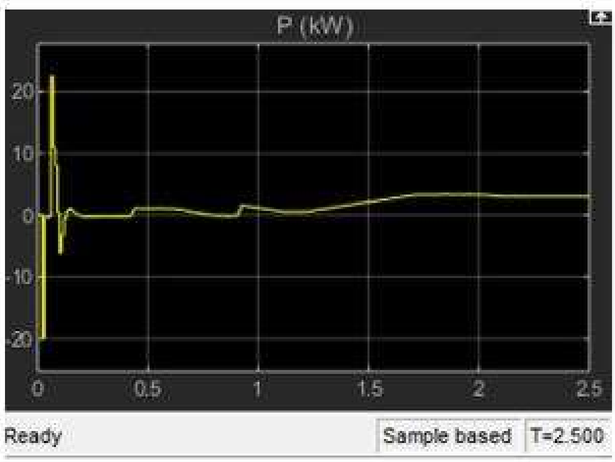


Figure 4.16 Output of the proposed PV module

For various irradiances and temperatures, I -V and P-V curves was simulated by using MATLAB. For this, the Talesun TP672M-330 module was chosen as it is going to be used during the process of optimization on PVsyst and HOMER. The I-V and P-V simulation results were verified by comparing the experimental results of the datasheet in Figures 4.17 and 4.18.

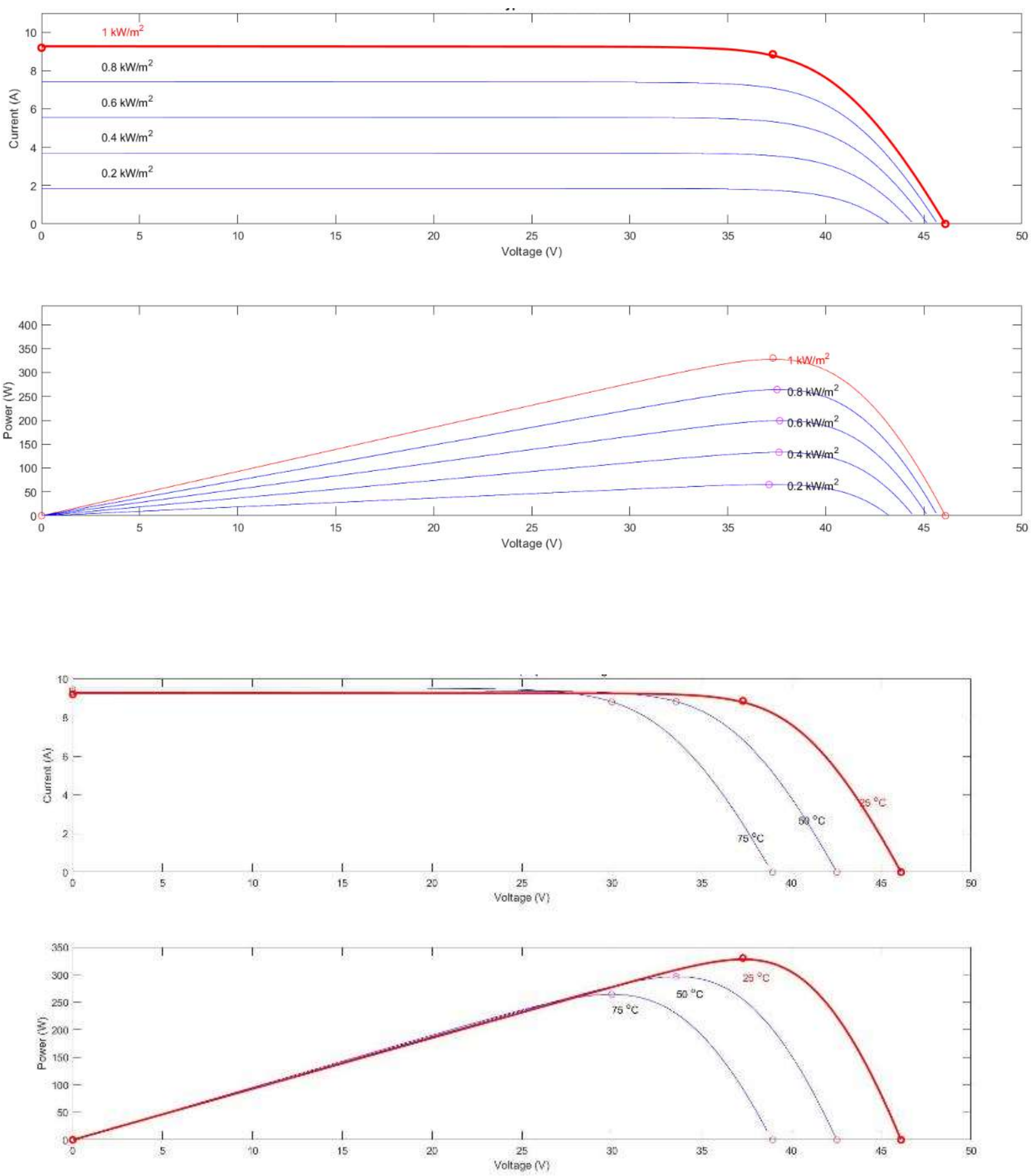


Figure 4.17 I-V and P-V curves of a PV cell array for Telesun TP672M-330 from MATLAB/Simulink

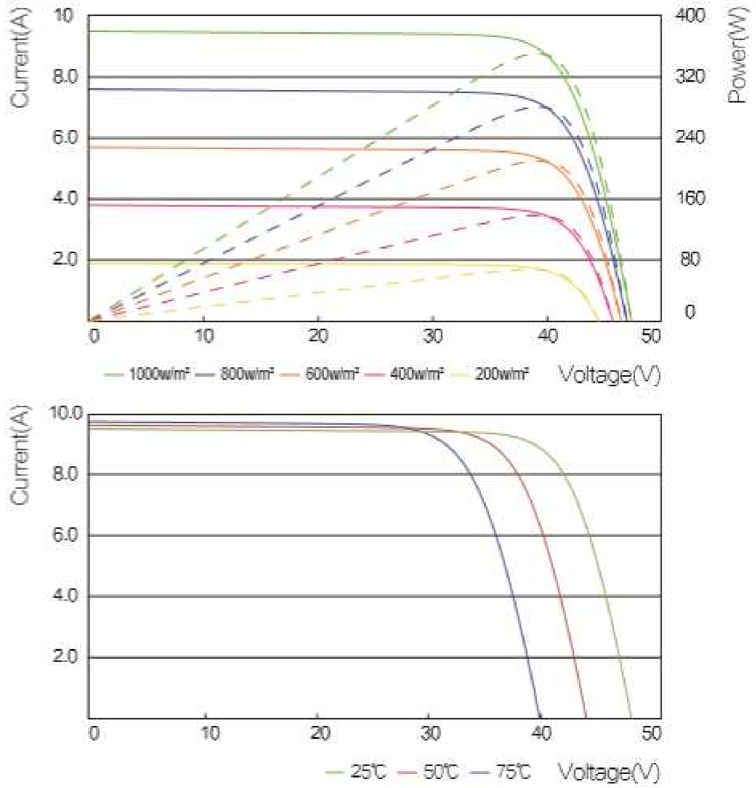


Figure 4.18 I-V and P-V curves for Telesun TP672M-330 (Source: Manufacturer's datasheet)

This result indicated that the created simulation blocks in Simulink/Matlab are similar to actual PV modules.

4.4 Evaluation of site meteorological data

For the performance evaluation of solar PV systems, it needs detailed data on the availability of solar radiation and its components. Hence in this second part of this chapter, the Meteonorm 7.3 software is used to obtain the relevant data for the main case study, Kathmandu valley.

Nepal is the roughly trapezoidal shape, about 800 kilometres (500 miles) long and 200 kilometres (120 miles) wide, with an area of 147,181 km^2 (56,827 sq. mile). It lies between latitudes 26^0 and 31^0 N, and longitude 80^0 and 89^0 E. It borders China in the North and India in the South, east, and west. The data of the Kathmandu valley represents the whole country because it is situated in the middle of the nation [51]. The valley is the potential, economic, and cultural hub, as well as the largest populous metro city in the country with moderate temperatures throughout the year. The studied area, Bishalnagar, is in the Kathmandu valley. Thus, it is not necessary to evaluate the horizon to assess the shadow generated by the hills. Also, climatic risks such as hail, strong winds, tornados are infrequent, so these are not considered in this study.

The valley climate is semi-tropical, and the monthly average maximum and minimum temperatures vary from 3.4^{0}C to 29.8^{0}C, and the average humidity of the basin is 75% [42]. May is the hottest month of the year, with the temperature ranging from 16^{0}C to 32^{0}C while January, February, and December are the coldest months of the year. Kathmandu has an annual average sun-hours varying from 80 to 290. July, August, and September are the lowest sun-hours months of the year, while March and April are the longest sun-hours month of the year with the sun hours ranging from 245 to 295 hours. Consequently, in the dry season, most of the Hydropower projects plummeted to half of their capacity.

4.4.1 Global irradiation

A large extent of the country has specific PV electricity output in the range of 1400 kWh and 1600 kWh (equals to average daily totals between 3.8 and 4.4 kWh/kWp). This position Nepal into the category of regions with very feasible potential for PV power generation by Solargis, as illustrated in the solar map of Nepal Figure 4.19. In addition, the solar irradiance figure on a month-by-month basis is shown in Figure 4.20, which shows the average daily irradiance, based on mounting the solar array flat on the ground.

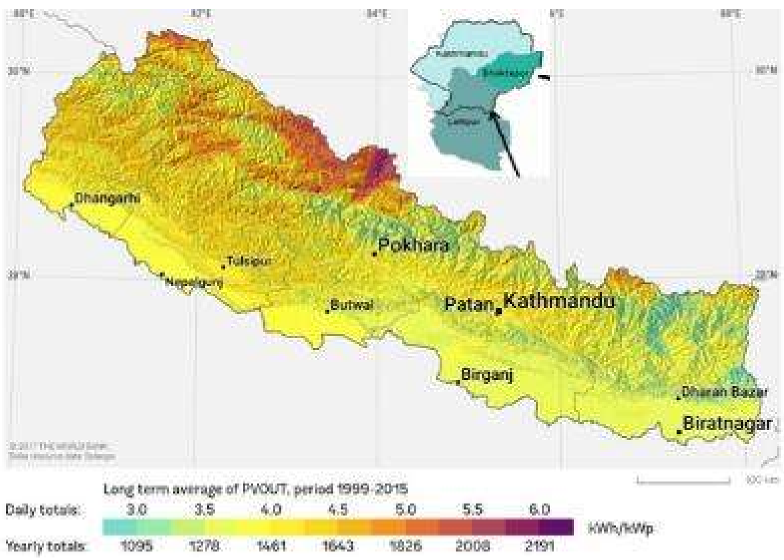


Figure 4.19 Solar map of Nepal [43]

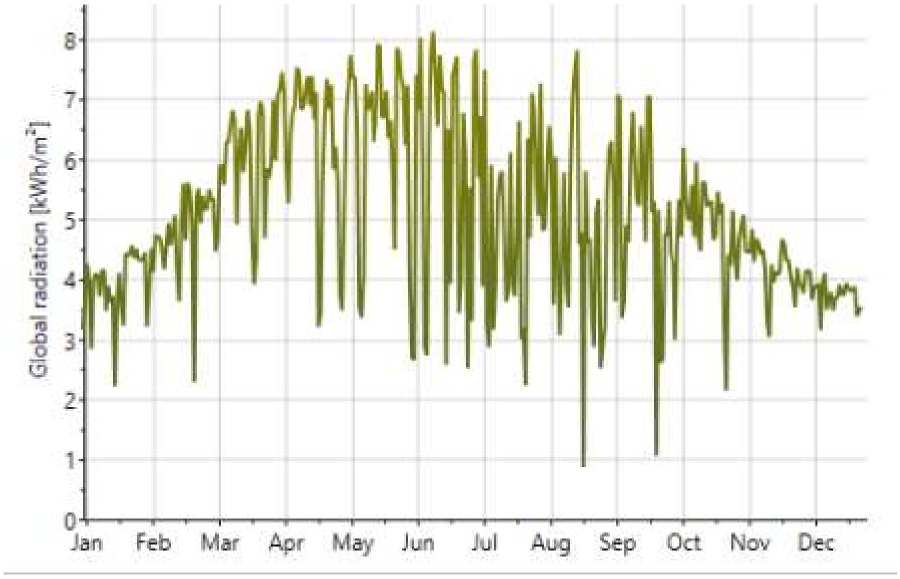


Figure 4.20 Daily global radiations

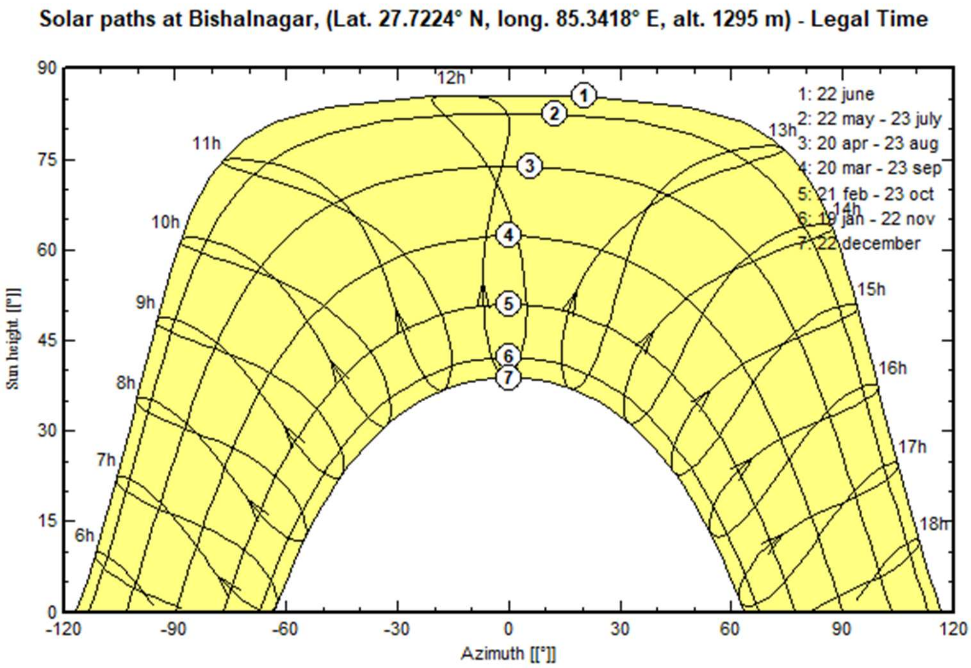


Figure 4.21 Solar path of Kathmandu, Bishalnagar generated by PVsysts

The solar path suggests the position of the sun relative to the view of the tilt and Azimuth angle, as presented in Figure 4.21 in a research site in Bishalnagar, Kathmandu. Nepal has abundant availability of solar energy throughout the year, as illustrated in Figure 4.19. With the average solar radiation varying from 3.6 – 6.2 kWh/m^2/day with 300 days sunny weather [2],[43]. Therefore, it is an ideal place for solar energy.

Table 4.7 Area under different annual direct normal radiation in Nepal [44]

S.No.	Solar Radiation Class (kWh/m^2/day)	Average Annual (kWh/m^2/day)	Area (Km^2)
1	3.5-4.5	4.16	2174.49
2	4.5-5.5	5.22	32587.00
3	5.5-5.75	5.561	2729.53
	Total	14.941	37491.02

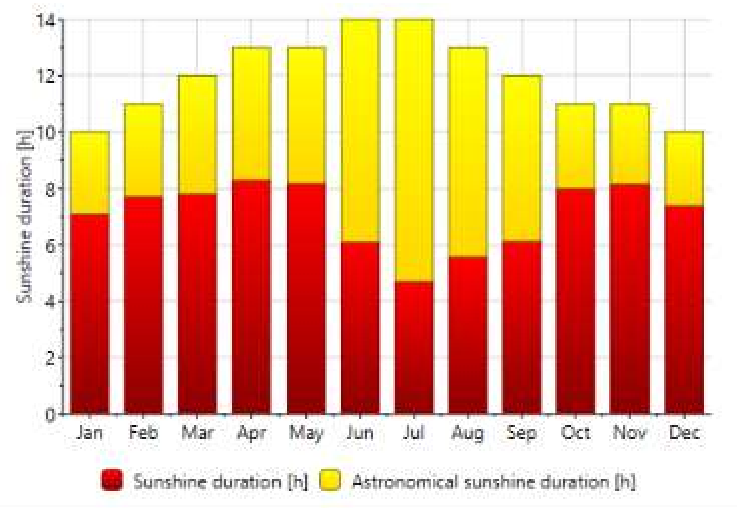


Figure 4.22 Sunshine duration

Sunshine duration of Kathmandu appears encouraging for the rooftop PV module as presented in Figure 4.22. April, May, October, and November have the highest sunshine duration of more than 8 hours, which means more electricity can be generated in these months while Nepal's hydropower system generates half of their capacity in April and May because of their seasonal flow of the river. In the long run, Nepal can make a balance by utilising the Solar PV system during this shortage months rather than importing electricity from India, which is generated from dirty coal and save the cost of 20 billion Nepali rupees every year [7].

4.4.2 Temperature

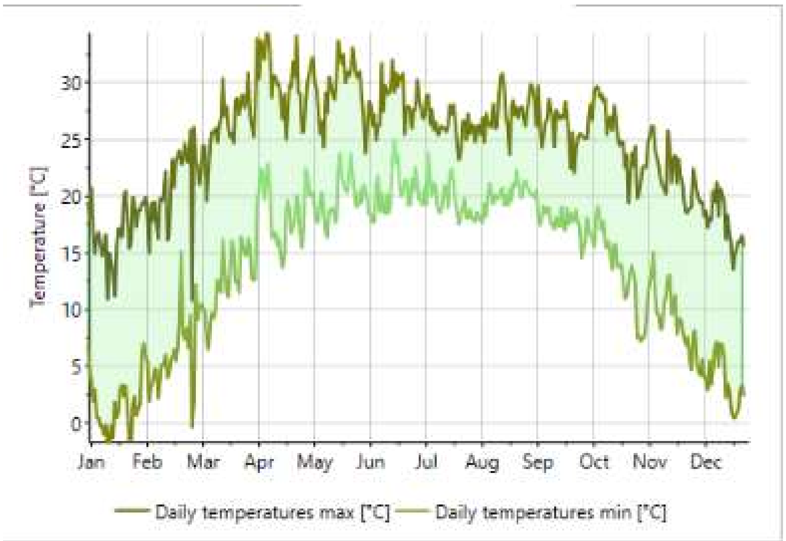


Figure 4.23 Daily temperatures

The temperature of Kathmandu, all round the year, ranges from 2.5 – 30^{0}c. Figure 4.23 illustrates the temperature of Kathmandu all-round the year, which is ideal as per the result of Matlab/Simulink simulation Figures 4.11 and 4.12 and Table 4.5. In general, high temperature decreases the efficiency of the PV system, and low temperature makes power conversion in PV modules more efficient.

4.4.3 Humidity and wind

The results of the effect of wind velocity on the performance of the solar system by Elsherbiny and Fath (1995) observed that increasing the wind speed from 0 to 8 m/sec decreases the total production by less than 10 per cent [45]. Low and medium speed winds, close to the ground, have cooling effects on the PV modules, which in turn increases their conversion efficiency and increases power generation. However, the occurrence of stronger winds poses a risk of damaging the modules and construction components. Although Kathmandu has a constant wind speed. March has the highest wind speed of 2.3 m/s, but this speed does not affect the solar generation in any case.

4.4.4 Precipitations

The average annual rainfall is about 55 inches, most of which falls in the period from June to September.

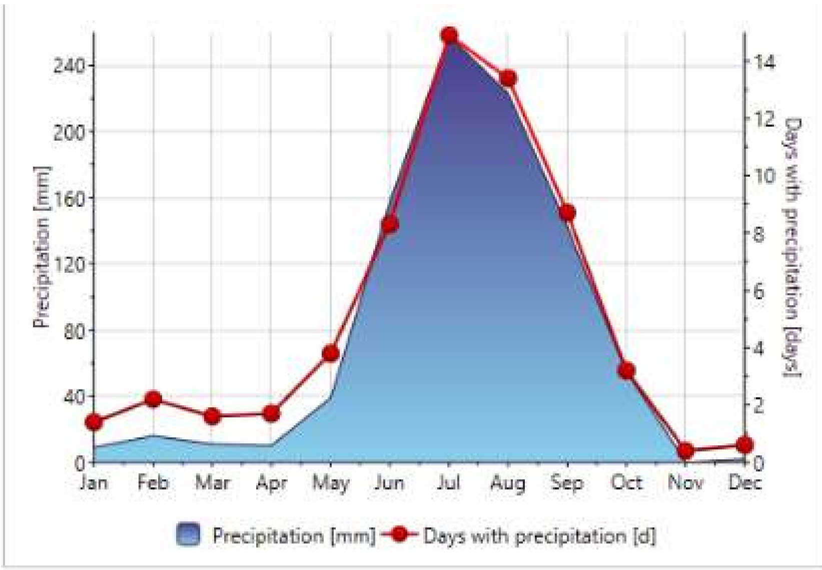


Figure 4.24 Precipitation

January to May and October to December have low precipitation where June to September have high precipitation, as shown in Figure 4.24. Although July has the highest rainfall, it still has 5hours of sunshine. The amount and periodicity of rainfall determine the cleaning efficiency of the surface of the PV modules. Manuel cleaning of PV modules requires special attention in a dry and dusty climate. Average Relative humidity in Kathmandu shows that most of the time, humidity remains 80 per cent throughout the year except March to May when it drops to 60 – 70 per cent.

4.4.5 Key findings

- The weather data obtained from Meteonorm 7.3 shows horizontal yearly irradiation in Kathmandu is high, which is 1950 [kWh/m^2/year].
- The valley has moderate temperatures throughout the year, having the average maximum temperature of 25.7^{0}C and the minimum average temperature of 11.4^{0}C. (PV cells have higher efficiency at 25^{0}C)
- The average sunshine hour is 7hrs.

- A large extent of the country has specific PV electricity output in the range of 1400 kWh and 1600 kWh (equals to average daily totals between 3.8 and 4.4 kWh/kWp).
- With an optimal 30° tilted angle, a solar PV module receives global irradiation of 2,224 [kWh/m²/year]. Thus, the return on investment time of a standard grid-connected plant will be about half what it is under central European conditions.
- During the dry season (February – June), both during morning and evening peak hours as well as during off-peak hours, the grid cannot provide the required energy. The lack of power is approximately 50 per cent. Solar PV arrays, with their main power production peak during the mid-day hours, could minimise the daily energy shortages significantly. Since load shedding affects the capacity of a grid-connected solar PV installation to deliver power to the grid, the first installations of this kind should be placed in locations where the phenomenon does not occur, such as hospitals, NEA buildings, For other areas, it is possible to consider systems that combine grid-connected PV systems with a local energy accumulation/storage facility, such as, e.g., batteries.

4.5 Simulation using PVsyst and HOMER

In this section, simulation is carried out using PVsyst and HOMER software. In PVsyst, the simulation is carried out for 3kW off-grid (standalone) and on-grid system, and in HOMER, the simulation is carried out for an on-grid plus battery system (hybrid). From the load demand and other necessary input details, the net present cost, operating cost per year, and the energy cost/kWh for three different models were obtained. In all three simulations, both technical and economic results were gathered, and the results were then analyzed for assessing the performance of the photovoltaic system.

4.5.1 Modelling using PVsyst software

The feasibility analysis of the PV system has been conducted with the PVsyst software for two scenarios: Case 1 - Standalone (off-grid) system and case 2 - Grid-connected system. The simulation results are presented below.

Case 1: Stand-alone (off-grid) system

Table 4.8 Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac
January	138.2	204.9	534.4	186.5	0.00	309.7	309.7	1.000
February	140.7	184.0	469.5	156.1	0.00	279.8	279.8	1.000
March	169.2	189.5	479.0	239.6	0.00	207.4	207.4	1.000
April	183.7	180.7	447.2	223.1	0.00	200.7	200.7	1.000
May	191.3	170.5	425.3	189.1	0.00	207.4	207.4	1.000
June	175.2	151.1	378.4	61.0	0.99	298.7	299.7	0.997
July	156.4	135.9	342.8	25.4	21.90	287.8	309.7	0.929
August	157.5	146.8	368.4	56.5	20.21	289.5	309.7	0.935
September	138.3	141.9	358.9	127.3	0.57	200.2	200.7	0.997
October	148.9	178.5	450.9	214.9	0.00	207.4	207.4	1.000
November	131.0	184.8	472.0	241.8	0.00	200.7	200.7	1.000
December	139.0	218.3	561.3	222.4	0.00	309.7	309.7	1.000
Year	1869.2	2086.9	5288.2	1943.7	43.66	2999.2	3042.9	0.986

Balances and main results are shown in Table 4.8 includes variables like global irradiance on the horizontal plane, effective global irradiance considering soiling losses and shading losses, DC energy available, and energy unused due to full battery loss. Apart from these variables, energy missed, energy user, energy load, and solar fraction are also calculated. The values of each variable mentioned in balances and main results were obtained in terms of monthly and yearly costs. For Bishalnagar, Kathmandu Valley, annual global irradiance on the horizontal plane is 1869.2 kWh/m^{2}and effective global irradiance after optical losses are 2086.9kWh/m^2. The yearly DC energy available from the Monocrystalline PV array is 5288.2kWh, energy unused is 1943.7kWh, energy missed is 43.66 kWh. The annual average solar fraction is observed to be 0.986.

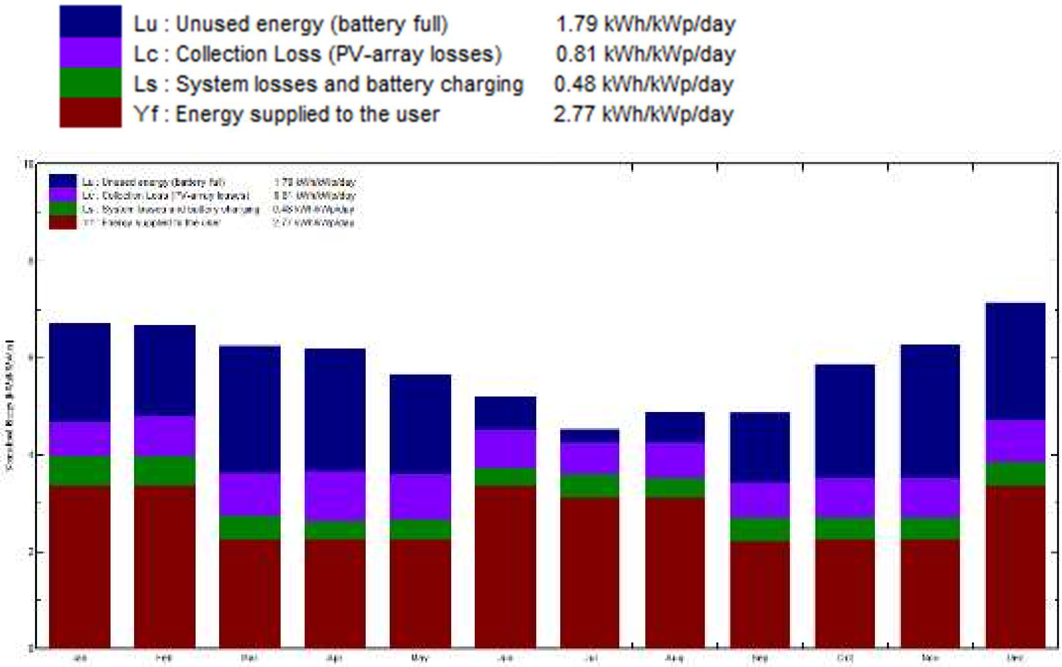


Figure 4.25 Nominalised energy production per installed kWp

Normalised energy productions such as unused energy (battery full), collection loss, system loss & battery charging and energy supplied to the user per installed kWh/kWp/day were evaluated from the simulation study, see in Figure 4.25. These normalized productions are defined by the IEC norms in the Photovoltaic system performance mounting guidelines for measurement, data exchange, and analysis [46]**.** Lu is the unused energy (battery full), i.e., 1.79kWh/kWp/day. Lc is the Collection losses or the PV array capture losses, i.e., 0.81 kWh/kWp/day. Ls is the system loss and battery charging, i.e., 0.48 kWh/kWp/day, and the Yf is the produced useful energy, i.e., 2.77 kWh/kWp/day.

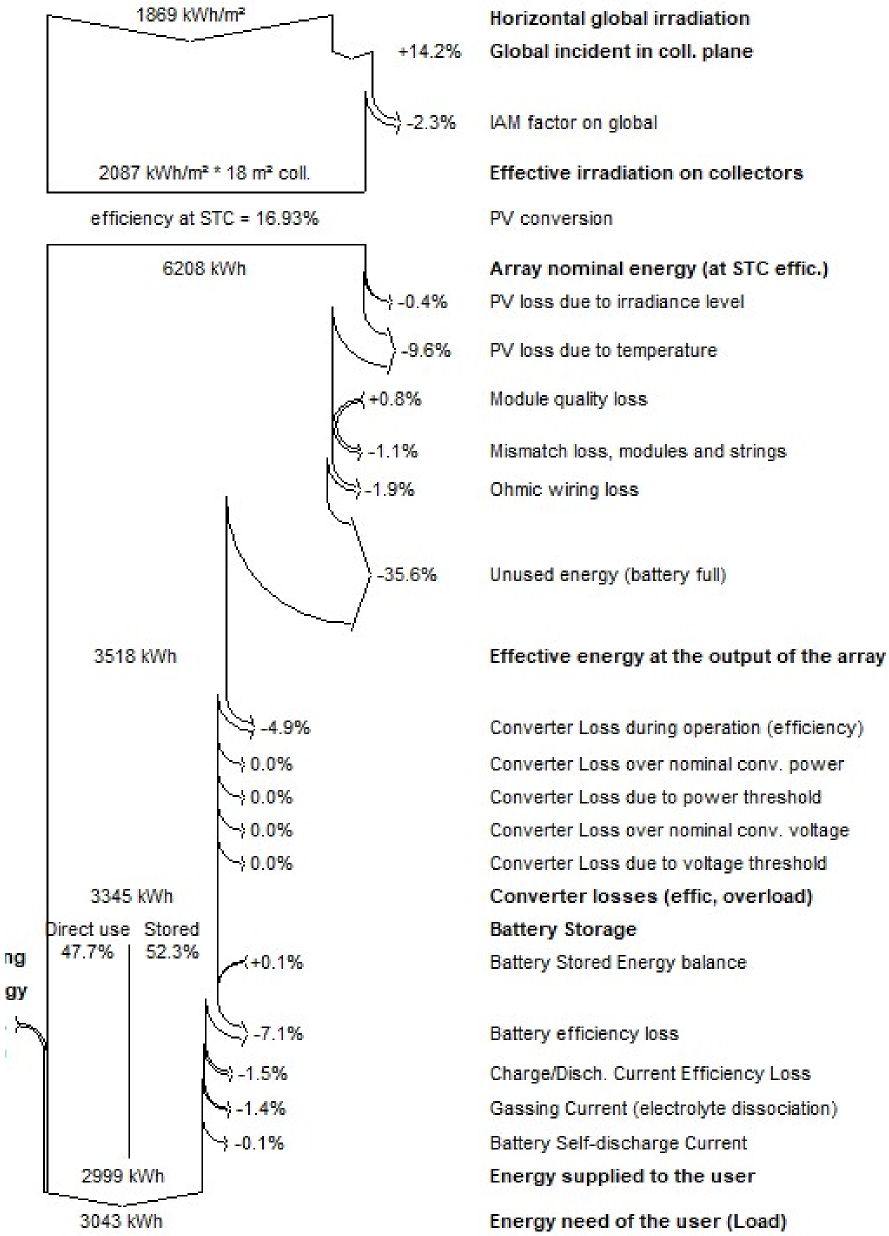


Figure 4.26 Arrow loss diagram for proposed monocrystalline 3kWp standalone system

The arrow loss diagram shown in Figure 4.26 is helpful in analysing the various losses that are to be encountered while installing PV plants or constraints to be considered. Global irradiance on a horizontal plane is 1869 kWh/m^2. Nevertheless, the effective irradiance on the collector is 2087 kWh/m^2. This result is the gain of 14.2per cent global incident in the collector plane and loss of energy, i.e., 2.3 per cent due to array incidence angle. When this effective irradiance falls on the surface of a photovoltaic module or array, electrical energy is produced. After the PV conversion, array nominal energy at standard testing conditions (STC) is 6208 kWh, and the efficiency of the PV array at STC is 16.93 per cent. Array effective energy at the output of the array is 3518kWh. The various losses occur in this stage are 0.4 per cent due to irradiance level, 9.6 per cent losses due to temperature, 1.1 per cent loss due to module array mismatch, and 1.9 per cent is the Ohmic wiring losses. Available energy on an annual basis at the converter output and battery storage is 3345 kWh. The loss occurs in this stage is 4.9 per cent due to convertor loss during operation. The energy supplied to the user is 2999kWh. Again, the various losses occur in this stage are 7.1 per cent battery efficiency loss, 1.5 per cent charge/discharge current efficiency loss, 1.4 per cent electrolyte dissociation, and 0.1 per cent battery self-discharge current. The missing energy current is 44kWh, and the energy need for the user is 3043kWh.

The detailed economic results show that the total yearly cost including 9.90 inflation per year is $1009.37USD /year, used solar energy is 2999kWh/year, excess energy(battery full) is 1944kWh/year and the cost of produce energy (sum of costs over lifetime/total production over lifetime) is 0.345USD/kWh.

Case 2: Grid-connected PV system

Table 4.9 Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR
January	138.2	25.98	8.90	208.1	204.9	618.5	597.9	0.871
February	140.7	32.69	13.34	186.9	184.0	544.0	525.5	0.852
March	169.2	58.43	18.84	193.7	189.5	550.0	531.3	0.831
April	183.7	66.20	23.70	185.5	180.7	513.3	495.8	0.810
May	191.3	77.28	25.06	175.7	170.5	489.4	472.2	0.814
June	175.2	88.42	24.25	155.9	151.1	441.6	426.0	0.828
July	156.4	82.90	23.41	140.5	135.9	401.7	386.9	0.835
August	157.5	78.17	23.27	151.3	146.8	429.8	414.6	0.830
September	138.3	70.56	22.40	146.0	141.9	414.4	399.8	0.830
October	148.9	55.05	20.34	182.0	178.5	518.6	500.9	0.834
November	131.0	31.37	15.55	187.9	184.8	541.8	523.7	0.844
December	139.0	19.92	11.06	221.5	218.3	648.0	626.4	0.857
Year	1869.2	686.98	19.20	2135.0	2086.9	6111.2	5901.1	0.838

Balances and main results are illustrated in Table 4.9 comprises the variables like global irradiance on the horizontal plane, ambient average temperature, global irradiance on collector plane without any optical corrections, effective global irradiance considering soiling losses and shading losses. Apart from these variables, DC energy produced by the photovoltaic array, energy injected into the grid, and system efficiency also calculated. The values of each variable mentioned in balances and main results were obtained in terms of monthly and yearly values. For Bishalnagar, Kathmandu Valley, annual global irradiance on the horizontal plane is 1869.2 kWh/m^{2}and the universal incident energy and effective global irradiance after optical losses are 2135kWh/m^2 and 2086.9kWh/m^2 respectively. The annual DC energy produced from the Monocrystalline PV array and annual AC energy injected to the grid is 6111.2kWh and 5901.1kWh, respectively. The annual average performance ratio (PR) for the simulated photovoltaic system is observed to be 0.838 (83.8per cent).

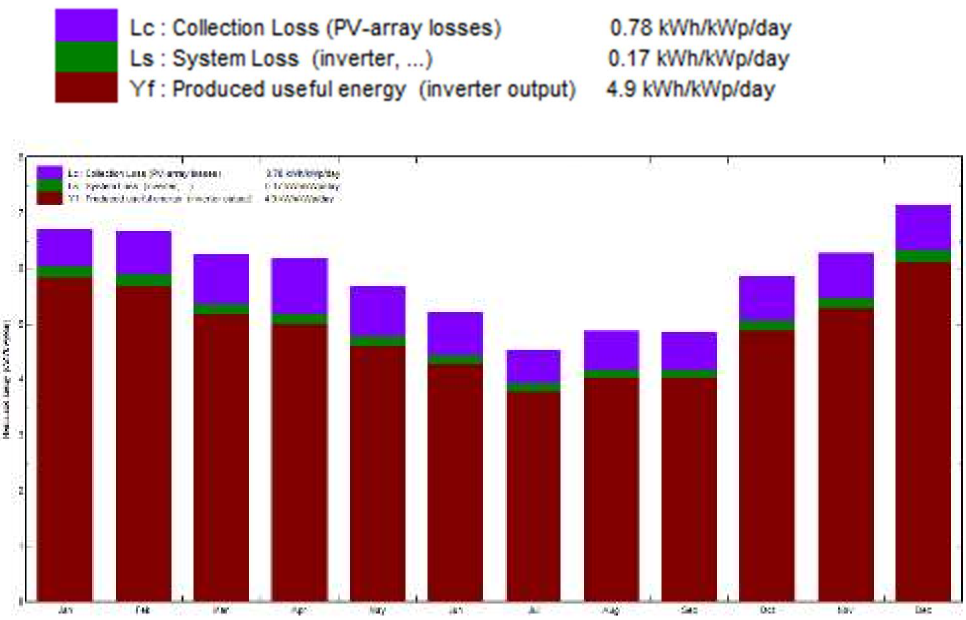


Figure 4.27 Nominalised energy production per installed kWp

Normalised energy productions such as collection loss, system loss, and produced useful energy per installed kWh/kWp/day were calculated from the simulation study, see in Figure 4.27. Lc is the Collection losses or the PV array capture losses, i.e., 0.78 kWh/kWp/day. Ls is the system loss, i.e., 0.17 kWh/kWp/day, and the Yf is the produced useful energy, i.e., 4.9 kWh/kWp/day.

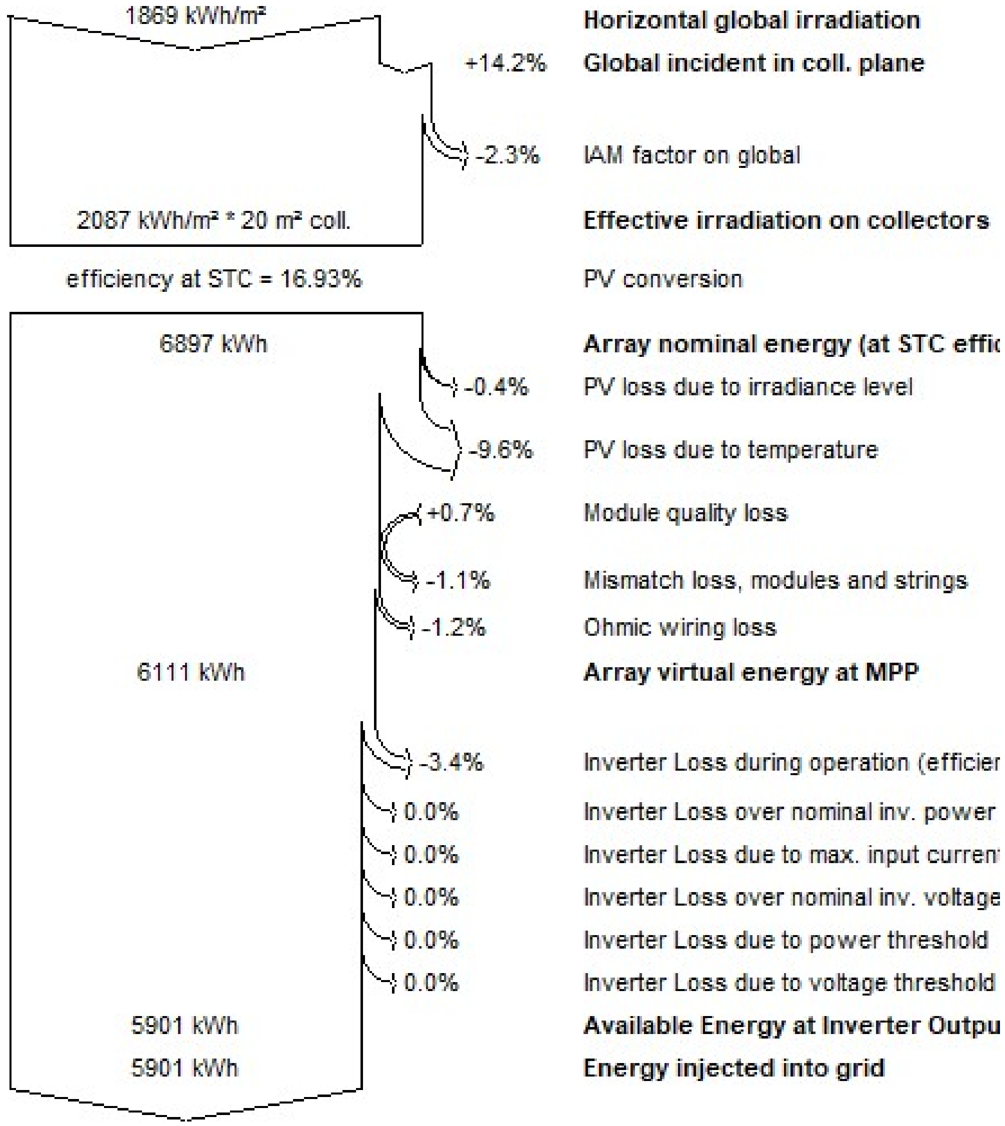


Figure 4.28 Arrow loss diagram for monocrystalline solar grid 3kWp photovoltaic system

Arrow loss diagram exhibited in Figure 4.28 helps analyse the various losses that are to be encountered while installing PV plants or constraints to be considered. Global irradiance on a horizontal plane is 1869 kWh/m^2. Nevertheless, the effective irradiance on the collector is 2087 kWh/m^2. This result is the gain of 14.2per cent global incident in the collector plane and loss of energy, i.e., 2.3 per cent due to array incidence angle. When this effective irradiance falls on the surface of a photovoltaic module or array, electrical energy is produced. After the PV conversion, array nominal energy at standard testing conditions (STC) is 6897 kWh, and the efficiency of the PV array at STC is 16.93 per cent. Array virtual energy at MPP is 6111kWh. The various losses occur in this stage are 0.4 per cent due to irradiance level, 9.6 per cent losses due to temperature, 1.1 per cent loss due to module array mismatch, and 1.2 per cent is the Ohmic wiring losses. Available energy on an annual basis at the inverter output facility is 5901 kWh, and the same is injected into the grid. Here inverter loss during inverter operation, i.e., 3.4 per cent loss was possible.

The detailed economic results show that the total yearly cost, including 9.90 inflation per year, is $250.59USD /year, produced energy is 5695kWh/year and the cost of produce energy (sum of the expenses over lifetime/total production over lifetime) is 0.060USD /kWh. Also, the payback period is 8.7 years, the net profit at the end of the lifetime is $1992.2USD, and the return of investment (ROI) is 86.6per cent. The system will save 10.333 tons of CO_2 emissions.

4.5.2 Modelling using the HOMER optimization tool

The feasibility analysis of the hybrid PV system has been conducted in the HOMER software. While designing the PV system in HOMER, the project lifetime of 25 years has been considered. A discount rate of 0.06 (6 per cent) and an inflation rate of 0.099 (9.9 per cent) are considered to calculate the real rate of interest. The costs and other parameters considered for HOMER optimization and the optimal capacity obtained in HOMER for Solar-Grid-Battery case is presented below.

Case 3: Solar PV-Grid- Battery (Considering net metering)

Table 4.10 System architecture and cost summary

System architecture

PV Array	3 kW
Grid	1,000 kW
Battery	6 Surrette 4KS25P
Inverter	2 kW
Rectifier	2 kW

Cost summary

Total net present cost	$ 5,660
Levelized cost of energy	$ 0.094/kWh
Operating cost	$ 48.5/yr

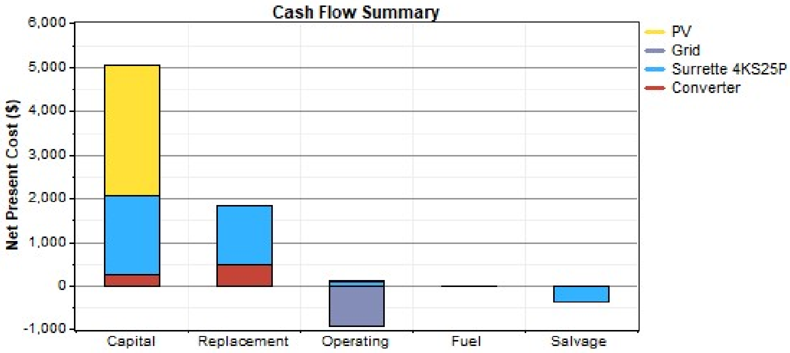


Figure 4.29 Cash flow summary

Table 4.11 Net present costs

Component	**Capital**	**Replacement**	**O&M**	**Fuel**	**Salvage**	**Total**
	($)	($)	($)	($)	($)	($)
PV	3,000	0	38	0	0	3,038
Grid	0	0	-938	0	0	-938
Surrette 4KS25P	1,800	1,339	77	0	-384	2,831
Converter	240	488	0	0	0	728
System	5,040	1,827	-823	0	-384	5,660

Table 4.12 Annualized costs

Component	**Capital**	**Replacement**	**O&M**	**Fuel**	**Salvage**	**Total**
	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)	($/yr)
PV	235	0	3	0	0	238
Grid	0	0	-73	0	0	-73
Surrette 4KS25P	141	105	6	0	-30	221
Converter	19	38	0	0	0	57
System	394	143	-64	0	-30	443

Table 4.13 Electrical production and consumption

Component	Production	Fraction	Load	Consumption	Fraction
	(kWh/yr)			(kWh/yr)	
PV array	3,528	72%	AC primary load	2,110	45%
Grid purchases	1,349	28%	Grid sales	2,608	55%
Total	4,877	100%	Total	4,718	100%

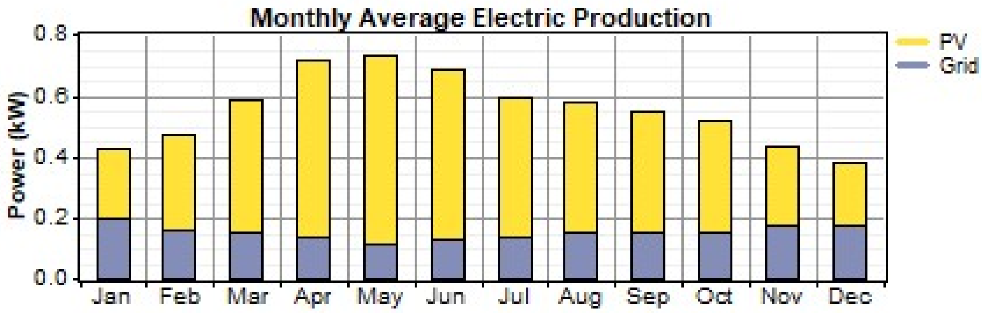


Figure 4.30 Monthly average electric production

Table 4.14 Monthly average electric production

Quantity	Value	Units
Excess electricity	10.4	kWh/yr
Unmet load	0.00	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.714	

Table 4.15 PV detail

Quantity	Value	Units
Rated capacity	3.00	kW
Mean output	0.403	kW
Mean output	9.67	kWh/d
Capacity factor	13.4	%
Total production	3,528	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	2.48	kW
PV penetration	167	%
Hours of operation	4,380	hr/yr
Levelized cost	0.0674	$/kWh

Table 4.16 Battery detail

Quantity	Value
String size	6
Strings in parallel	1
Batteries	6
Bus voltage (V)	24

Quantity	Value	Units
Nominal capacity	45.6	kWh
Usable nominal capacity	27.4	kWh
Autonomy	114	hr
Lifetime throughput	63,412	kWh
Battery wear cost	0.032	$/kWh
Average energy cost	0.091	$/kWh

Quantity	Value	Units
Energy in	30.8	kWh/yr
Energy out	24.6	kWh/yr
Storage depletion	0.323	kWh/yr
Losses	5.84	kWh/yr
Annual throughput	28	kWh/yr
Expected life	12.0	yr

Table 4.17 Converter detail

Quantity	Inverter	Rectifier	Units
Capacity	2.00	2.00	kW
Mean output	0.39	0.00	kW
Minimum output	0.00	0.00	kW
Maximum output	2.00	1.81	kW
Capacity factor	19.4	0.1	%

Quantity	Inverter	Rectifier	Units
Hours of operation	4,386	12	hrs/yr
Energy in	3,533	22	kWh/yr
Energy out	3,391	21	kWh/yr
Losses	141	1	kWh/yr

Table 4.18 Grid-connected

Month	Energy Purchased	Energy Sold	Net Purchases	Peak Demand	Energy Charge	Demand Charge
	(kWh)	(kWh)	(kWh)	(kW)	($)	($)
Jan	149	128	20	3	2	0
Feb	110	154	-45	2	-3	0
Mar	115	243	-128	2	-8	0
Apr	100	324	-225	2	-13	0
May	83	354	-271	2	-16	0
Jun	91	297	-207	2	-12	0
Jul	104	245	-141	2	-8	0
Aug	115	225	-110	2	-7	0
Sep	111	206	-95	2	-6	0
Oct	113	200	-86	2	-5	0
Nov	127	133	-6	2	0	0
Dec	132	98	35	2	3	0
Annual	1,349	2,608	-1,259	3	-73	0

The optimization considers a total PV capacity of 3.0 kW, inverter capacity of 2kW, rectifier capacity of 2 kW, and 6 No. Surrette 4KS25P battery. The yearly total electrical output from the PV system is 3528 kWh/year (72per cent), and grid purchases is 1349 kWh/year (28per cent), respectively. The levelized cost for the PV system is US$0.0674/kWh. The total power output from the PV system is 3528 kWh/year, and the maximum power output at any hour is 2.48 kW. The yearly AC primary load is 2110 kWh/year (45per cent), and grid sales are 2608kWh/year (55per cent). Hence grid sale is more than grid purchase. The system, therefore, not only meets all the load demand but also produces excess energy of approximately 10.4 kWh/year.

HOMER suggests the total net present cost of the optimal system as US $5660. The net present cost of the PV system is US$3000. The replacement cost and fuel cost of the PV system are zero, but the operation and maintenance cost is US$38. The net present cost of the grid, battery, and converters are 0, US$1800, and US$240, respectively. The replacement value of the battery and converter are US$1339 and US$488, respectively. The salvage value of both grid and converter is 0, but the salvation value of the battery is US$ -384 (negative). It may be observed that the net present cost of the battery is predominant. Besides, the battery capital cost is US$1800; replacement is US$1339, its operation and maintenance cost is US$77, the effective use of storage and cost of the same will play a pivotal role in the decision making of installation of the system application.

Although the PV capital cost is US$3000, the operation and maintenance costs of PV is only US$38, the battery is US$77, and the grid is US$ -938 (negative). Therefore, the TAC of the system is reduced to US$5660. It is observed that the annualized costs of the PV system, grid, battery, and converter are US$235, 0, US$141, and US$19, respectively. The annualized cost of the system is US$443.

The simulation results for solar PV-grid- battery system in HOMER, show the system to be feasible. Notably, initial investment and operating costs of solar PV-grid-battery system is higher because of the battery backup system. The total net present cost is $5660, which is nearly double than solar PV-grid system. Besides, the Levelized Cost of energy and operating cost of solar PV-grid-battery system is $0.094/kWh and $48.5/year, respectively.

4.6 Results analysis and discussion

This section illustrates the results in section 4.5 and explores the techno-economic feasibility and environmental measures of all three systems: Stand-alone system, grid-connected system, and grid-battery connected(hybrid) system.

It is observed in both simulation results of PVsyst and HOMER that the power output from the solar PV is quite significant due to the high solar irradiance throughout the year. This output power is quite significant, which can be used to cater to the electrical load of the medium-sized household. The electrical performance analysis and economic consideration in PVsyst for the off-grid system show that the system is feasible in terms of electrical power output, but the system is not feasible in terms of economic aspects. The grid-connected system, on the other hand, is both feasible in terms of electric power output and finance. Also, the economic analysis confirms the payback period of the grid-connected PV system is 8.7 years, the rate of investment is 86.6per cent, and CO_2 saving is 10.3 tons making it environmentally friendly technology.

The comparative simulation result of the standalone and grid-connected system is illustrated in Table 4.19. The produced energy is 5.9MWh/year for the grid-connected system, but the used solar energy for stand-alone is 2999kWh/year, which is almost half. Similarly, the cost of produce energy (sum of costs over lifetime/total production over lifetime) is 0.345USD/kWh for standalone, and for grid-connected, it is 0.06USD /kWh. The result also shows the payback period for the stand-alone system to be indefinite because of the high battery cost and its short life cycle. The initial investment, operation, and maintenance costs are higher compare to the grid-connected system. The low electricity price also outweighed the cost, therefore, making the investment infeasible. Nonetheless, this system has the added advantages of supporting the reduction of CO_2 emissions and a yearly reduction in electricity bills, which will go higher in the coming years. The system is also independent of a grid system; therefore, the power outage and the voltage fluctuation in the grid will not be affected. Furthermore, projections show that the systems can be feasible if the declining trend in PV system prices continues, and electricity prices increase. For the grid-connected system, the payback period is 8.7 years, the net profit at the end of the lifetime is $1992.15USD, and the return of investment (ROI) is 86.6 per cent. The system is, therefore, techno-economically viable.

Table 4.19 Comparison between Standalone and Grid-connected system

	Standalone PV System	**Grid-connected PV system**
Total yearly cost including inflation	$1009.37USD /year	$145.89USD /year
Produced energy	2999kWh/year	5.9 MWh/year
Payback period	Indefinite	8.7 years
Net profit at the end of the lifetime	-	$1992.2USD
Return of investment (ROI)	-	86.6%.
Used Energy cost	0.345USD /kWh	0.060USD /kWh
CO_2emissions saved	5.0 tons	10.3 tons

In HOMER, the net present cost and the annualized cost of the grid plus battery simulations are US$5660 and US$443/year, respectively. The Levelized cost for this hybrid system is US$ 0.094/kWh. The NPC and annualized cost of the system are affected mostly by the battery cost, especially the operation and maintenance cost of the same. It is observed that for the solar-grid-battery system, the net present cost of the battery is predominant. Besides, the battery capital cost is US$1800; replacement is US$1339, its operation and maintenance cost is US$7. Hence the effective use of storage and cost of the battery will play a pivotal role in the decision making of installation of the system in an application.

The simulation result shows that all three systems have advantages and are technically viable. The solar-grid system is the best out of off-grid and solar-grid-battery systems when there is a reliable grid connection. Nevertheless, if there is no grid connection, then the stand-alone system can be cheaper than extending power lines like in some remote regions. Likewise, if there is an unreliable grid connection, then the hybrid system is better as it is less expensive than the off-grid system as the capacity of the battery bank can be downsized, and there is no need for a backup generator.

4.7 Conclusion

The principle idea of this research was to analysis the techno-economic feasibility of a 3kWp standalone, grid-connected, and hybrid PV systems in the residential building of Kathmandu valley. This research has evaluated the technical, financial, and environmental aspects of the proposed PV power system by using PVsyst and HOMER software. Monocrystalline TP672M – 330 PV module manufactured by Zhongli Talesun Solar Co. Ltd was selected, and the values in the datasheet of the PV module have been verified and found similar to characteristics as Simulink PV model. In addition, the simulation result showed that the panel performance to be noted best at 25°C and 1000W/m^2 irradiance.

Noteworthy, Nepal receives a high amount of solar radiation throughout the year. The data obtained from Meteonorm showed that the horizontal yearly irradiation in Kathmandu is 1950kWh/m^2/year and has moderate temperature throughout the year, having the average maximum temperature of 25.7^{0}C and the minimum average temperature of 11.4^{0}C. The weather data analysis demonstrated that the PV power plant is auspicious in the Kathmandu valley, which has the potential to generate electricity for public consumption. Similarly, the simulation result in PVsyst and HOMER proved that there is an enormous potential for solar PV systems in Kathmandu, Nepal. The study highlighted the fact that Nepal's transmission network is outdated and is in no position to accommodate large power generation that the government plans to achieve in the next 10 years. In these circumstances, on-site solar PV generation has the capacity to reduce not only pressure on transmission and distribution but also reduces power losses that occur upon using the outdated infrastructure and colossal electricity theft. One notable advantage is that there will be higher energy access for rural consumers.

As per the result of this research, it is evident that the grid-connected system is economically best out of all. However, all three PV system could be adapted to make a balance in the annual rising electricity demand. A stand-alone PV system would be beneficial for rural areas where there is no grid connection. Likewise, the grid-connected and hybrid system would be beneficial in urban areas. However, considering power quality and grid stability, in the context of the Kathmandu valley, the hybrid system would be the perfect match for uninterrupted energy supply.

Government policies and actions play a crucial role in how energy systems develop. Although Nepalese Government has set a goal to increase the share of renewables from less than 1 per cent to 10 per cent and further to improve access to electricity from alternative sources from 10 per cent to 30 per cent within the next 20 years, the implementation of these policies in real life is often lacking. According to the energy progress report 2019, 1.3 million people have no access to electricity, and Nepal has targeted to achieve 100per cent of electricity within a few years. Hence the stand-alone PV system would be the game-changer and help to achieve this target.

In addition, the Nepalese government should consider the solar-powered micro-generation from a broader perspective. If 100,000 homeowners of Kathmandu valley installed a 3kW PV system, then 300MW electricity could be generated. While solar PV by itself cannot solve future planning and supply issues, it can certainly play a significant role in meeting a sizeable portion of annual demand. However, to our knowledge, an extensive evaluation of rooftop PV solar potential has not yet been undertaken in this city and country on a broader scale.

4.8 Recommendations

As mentioned above, several barriers still hinder the full development and installation of solar PV-grid technology in Nepal. Real implementation needs to be prioritized by the government of Nepal. The novelty of this chapter is the optimization and integration of locally available renewable energy resources based on Nepal's weather conditions, irradiations, temperature, geographic situation, the geopolitics of energy, and robust energy security.

This study can be instrumental in further recommending the society towards integrated renewable energy adaptation in developing countries like Nepal and similarly in other parts of the world. The study reveals that the purposed PV system could be an example of the sustainable future of Nepal. Moreover. Optimization in business scale adaptation of such systems will play a significant role in mitigating the energy crisis in a short time sustainably.

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Chapter 5
Energy efficiency improvement and sustainability issues of cement production in Nepal

This chapter presents the work described in Poudyal et al. 2019. It is the fifth chapter, in continuation of the Renewable energy and other strategies for mitigating the energy crisis of Nepal concept introduced in Chapter 1 and discussing throughout chapters 2, 3 and 4.

5.1 Introduction

Cement is the most used building material in the world, and its consumption is continuously growing. The cement industries must comply with ever-stricter environmental regulations while being among the largest carbon dioxide producers. They are also faced with shrinking revenues due to growing energy costs and persistent inefficiencies of manufacturing processes [1]. The cement utilisation has a direct correlation with the economic growth, and indirectly also with improvements in the living standards of citizens. The cement industry represents almost 15 per cent of the world's total energy consumption in all industries [2]. The global cement demand is expected to grow from approximately 2,450 million metric tonnes (MT) in 2006 to as much as 4,380 million MT in 2050 [3].

In December 2015, 195 countries, including Nepal, signed the Paris Agreement to fight climate change. The agreement requires all countries to monitor and report greenhouse gas (GHG) emissions and to define their contributions towards the low-carbon economy. Cement production is very energy-intensive, so there is a considerable amount of CO_2 emissions. The primary cause of CO_2 emissions is the chemical reaction yielding clinker, the main component of cement. In this reaction, the carbonates (mostly limestone, $CaCO_3$) are decomposed into oxides (mainly lime, CaO) and CO_2 with the help of heat. The amount of CO_2 discharged for a given amount of CaO can be calculated by means of chemical stoichiometry. The end result is that the cement industry worldwide is responsible for as much as 8per cent of the global CO_2 emissions [4]. In addition, the heat generated by the combustion of fossil fuels as well as waste gases and dust during production is the critical source of airborne pollutants. The improvements in energy efficiency and the use of better materials not only help to reduce production costs but also reduces material wastes, wastewater effluents, gas emissions, waste heat, and ambient noise.

Nepal is still in the early stages of its industrial development, so the share of the industrial sector in its national economy is relatively small. The contribution of the Nepalese industrial sector to the GDP was 9per cent in fiscal year (FY) 2000/01, but only 6.35% in 2012/13, and it is now stabilized at about 5.7per cent for the past several years [5]. The industrial output shrank substantially in 2015/16 due to the huge earthquake as well as due to the border obstruction from India, which also caused a massive deficit in the petroleum and LPG supplies (GoN, 2016). However, the country aspires to raise the share of manufacturing in GDP to 13 per cent in 2030. The real GDP is set to grow by 8.7 per cent on average during the SDG period, according to the SDG and Roadmap Report 2017 [7].

Cement production is one of the key industrial activities in Nepal, and it is currently under strong growth [8]. The demand for cement had increased sharply in the past few years, especially after the 2015 earthquake, when over 500,000 houses were damaged [9]. In addition, the recent government initiatives are aiming at significant expansion of the hydropower generation capacity and the road networks in Nepal. For comparison, the annual growth of the cement demand in Nepal is estimated to be 10–15per cent, whereas the world average is below 3 per cent. The current overall cement demand in Nepal is about 5 million MT, of which about 80 per cent is satisfied by the national production, and the remaining amount is imported. According to the data from the Trade and Promotion Centre (TEPC), Nepal had imported USD$9.18 million of cement in FY 2017/18, and USD $10.16 million of cement a year earlier (TEPC,2016). In addition, Nepal imported clinker worth USD $267.63 million in FY 2017/18 compared to USD $222.52 million in the previous year. Thus, for every 100 sacks of cement, 44 sacks are imported either directly as cement or indirectly as clinker, so the cement production in Nepal is strongly dependent on imports from abroad. Despite enormous and proven limestone reserves of 210 million tonnes located in various parts of Nepal, the clinker-based cement industry exceeds the limestone-based industry, and the former must rely on 30per cent clinker imports from India [8].

There are two types of cement plants: namely, the limestone-based and the clinker–based plants. The first cement plant in Nepal, Himal Cement Company Ltd., was established in Chobar of Kathmandu valley in 1972 due to the collaboration between the Nepal Industrial Development Corporation (NIDC) and Germany. The initial production capacity was 160 tonnes a day, which was later to 360 tonnes per day after the investments form the Chinese Government. However, this plant was closed in 2002 due to environmental concerns [10]. In 1976, Makawanpur Hetauda Cement Industries Limited was opened with a production capacity of 750 tonnes a day. The UCIL plant was opened a decade later in 1987 to produce 840 tonnes of cement per day. Today, there are 2 government-owned and other 114 cement plants that are registered under the Department of Industry, although only 68 of these plants are currently in operation. These plants are producing 160 million sacks of cement annually. The underlying investments are estimated to be USD 1.8 billion [11]**.**

The cement manufacturers in Nepal are facing a highly competitive global business environment. The high production costs of cement in Nepal do not allow the local producers to sell cement in the foreign and national markets at competitive prices. The key factors behind these high production costs, which are negatively affecting sales as well as earnings, the inefficient use of energy, uncertain energy supplies, and also the rising prices since the energy costs account for 55 per cent of the final cement value with 9 per cent spend on electricity and 9 per cent on fuels such as coal, oil, and LPG. The amount of 55 per cent is considerably higher than the industry average of 20-40 per cent. The objective is then to reduce the production costs without affecting the production yield, and without sacrificing the quality or environmental issues. The energy efficiency considerations in Nepal go back only to 2010 when the collaborative initiative between the Nepalese and German governments led to the establishment of the Nepal Energy Efficiency Program [12].

Fortunately, there are many opportunities to improve the situation in the Nepalese cement industry. In this paper, the researcher focuses on reducing energy consumption in order to develop the competitiveness of the Nepalese cement producers. A winning strategy can promote investments into technologies with better energy efficiency and adopting other measures that can reduce the overall energy consumption. In general, it is well known that there are additional benefits from improving energy efficiency, such as increasing productivity, which usually naturally follows [13]. These benefits are summarized in Figure 5.1. Figure 5.2 presents the energy consumption for each section in the cement industry. Cement mill consumes 38 per cent, Raw material grinding 24 per cent, Kiln 22 per cent, mines and crushing and Material Handling and packaging consumes 5 per cent each, and Raw mill homogenising has 6 per cent.

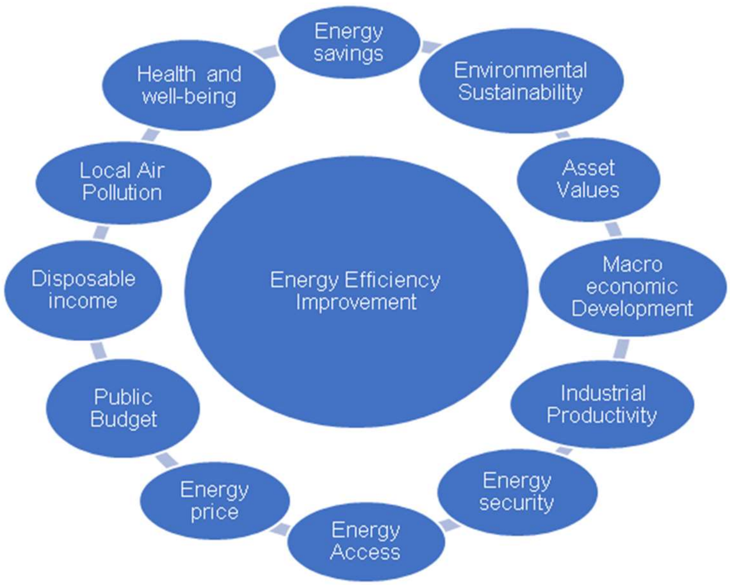

Figure 5.1 Benefits of improving energy efficiency [14]

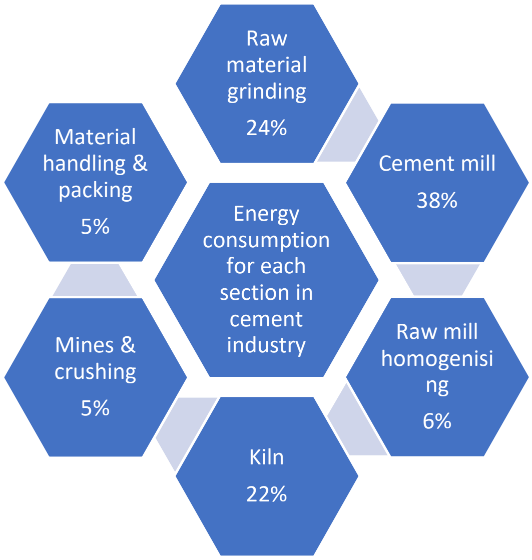

Figure 5.2 Energy consumption for each section in the manufacturing of cement [15]

Within the literature, the best practices for improving the thermal and energy efficiencies in the cement plants were reported in [16]. State of the art and future views at cement production are outlined in [17]. The investigations of energy efficiency issues in the cement industry in different countries can be found in the following papers: for Morocco in [18], for Ethiopia in [19], for China in [20], for Italy and

Germany representing two large EU economies in [21], for Germany also in [22], and for Turkey in [23]. The sustainability and general energy efficiency issues in the cement industry are studied in [24], [25], [26], and [21]. The strategies to address the rising production costs are discussed in [22]. Moreover, understanding the environmental performance of a cement plant is equally important as assessing the energy efficiency and sustainability of production. For instance, the environmental concerns of cement production in China are studied in [20] and [27]. The cement production processes in the Nepalese cement industry are evaluated in [28]. The energy usage in the UCIL plant was reported in [10]. However, so far, there appear to be no other articles on the adoption or implementation of the energy efficiency measures and the sustainable practices for cement plants in Nepal.

This study focuses on the specific case of the government-owned UCIL plant. Our main objective is to investigate the energy efficiency approaches to (1) reduce the production costs and improve the sustainability outlook of the UCIL plant by lowering its energy intake, (2) reduce the carbon emissions of the UCIL plant by utilising locally available raw materials and fuels, and (3) explore the use of alternative materials and ammunition in the cement production processes which could be used at UCIL. Our study relies on the data compiled from open literature, including official reports from various institutions and the government in Nepal. Additional data were obtained directly from the UCIL and HCIL plants during the site visits and interviews with the company officials.

The main cement production issues discussed in this paper can be summarized as follow. The sustainability of cement production in Nepal is threatened by the high production costs compared to the neighbouring countries. This is reflected in the price of the end-product. The sustainability of cement production is also affected by the chaotic implementation of the environmental policies and the need to physically deliver clinker, coal, limestone, clay, and other materials required for cement production by trucks over long distances on the roads which are not in good condition. These issues are further exacerbated by the insecurities in energy supply, the need for employing diesel generators, and vulnerabilities to recurring natural disasters. Also, the health and safety concerns in the cement industry have not been so far adequately addressed. UCIL is using more energy to produce per ton of cement in comparison with regional and international trends.

The rest of the chapters is followed, such as the methodology of the research is described in 5.2. Cement production processes at UCIL are outlined in Section 5.3. Assessment cement production at UCIL is carried out with a focus on improving the sustainable production and efficiency of utilizing the raw materials. Similarly, reducing greenhouse gases is described in section 5.4. Improving capacity utilizing is highlighted in section 5.5, which is followed by other barriers to sustainability in section 5.6. The discussion and recommendations on how to reduce energy consumption and lower the production costs are given in Section 5.7. The paper is concluded in Section 5.8.

5.2 Methodology

This study relies on the data compiled from open literature, including official reports from various institutions and the government of Nepal. Additional data were obtained directly from the UCIL during the site visit, talk program, and informal interviews (Focus group discussion) with the company officials.

For this case study, the researcher has undertaken site visits to UCL and has collected data and has interacted with the plant officials together with an informal interview.

The study enveloped statistics of cement industries of Nepal and compare the international trend in cement production. The data has been gathered through personal contact with the plant official. Government white papers, annual reports, an International organization like IEA, IRENA, Industrial reports, conferences, and journal articles have been gathered for related literature and required data for analysing the case study. After collecting the data, it has tabulated and compared with national and international standards. A set of focus group discussion questions has been presented in Appendix A.

5.3 Assessment of cement production at UCIL

The UCIL plant is a state-owned enterprise located at Jaljale, Udayapur, about 200 km south-east from Kathmandu. It was established in 1987 with the financial and technical support from the Japanese government. The designed production capacity of the plant is 800 MT of clinker or 277.2 MT of cement per day, which makes it the most significant and most crucial cement plant in Nepal. At the consumption rate of 330,000 MT of limestone a year, the plant has the limestone reserves for another 150 years. More importantly, the UCIL factory has never been able to reach its full production capacity of 800 MT of clinker per day. The current output is 600–700 MT of clinker per day, although it was a considerable improvement to 35-45per cent of capacity utilization only a decade ago. The average capacity utilisation between 1992 to 2015 was 36 per cent [10], [29]. The Udayapur cement is sold under the trade name "Gaida Chhap Cement." It is regarded as the best quality cement in Nepal and is known for its quality and strength. However, UCIL cement is expensive because of the high production costs. Specifically, the cost of a 50kg bag of cement from UCIL is nearly double the price compared to imported cement from India and China, as seen in Figure 5.3. Consequently, the large number of builders in Nepal prefer the cheaper but lower quality cement imported from the neighbouring countries.

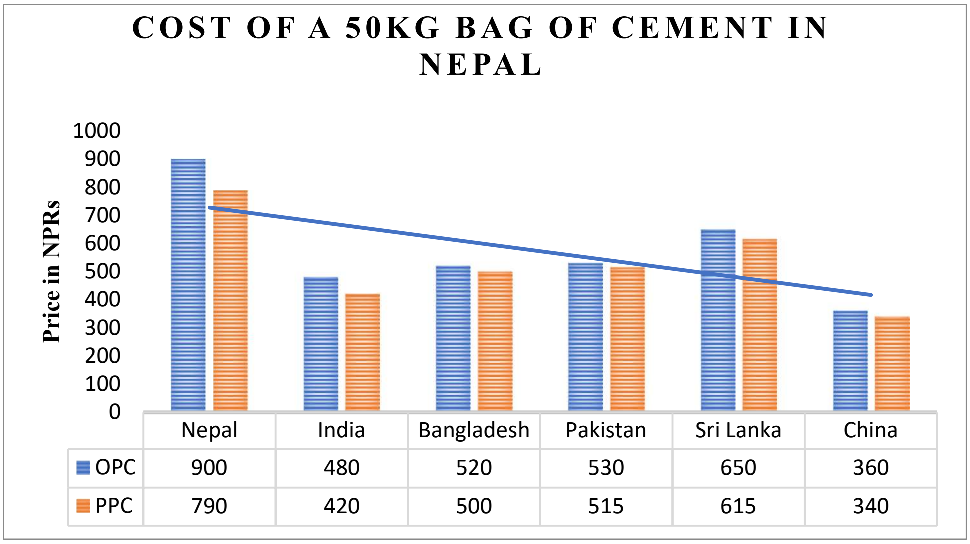

Figure 5.3 The prices of a 50kg cement bag in several South-Asian countries

The limestone mines are located 27km from the Jaljale site. Limestone is extracted by open-cast mining with drilling and blasting before it is loaded onto a dump truck and moved over to a nearby primary crusher. The crusher reduces the limestone particles to less than 100mm in diameter before they are transported to the UCIL site at Jaljale via a 13.8km long bi-cable ropeway. There, the limestone particles are further reduced to 25mm in size in the secondary crusher, after which they are conveyed to a pre-blending unit for the homogenisation and storage. The homogenised limestone is sent onto a limestone feed hopper together with other feed hoppers containing clay, iron ore, and silica sand. The overall annual requirements for the raw materials and energy at the UCIL plant are given in Table 5.1.

Electricity and coal are the primary sources of energy at UCIL. Coal is mainly used as the source of thermal energy, whereas electricity is used for raw material extraction and preparation, clinker production and grinding, cement grinding, and cement packing and loading. The UCIL is supplied with electricity from the NEA distribution network through the 11kV overhead feeders. At the plant, the 11kV power is stepped down to 6.6kV, employing an 8MVA transformer. Even though these are dedicated feeders for supplying electricity to the plant, the electricity production deficiency of NEA, which cannot satisfy even the country's daily demands, causes frequent power outages. This is one of the most pressing issues for the UCIL to resolve. Now, a stand-by, manually operated diesel generator is used. The electricity interruption creates severe problems for kiln, and cement and raw mills. The power cut can result in a severe distortion of the kiln shell if the power is not restored within 15-30 minutes. The immediate solution could be to automatically start the diesel generator as soon as the primary power supply failure is detected to provide at least 1 MW of electrical power to the bus feeder connecting the critical equipment which needs to run continuously. The breakdown of electricity requirements at different stations at UCIL is listed in Table 5.2. Although some sites have much smaller electricity needs, all sites must be connected to the internal electricity grid. The energy consumption at UCIL is driven up by significant losses, which are enumerated in Figure 5.4 as the total electricity and thermal losses per bag of cement in the years 2015 and 2016, respectively.

Table 5.1 The annual material and energy requirements at UCIL plant

Material	Volume and pricing	Source
Limestone	330,000 MT	Own source
Iron ore	4,000 MT @ NPR 15,000/MT	Import
Clay	57,000 – 82,000 MT	Own source
Gypsum	10,500MT@ NPR 8,000/MT	Import
Silica sand	Up to 21,000 MT	Own source
Coal	50,000MT	Import
Furnace oil/diesel	12,000 KL@ NPR 1,00,000/KL	Import
Water	1500m3/day	Local supply
Electricity	8,000 KW	NEA supply
Cement bag/sag	@ NPR 20 per bag	

Table 5.2 The average power consumption of each station at UCIL in 2017

Station	Feeder / Station	Per centage
1	Quarry - Limestone crushing & ropeway system	2. 50%
2	LSS-1 - Limestone receiving, crushing& stacking	1.75%
3	LSS-2 - Raw grinding mill	20.50%
4	LSS-3 - SP and kiln + LSS-4 – APC and coal mill	30.50%
5	LSS-5 - Cement mill and packing	0.75%
6	LSS-6 – General use and colony	7.00%
	Total	100.00%

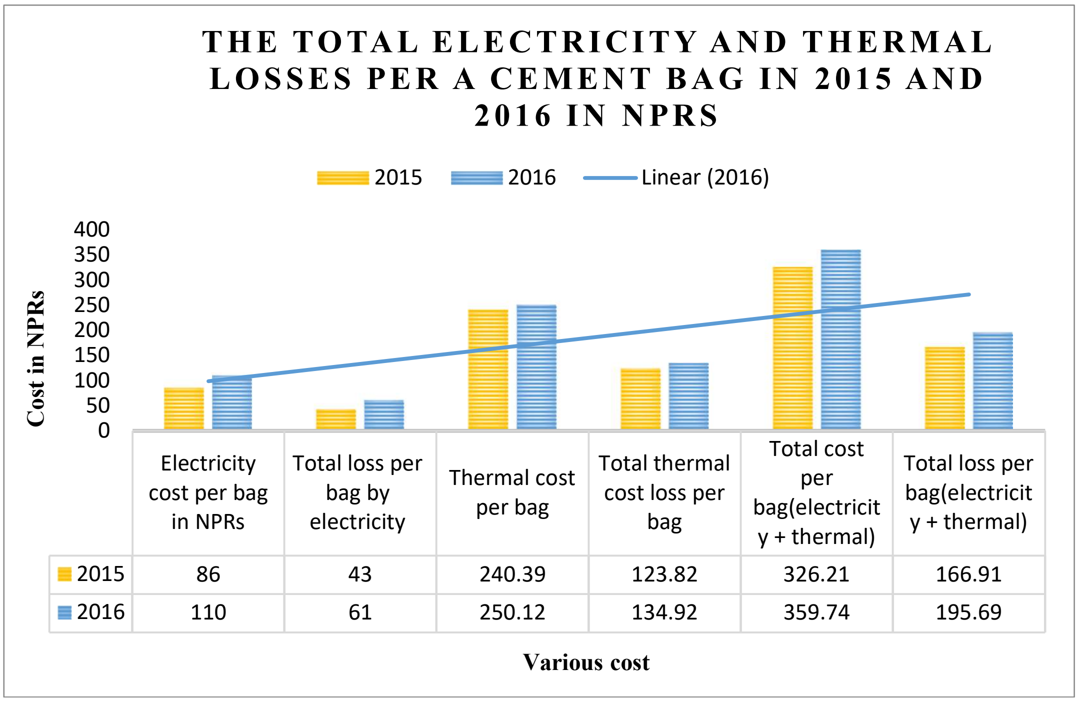

Figure 5.4 The total electricity and thermal losses per a cement bag in 2015 and 2016

Total electricity consumption at UCIL varies over the year, and there are large, unpredictable variations in different years. In 2016/17, the consumption increases from 140-220 kWh per ton of cement in December to May, while it tends to exceed 420 kWh/ton of cement in September and October. A year earlier, in 2015/16, the consumption was between 150 and 280 kWh throughout the whole year. However, these figures are substantially higher than the international average of about 100 kWh/ton of cement, so there is plenty of room for optimizing the electricity usage in the plant.

The most power is used in the milling process (1777 kW in cement mill, and 1434 kW in the raw mill). The pyro processing (B/Silo, pre-heater, kiln, and cooler) requires

1145 kW. Raw material handling, coal mill, water utilization, packing, and coal handling consumes 464, 237, 144, 137, and 41 kW, respectively. This gives the total energy consumption of 5379 kW at UCIL. In terms of thermal energy use, heat consumption fluctuates over the year between 1500 and 2000 kCal/kg of clinker. However, this is much larger than a typical value of about 100 kCal/kg of clinker in the developed countries.

The thermal load in the kiln at UCIL varies between 23 and 32 GJ/hour per $m^{2,}$ whereas the standard value is nearly half of it, i.e., about 13 GJ/hour per m^2. This load can be reduced by adopting energy efficiency measures. Overall, energy use in the Nepalese cement industry is 9 per cent for electricity and 91 per cent thermal (coal). Thermal energy is imported from India, as Nepal is dependent on imported petroleum products.

Unfortunately, Nepal has no coal mines and must import all coal from India. In 2016, Nepal imported USD $46,394 of coal per month from India. The costs related to the transport of coal and raw materials must also be considered. On several occasions, UCIL was forced to shut down the operations due to the lack of raw materials or coal, and due to a trade embargo or prolonged strikes.

The whole process of cement production adopted in UCIL is depicted as an annotated flowchart in Figures 5.5 and 5.6. The energy efficiency measures, and carbon reduction measures are also displayed. The production of Portland cement starts with quarrying and mining of raw materials. The raw mix variations are reduced by crushing the larger sized particles. The mix is then homogenised and grounded to secure a uniform bled and achieve a proper reaction. A mixture of clay and limestone or other suitable material is sintered in the kiln at temperatures of 1450–1500^{o}C for a certain amount of time. The pulverised coal, fuel oil, or natural gas (LPG), and sometimes their combination with waste-derived fuels are introduced at the front for combustion. After cooling ground with 4-6 per cent of gypsum or another form of calcium sulphate, the resulting product is known as clinker. During grinding of clinker, some materials may be added depending on the cement specification. Cement as the final product is stored in silos, where it is awaiting its shipment in 50 kg bags[29].

Some of the heat released during the fuel burning is used to evaporate the moisture from the fuel and to superheat the vapours to the gas fuel temperatures. Removing the humidity is essential, since the moisture in coal reduces the flame temperature, slows down the rate of combustion, and increases the burnout time while creating the flame instability. Every single per cent of moisture requires additional 7.22 kcal/kg of energy from burning the coal, or equivalently; it represents 0.1per cent heat loss. However, a certain amount of moisture is essential to avoid the risk of explosion. At UCIL, the sidewalls of the coal yard are open, so the rainwater can easily splash onto the coal in the yard, which dramatically increases its moisture content. Moreover, the presence of ash in the coal increases its weight, which adds to the handling costs. The high ash content in coal delays and prevents complete combustion of the coal particles and lowers the flame temperature and flame intensity. The presence of ash also gives rise to the ring and ball formations in the kiln, which may damage the kiln lining by chemically reacting with it.

The endothermic reactions of processing raw materials during the clinker production require temperatures up to 1,450^{o}C for the formation of stable clinker phases. This translates to theoretical energy demands of 1,650-1,800 MJ/ton of clinker. The humidity content of 3-15per cent in raw materials, however, increases this theoretical value by an additional 200-1000 MJ/ton of clinker, which is used to dry off the raw material by removing the moisture [17].

5.3.1 Improving sustainable production

According to the report [17] and our own findings during the site visit to UCIL in summer 2018, the lack of proper maintenance of the plant machinery and equipment is one of the key contributors to increased production costs. The regular maintenance is neglected and not timely, so the production capacity often drops below 30per cent. The machinery and equipment have not been upgraded for years, so they became outdated. The vital spare parts are not available for immediate replacement when needed, some subsystems in the plant are left in a bypass operational mode for already several years, and most systems require partially or fully manual operation. In addition, there is no provisioning of data-driven preventative and predictive maintenance, and the widely prevailing corrective support is a great contributor to frequent machinery and equipment breakdowns.

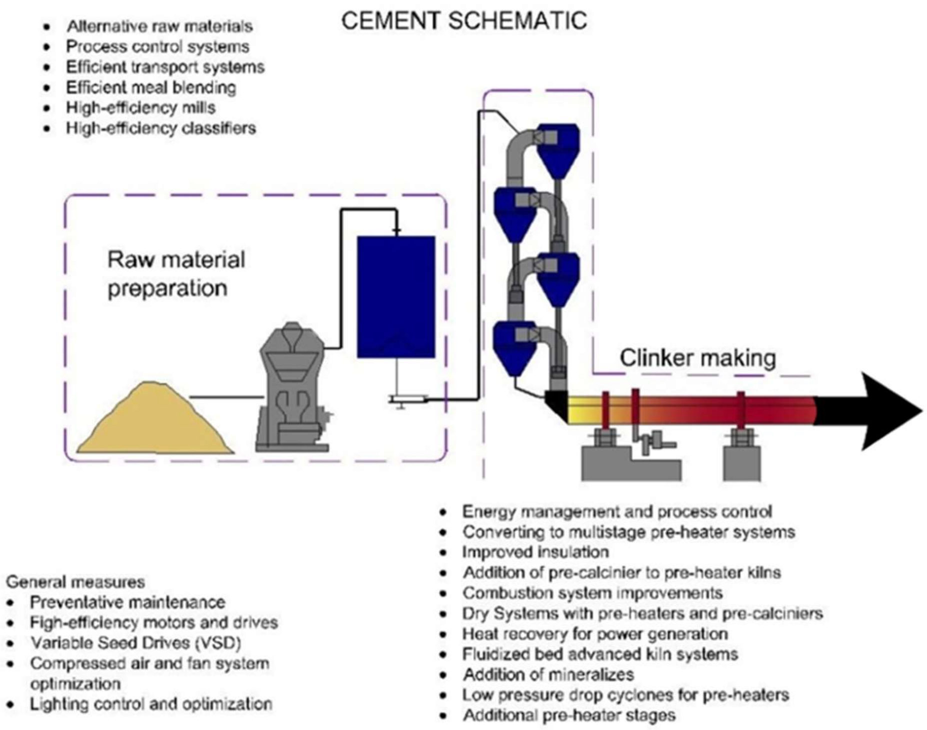

Figure 5.5 The processes of cement production and energy efficiency measures cont.

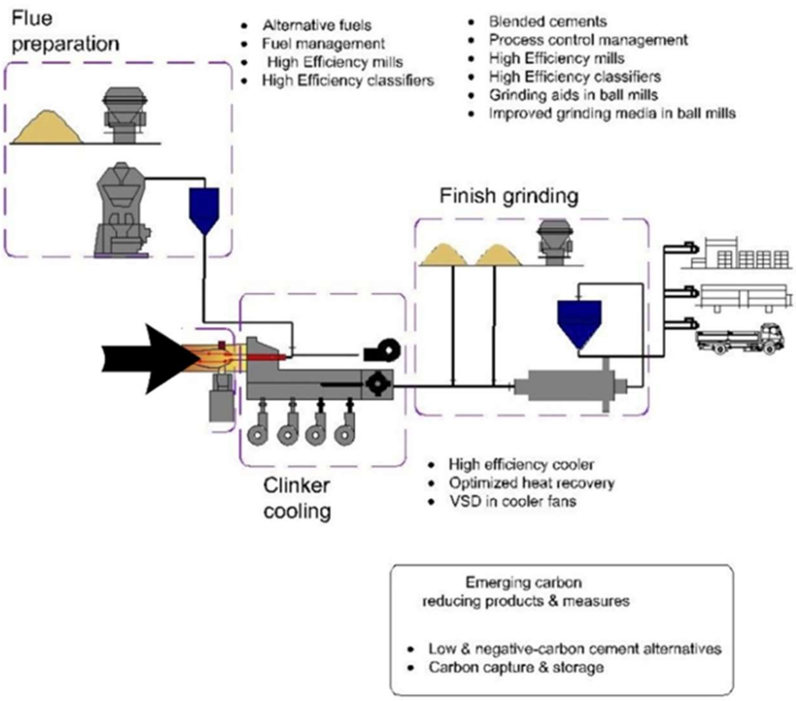

Figure 5.6 The processes of cement production and energy efficiency measures

UCIL can be assumed as a primary example for investigating the effects of equipment failures on environmental pollution. In particular, the failure of 2 out of 3 electrostatic precipitators at UCIL resulted in substantial emissions of particles creating huge losses both in materials and energy. The remaining electrostatic precipitator was switched from automatic to a manual operation. At the same time, the coal mill energisation system was not working correctly, so large amounts of rejected material were observed. The resulting smoke spread all over the Jaljale area creating the health hazards to inhabitants. Following this incident, the UCIL management immediately adopted many health and safety measures to minimize the impact of plant operation on the local environment. The longer-term plans are concerned with reducing CO_2 emissions and other airborne pollutants and improving the effective and efficient use of fuels and raw materials.

5.3.2 Improving energy efficiency

"Energy efficiency is not just low-hanging fruit; it is the fruit that is lying on the ground." - Steven Chu, Former US Secretary of Energy.

The IEA projections until 2035 show that as much as two-thirds of the energy efficiency potential would remain untapped unless the relevant policies are going to be changed [30]. The energy efficiency technologies and conservation practices not only help in reducing the production costs but at the same time, they enable decreases in CO_2 emissions and create more profit for the business [23]. According to the Energy Efficiency study [12], the cement industry in Nepal has the enormous potential for savings of 15 per cent in electricity and 30per cent in thermal energy. Provided that the proper energy efficiency measures are adopted at all Nepalese cement plants, at least 30-50 MW of electricity can be saved within 6 months. However, the theoretical energy consumption of the kilns already corresponds to their 63per cent efficiency [31]. Thus, modern kilns are probably today's most efficient thermal machines in industrial use.

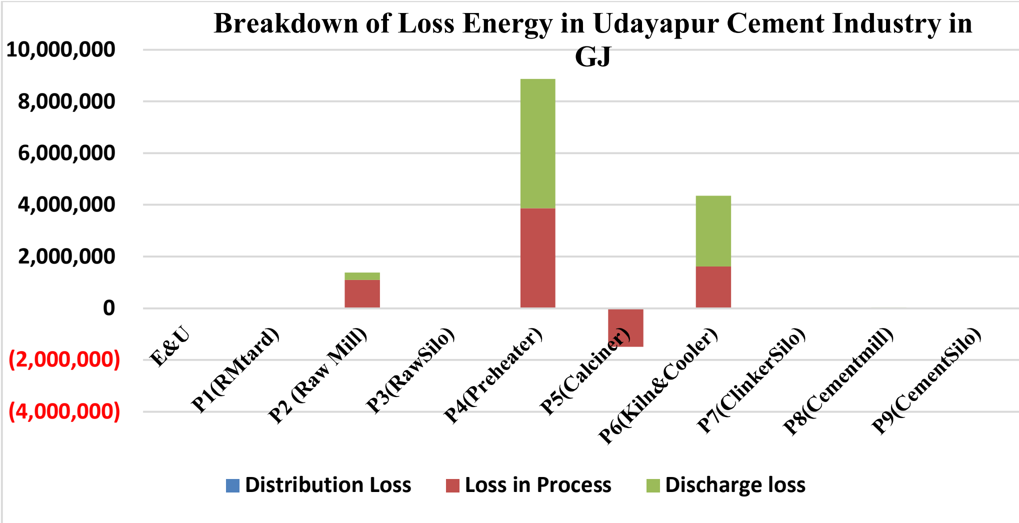

Figure 5.7 Breakdown of loss energy in UCIL

The International Energy Agency (IEA) defined the following 4 strategies for energy and emission reduction measures in the cement industry. In particular, 10 per cent savings can be achieved by exploiting long-term energy and raw materials usage forecasts, 24 per cent savings may come from introducing alternative fuels, 10 per cent savings can be obtained by assuming clinker substitutions, and the most significant 56per cent savings can be attained by the carbon capture and storage technologies. The report "Eco-Efficient Cement" by the UN Environmental Committee explains the central role in our modern societies of the raw materials which enter the cement production [32]. These materials represent more than half of all the materials manufactured in the world. It is essential to understand that most demand growth is happening in emerging economies. For instance, it is expected that the demand for cement will increase 2-3-fold in India in the next few decades.

The current average thermal energy consumption in the cement industry is about 760 kcal/kg of clinker. However, at UCIL, the thermal energy consumption reaches 1729 kcal/kg of clinker, i.e., it is 2-3 times higher than the industry average. The electricity consumption at UCIL is 243 kWh/ton of cement, whereas the modern cement production plants can achieve 715 kcal/kg of clinker and 75 kcal/ton for OPC-43 grade cement. Much larger energy consumption per unit of cement (e.g., 50 kg bag) at UCIL is the critical reason for its excessive production costs. However, it is unlikely that significant energy efficiency gains can be achieved by upgrading to the best available technology. The following upgrade of old technology where it is economically feasible can provide only about a 10% reduction in the targeted 18% CO_2 reductions [33]. Moreover, the technology upgrade usually requires substantial financial investment, and one needs to estimate the necessary time to pay it off carefully. Other measures for reducing electricity and thermal energy consumption involve periodically scheduled maintenance works, replacing equipment with high energy consumption, and installing energy recovery systems.

Apart from fossil fuels, the use of alternative fuels in the clinker burning process is gaining attention. Besides the economic advantages, alternative fuels are better suited for the environment protection. Most alternative fuels are nowadays derived from industrial and municipal wastes and biomass [34]**.** The energy efficiency of cement production should not be affected by these fuel substitutes [35].

5.3.3 Processing raw materials

The quality of raw materials and their usage in the UCIL production processes are not evaluated constantly. For instance, the moisture and ash contents in coal are not adequately monitored, which increases the energy consumed during the cement production, and thus, also the production costs. There is a need to implement adequate quality control systems and procedures for continuously checking the raw materials and fuels. This would ensure that the raw material processing is done in an environmentally friendly and safe manner, reducing the health and safety concerns for plant employees as well as citizens living nearby. Closer monitoring of raw materials and processes at UCIL can also be used to evaluate the environmental impacts of cement production, to ensure the quality of the final product, and most likely to identify further improvements in the production processes [36].

The availability of natural resources constrains the long-term sustainability of cement production. The raw materials for cement production are becoming increasingly scarce. There is enough evidence in research literature clearly showing the advantages of utilising alternative fuels such as the waste generated at different steps during clinker and cement production [37]. The kilns are particularly suitable for utilizing the clinker waste due to their high incineration temperature, large area and length of the furnace, and the alkaline environment inside**.** Other characteristics of rotary kilns, such as the speed of the gas stream, internal temperature, and duration of material storage guarantee that the use of alternative fuels is ecological and safe [37].

Alternative fuels were used to satisfy 65per cent of the total fuel demands in the German cement industry in 2017 [35]. In Mexico City, 800 tons of municipal waste a day is burned in the local cement plant. Such kind of alternative fuel may be very suitable for the UCIL plant to reduce its reliance on coal and petro-fuels. Another promising possibility is to utilize supplementary cementitious materials. In particular, the substitution of clinker with alternative materials containing mineral components such as gypsum, pozzolana, limestone, fly ash, and slag contributes to the reduction of CO_2 emissions while also altering the essential properties of the blended cement. This trend is evident in lowering the clinker to cement ratio, which fell from 82.9per cent to 75.3per cent [36].

5.3.4 Waste heat recovery and utilising by-products

The UCIL plant is, unfortunately, utilizing the electrical and thermal energy very inefficiently, so a proportion of heat is being lost in the form of waste heat. In the dry process cement plants, nearly 30-40% of the total heat input is rejected as the waste heat of exit gases of the preheater and coolers. In UCIL, on average, 55% of the input heat is lost as the waste heat. In these types of cement plants as in UCIL, the preheater exits gas temperatures of 350-400^{o}C, and the cooler vent air temperatures of 250-275^{o}C are estimated to represent a potential electricity generation of 4-5 MW a day from the waste heat alone. This needs to be compared with the overall electricity consumption at UCIL, which is presently about 6.6 MW per day. It is realistic to assume that at least 50% of the electricity demands could be supplied from the waste heat recovery process [29].

The thermal energy from the kiln bypass can be utilized by operating a waste heat boiler. Alternatively, if the extracted gases are cooled with the air and water and then de-dusted, the cooling of gas with air and water is not required. The dust collecting equipment usually has lower capacity requirements. The bypass gases and dust have the temperatures of about 700-800^{o}C, and they are cooled down to 350^{o}C. A rotatory kiln producing about 2,000 TPD of clinker has a bypass of 18% and the exit gas rate of 10,000 Nm^3/hour. It yields the heat output of 3,600 kW and 488 kg of steam per hour. The following sources can be considered as the waste heat: the preheater exit gas, the exhaust air from the clinker cooler, and thermal radiation of the kiln shell. The boilers attached or integrated to the kiln for electricity generation are widely used in China and Japan, and it is desirable to consider their installation also at the UCIL premises.

There are other by-products in the cement production process that can be exploited to improve its efficiency. For instance, a press swing absorption technology was recently developed at the Hyundai Heavy Industry Company in South Korea to recover high purity CO_2 from the cement kiln emissions. It is then used as the raw material for producing fertilizers, dry ice, carbonates, and caprolactam after additional purification and concentration processes. The M/S Imperial Chemical Industries in the UK devised a process for producing 0.75 tons of sulphuric acid simultaneously with every 1 ton of clinker for the Portland cement. Asland Portland Cement company in Spain uses a process in which raw materials, including limestone, coke, and iron ore, are burned in a rotary kiln while the molten iron is collected in a pool following the burning zone.

5.4 Reducing greenhouse gases

Cement production contributes 8 per cent of the total world CO_2 emissions. The clinker burning process emits a considerable amount of greenhouse gases being almost entirely CO_2. Other greenhouse gases, such as the di-nitrogen monoxide (N_2O) and methane (CH_4) are only generated in minimal quantities. On average, 1 kg of CO_2 is emitted per 1 kg of ordinary Portland cement produced. However, exact amounts vary significantly depending on the materials used. For instance, only 0.3 kg of CO_2 is created for CEM III B 32.5 N cement with a 70 per cent slag [39]. Moreover, the CO_2 emissions are dependent on the raw materials and fuels used. The former is related to the limestone decarbonisation ($CaCO_3$) and accounts for about 60 per cent of the total CO_2 emissions. The associated energy emissions are generated during fuel combustion, and also indirectly by utilizing electrical power [35].

All emissions must be controlled and mitigated with regular measurements of the key pollutants. If the plant emission level is below 25 $\mu g/Nm^3$, the analyses can be conducted once every two years - the continuous measurements are required for dust,

NO_x, SO_2, Hg, and NH_3, and all organic carbon compounds. The ambient pollution by other particles is usually determined discontinuously by individual measurements [35].

Most CO_2 emissions in cement production come from the fuel combustion inside the rotary kiln process, the calcination process of limestone, and the required power generation. Therefore, any material that can replace clinker in cement formation would contribute significantly to mitigating these emissions. The most promising are the supplementary cementitious materials. These materials can be a by-product of different industrial processes, or they can be naturally occurring. The by-product examples are so-called flashes from the coal-fired furnaces at power generation facilities, the ground granulated blast furnace slag from steel manufacturing, and silica fume from silicon production. Examples of common natural supplementary cementitious materials are metakaolin and clay [39]. Table 5.3 summaries the technologies which are aimed at reducing the CO_2 rate and optimise the efficiency of cement production processes. These international trends have not been followed nor considered at UCIL so far.

The cement production-related activities have substantial impacts on the natural environment and the local communities in proximity. The limestone quarries are long-lived assets with operations extending over 50 years. Their impact on the environment through dust, noise, and other factors must be adequately managed. For instance, the removal of soil affects local ecosystems and water levels. However, the water footprint of the cement industry is relatively small compared to other industrial sectors. The cement production requires water for cooling the heavy equipment and cooling exhaust gases. Water is necessary for the emission control systems, including wet scrubbers, and to prepare slurry in the wet process kilns, although the wet kilns are progressively being phased out and replaced by more modern and efficient dry processes with significantly reduced water usage. In addition, water evaporates in all processing stages. The discharged water can be affected by high temperature, altered acidity, and the presence of solids. Quarry de-watering can have an impact on the river basin, depending on the point of discharge. The aggregates businesses and, to a lesser extent, ready-mix businesses require significant quantities of water. There are other opportunities to further offset the water footprint of the cement industry, mostly at the local level, where the individual facilities and activities have a direct impact. The risk-based approach is required to manage the quantities of water withdrawn by the cement plant, and the quality and amount of water released with particular attention if the plant is located in a water-stressed area.

Table 5.3 The energy efficiency and CO_2 emission reduction technologies in cement industries [40]

Category / Technology	Development Stage
High activation grinding	Semi-commercial
Fluidized bed kiln	Demonstration
Steel slag as kiln raw material,CemStart technology	Semi-commercial
Non-carbonated raw material with carbide slag	Semi-commercial
Cement with low lime saturation factor	Semi-commercial
Calcareous oil shale as an alternative raw material	Pilot
Cement primarily of fly ash and recycled materials	Semi-commercial
Cement and construction materials with magnesium oxide	Pilot
Geopolymer cement	Demonstration
Celitement: hydraulic binder based on calcium hydro silicates	Development
Oxygen enrichment technology	Commercial
Oxy-fuel technology	Pilot
Post-combustion carbon capture with absorption	Pilot stage
Calera process	Pilot stage
CO_2 sequestration in concrete curing technology	Development
Carbonate looping technology	Development
Industrial recycling of CO_2 from cement process into high energy algal biomass	Demonstration
Biotechnology carbon capture	Development
Capturing the CO_2 resulting from limestone calcinations	Research
Use of nanotechnology in cement and concrete production	Research

Furthermore, the Efficient World Strategy by the IEA identifies opportunities and government policy actions in different economic sectors [33]. For instance, the energy consumption in the transport sector could remain flat despite doubling its activity with passenger cars and cargo trucks offering two-thirds of the prospective energy savings. The government can increase coverage and strengthen transport policies and incentivise the uptake of energy-efficient vehicles. In the construction sector, the building space can be increased by 60% without additional energy usage. The room heating, cooling, and water heating offer 60% of potential energy savings. The government can put in place comprehensive policies for energy efficiency for existing (e.g., by energy retrofitting) and new buildings as well as home and industrial appliances. Across all industrial sectors, the value-added production per unit of energy is likely to double. The move towards less energy-intensive processes can offer as much as 70% potential energy savings. Moreover, the government can focus on standards for energy efficiency, and encourage the adoption of energy management systems and stimulate business model innovations.

5.5 Improving capacity utilisation

According to the capacity, the utilisation of Nepalese industries average is only 57.8 per cent as illustrated in detail in Figure 5.8, which is extremely poor in comparison with the regional and international trend of capacity utilisation. There is much room to improve their capacity utilisation by applying the measures of an international tendency. This is the focus of this chapter.

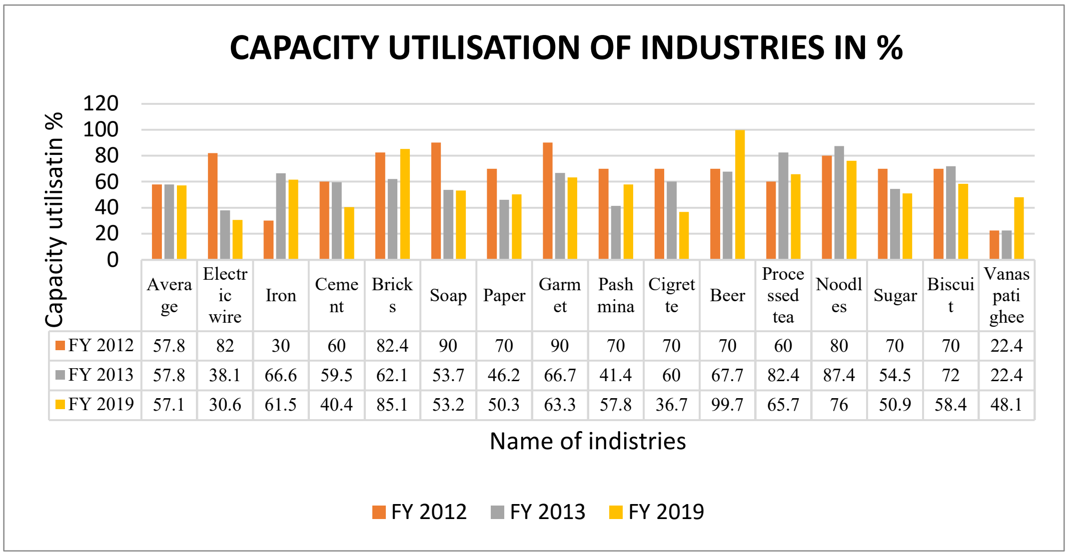

Figure 5.8 Capacity utilisation of Nepalese industries [41]

Capacity Utilisation Factor is 42 per cent in 2007 from around 35per cent in the previous four years, according to the General Manager of UCIL. This is below the national average of 60 per cent as seen in the Asian Development Bank’s Study 2014 and Economic Study Report published by the Central Bank of Nepal. The average industrial capacity utilisation in the fiscal year 2019 stood at 57.1 per cent, lower than average CU in the two preceding years [42]. According to Figure 5.8, the average capacity utilisation percentage of cement industries is just 40 per cent in FY 2019. Industrial capacity utilisation is the actual production capability utilised for the total potential output of the industry. Capacity utilisation of over 85 per cent is optimal for industries in terms of cost of production and profitability. However, the UCIL the factory has not been able to utilise its full production capacity. The utilisation factor is only around 36.3per cent of the installed capacity. This inability arises from the unavailability of electricity, and the power cut is the major problem. Having said that, the electricity problem has been recovering, and factories are trying to optimise their production, but this is occurring slowly. The estimated total production capacity of the factory is 277,200 metric tons of cement per year. This capacity was only met in the FY 2001/2002. The production was 45per cent of the total capacity in 2006/07. Records of the previous three years show that the capacity utilisation then was only around 35per cent.

UCIL produced nearly 1.5 million sacks of cement in the first 10 months of 2016/17, up from 1.3 million sacks in the same period a year earlier. This translates to a predicted net profit of NPR 250 million for this fiscal year.

The capacity utilization of the annual clinker production has dropped down below 30% for the past few years. Similarly, the plant is running in the loss; current assets are below the margin, and existing debt has crossed the margin. These might be the absolute indicators of the plant shut down phase. Few vital things are still making the plant run and sustainable in front of those significant losses and damages. The key sustainability factors are the high efficiency of utilizing natural resources and producing good quality cement to generate market demand. In addition, UCIL contributes to the local economy by employing over 500 people, and its profits are taxed. It also supports the development of local infrastructure, including roads and utility networks.

Energy consumed when producing cement accounts is much higher than the amount of the total production costs. Energy-efficient technology often provides additional benefits, such as increasing the productivity of the company. The cost of energy as part of the entire production costs in the cement industry is high. In Nepal, approximately 40-50% of cement manufacturing costs are energy-related. The price of 50Kg of cement in selected countries is illustrated in Figure 5.3. Such high costs are characteristics of developing countries, which generally experience higher energy costs in comparison with developed countries.

In consequence, the final price of a 50 kg cement bag is 900 NPR for OPC (Ordinary Portland Cement), and 790 NPR for PPC (Portland Pozzolana Cement) whereas the price is about 30 per cent cheaper in Sri Lanka, 40per cent cheaper in Bangladesh and Pakistan, 50per cent less high in India, and 60per cent less expensive in China Figure 5.3. The financial loss per bag of cement in 2015 was 52per cent and reduced to 48 per cent in 2016.

The installed capacity of cement plants in Nepal has increased drastically; capacity utilisation has no kept pace. For instance, the capacity utilisation of the cement sector has dropped dramatically to 40 per cent from about three-quarters just two years ago. In fact, it is now at its lowest comparable data started to become available [42]. Furthermore, small CU results in low profitability because industries cannot lower per-unit costs or attain economies of scale. It also reduces the employment prospect. There is also a need to boost the cost and quality competitiveness of cement to substitute imports. A higher rate of industrial CU, together with a stable and competitive supply of inputs such as electricity and enabling infrastructure, will be helpful [42].

5.6 The causes of kiln stoppages in UCIL

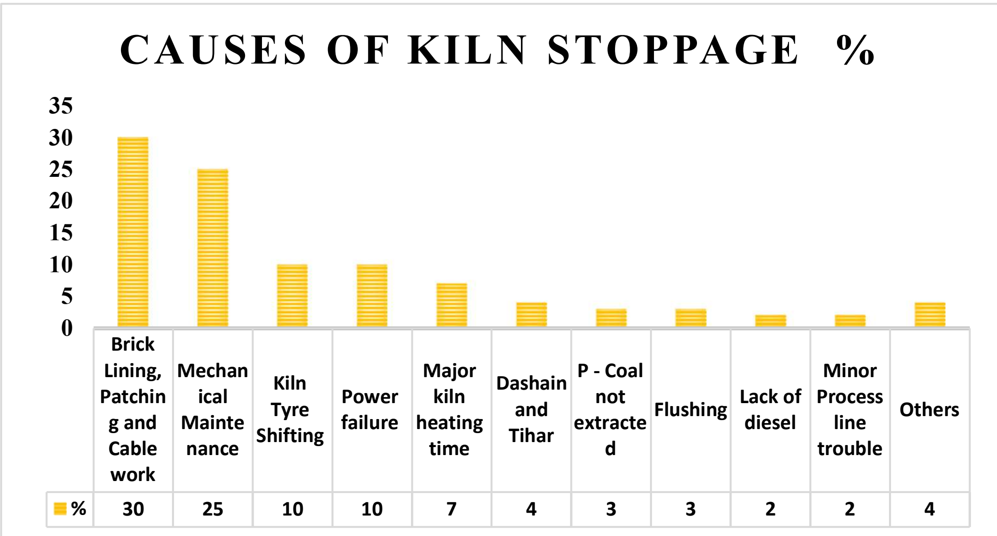

Figure 5.9 The causes of kiln stoppage in UCIL

As presented in Figure 5.9, the detail discussions of the causes of Kiln stoppage in UCIL were as follows:

- In UCIL brick lining, patching and cable work is the lengthy process. It needs special kind of bricks and accessories which are not available in Nepal. The brick is a very exceptional heat resistive kind, so it has to be imported from Germany. UCIL is the state-owned factory; therefore, the procurement system is a very long process. The plant should be closed during brick lining. It is one of the highest per cent and the main reason for kiln stoppage with 30per cent in UCIL. It could be suggested that to reduce this downtime; the UCIL has to buy bricks and cables in advance and keep them stocked in order to minimise the lengthy procurements process.

- Another high percentage of kiln stoppage is mechanical maintenance, with 25per cent in UCIL. UCIL give less focus on preventive maintenance practices, so it causes more mechanical faults around plants. As the UCIL is a Japanese government-funded project, spare parts have to be imported from Japan, which takes time. There is no proper energy management system to conduct preventive maintenance and to find the fault for emergency stoppages.
- Kiln tyre shifting is another crucial cause of the kiln stoppage with 10per cent in UCIL, as the kiln is the heart of the cement plant. UCIL needs to minimise this downtime by following international trends as adopted by the cement plant of India and China.
- Power failure is also the primary problem, with 10per cent in UCIL. There is still some voltage fluctuation problem in the plant according to the factory source.
- Major kiln heating time is another cause of the kiln stoppage with 7per cent in UCIL, as kiln has to be heated to 1400 ^{0}c high temperature to cook its clinker.
- To celebrate Dashain and Tihar festivals, employees are given long vacations, which then result in 4per cent of Plant stoppages in UCIL.
- The quality of coal is another cause of kiln stoppage, which is 3 per cent in UCIL. The use of wet coal and the inferior quality of coal is the leading cause of the problem.
- Flushing and lack of diesel cause kiln stoppage by 3 per cent and 2per cent respectively.
- The minor process such as line trouble causes 2 per cent whereas earthquake disturbances, electrical trouble, heavy rain, and cyclone jam cause 1per cent each (Total 4 per cent) of kiln stoppage in UCIL.

The utilization factor of UCIL is only 36 per cent on average. Similarly, energy efficiency was found to be 63 per cent on average. The electricity consumption per ton of cement was 243.04 kWh on average, and thermal energy per kg clinker was 1728.91Kcal. This result is deficient in comparison to the other countries' cement plant.

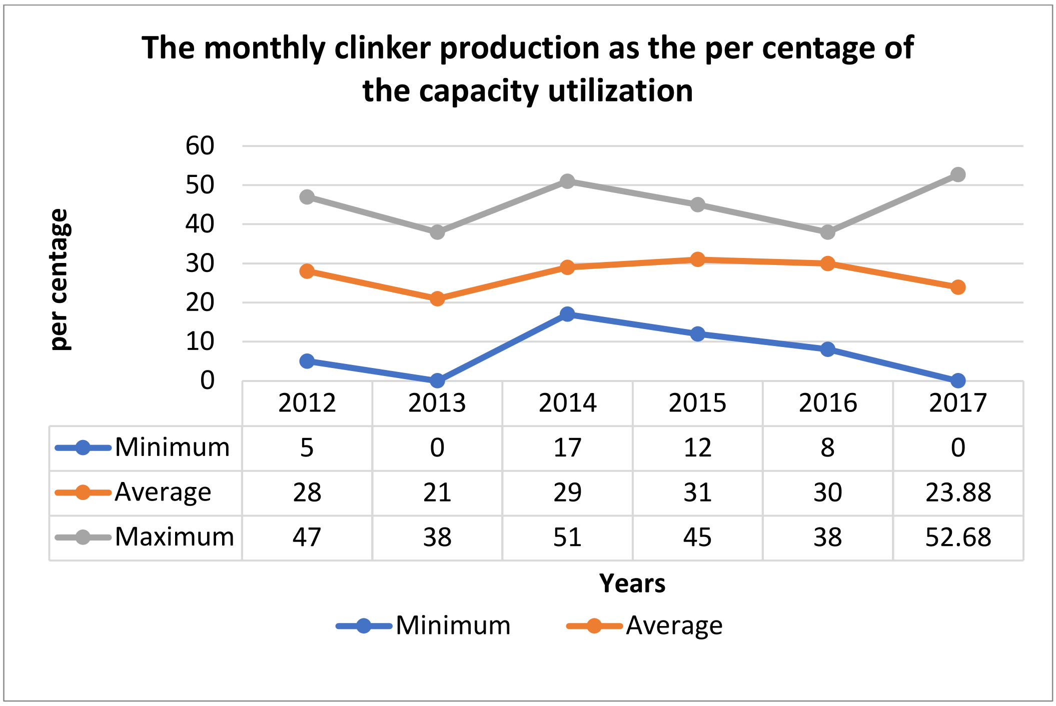

Figure 5.10 The monthly clinker production as the percentage of the capacity utilisation

According to the US Department of Energy, 37 per cent of CO_2 emissions are generated in kiln heating, 46 per cent due to chemical reactions, 9.5 per cent mechanical processing, and only 5.4 per cent transportation of raw materials and cement, respectively.

The most substantial energy losses are occurring in the pre-heater, followed by the kiln with cooler, calciner, and raw mill processing. A remarkable amount of the heat wastes in the cooler and or released to the air from the stacks. Recovering this wasted heat to reuse or to produce electricity may ensure considerable potential energy savings. Globally, Coal is the primary fuel burned in cement kilns, but petroleum coke, natural gas, and oil can also be combusted in the kiln. Wastes fuels, such as hazardous wastes from painting operations, metal cleaning fluids, electronic industry solvents, as well as tires, are often used as fuels in cement kilns as a replacement for more traditional fossil fuels [43].

The capacity utilization of the global cement industries to this date is around 70 per cent, and they are upgrading their technology to reach capacity utilization of 85 per cent shortly. In light of these findings, Nepalese cement industries should follow the valuable steps to increase their capacity utilization at an international level.

It is estimated that the global cement production has increased more than 4-fold in the past 40 years. China leads to waste heat recovery technology. It is capable of producing 36 kWh of electricity per ton of clinker, which represents 25 to 30 per cent of the total requirement. This is enough to operate the kiln section on a sustained basis. However, in Nepal, this is a very new concept.

5.7 Other barriers to sustainability

It is generally expected that businesses can manage not only their sustainability issues but also other broader societal issues. This has been outlined in the Cement Sustainable Initiative (CSI), where the ambition is to develop better management practices of biodiversity and water and control impacts in the upstream quarrying activities while encouraging the sustainable construction practices involving cement products in the downstream [36]. The main issues in the general sustainability of the cement industry are summarized in Figure 5.11, and conditions, barriers, and constraints of UCIL are presented in Figure 5.12.

Figure 5.11 The major issues in the sustainability of the cement industries [36]

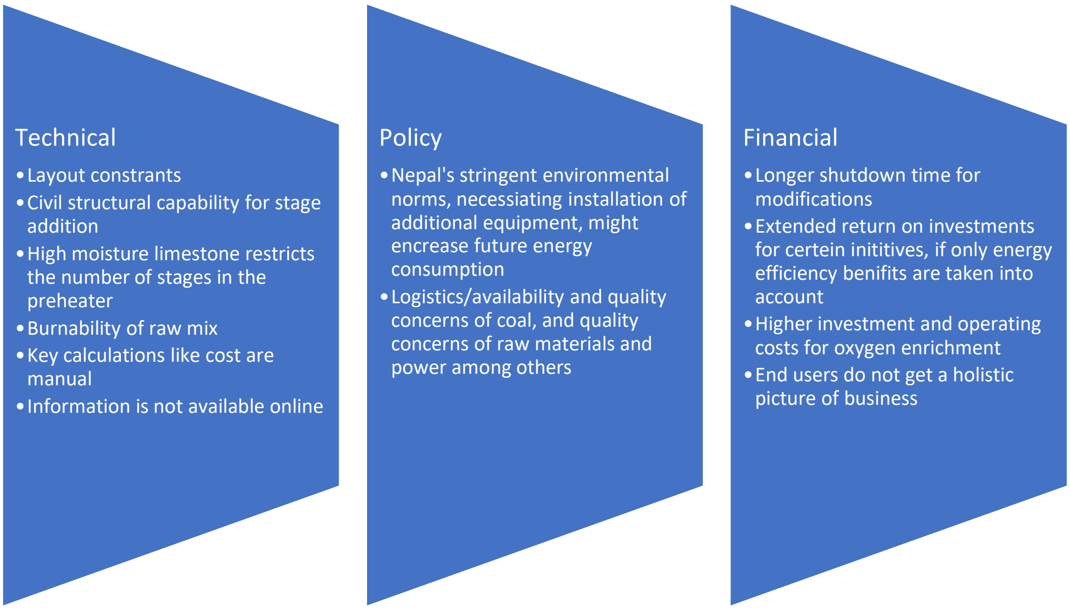

Figure 5.12 Conditions, barriers and constraints of UCIL

Another critical component of production sustainability is financial stability. The UCIL plant can improve its economic outlooks by focusing on the reduction of financial losses, utilising natural resources such as limestone mine, clay, and silica locally, and targeting the markets where there is the demand for high-quality cement. Among indirect factors that affect the sustainability of UCIL plant operations are maintaining employment opportunities, contributing to the national revenue by timely paying taxes and other government fees, and participating in the local infrastructure development, including supporting the maintenance and construction of roads, electricity grids, and access to clean water.

The IEA and the Cement Sustainable Initiative presented a roadmap for the CO_2 emissions reduction in the cement sector until 2050 at a global scale. The global cement demand is set to grow by 12-23% by 2050 under the reference technology scenario, while the direct CO_2 emissions are expected to increase by 4% by 2050. In order to curb global warming within 2^{o} C, it was suggested that the direct emissions from cement manufactures are cut by 24% in 2050 compared to their current levels. This can be achieved by targeting energy efficiency, switching to alternative fuels, reducing clinker contents, for example, by using alternatives, and by adopting the carbon capture and storage technologies. This will create investment opportunities of at least USD $107-127 billion USD by the year 2050 [44]. The barriers to energy efficiency and energy-saving opportunities are listed in Table 5.4.

Figure 5.13 shows the IEA's Energy Technology Perspective (ETP) model of the cement sector. This model can be utilized to track energy and materials flows in the cement production in a typical cement plant. Such a model, together with data-driven simulations, can help to identify the bottlenecks in energy consumption so that the whole process can be optimized.

5.8 Discussion and recommendation

The cement manufacturers in Nepal are facing a highly competitive global business environment. The high production costs of cement in Nepal do not allow the local producers to sell cement in the foreign markets at competitive prices. The key factors behind these high production costs are the inefficient use of energy, uncertain energy supplies, and the rising prices of energy.

The number of cement factories continues to grow globally. Nepal can become self-sufficient in cement production; however, the sustainability of cement production is much more challenging to achieve. The current average capacity utilisation at UCIL is only 36%, and it operates with low energy efficiency under no energy audits. There are also other enhancing issues, including environmental impacts, late adoption of new technology, insufficient maintenance, low efficiency of utilizing fuels and materials, and no development of best practices, e.g., for proper energy and materials management. It drives the consumption of electrical and thermal energy well above the national average. The production cost per unit of energy is doubled compared to the international standard.

Although the 28-year-old kiln at UCIL was replaced with a new one during last summer, inefficient and obsolete processes and technologies are still used. Many energy efficiency measures and strategies can be adopted to improve sustainability and to increase the utilization of production capacity. The rising energy costs and supply shortages for fuels and raw materials present severe threats to suitability. As mentioned previously, the production costs are too high for UCIL to competitive in the international markets. After an investigation of the energy consumption in UCIL was carried out, the following recommendations were made:

- Improving maintenance beyond corrective works is crucial for implementing periodic preventative and predictive practices.
- There is a need for maintaining the inventory of spare parts for timely maintenance.
- The energy and material processing efficiency of the plant machinery and equipment should be evaluated and monitored with the aim to improve the production capacity utilization. Sadly, the UCIL plant dropping down below 36%.
- The quality of raw materials and fuels needs to be consistently assessed.
- The priority should be given to correct or repair systems that are currently left in a bypass mode of operation with the aim to switch from manual to automatic process.
- Ignorance of Periodic, preventive, and predictive maintenance works while practising only corrective support is the primary reason behind frequent machinery and equipment breakdown.

Table 5.4 The barriers in energy efficiency and energy savings [38]

Origin	**Barriers**
Market	•Energy price distortion
	•Low diffusion of technologies
	•Low diffusion of information
	•Other market risks
	•Difficulty in gathering external skills
Government/politics	•Lack of proper regulation
	•Distortion in fiscal policies
Technology/services suppliers	•Lack of interest in energy efficiency
	•Technology suppliers not updated
Designers and manufacturers	•Technical characteristics not adequate
	•High Initial costs
Energy suppliers	•Distortion in energy policies

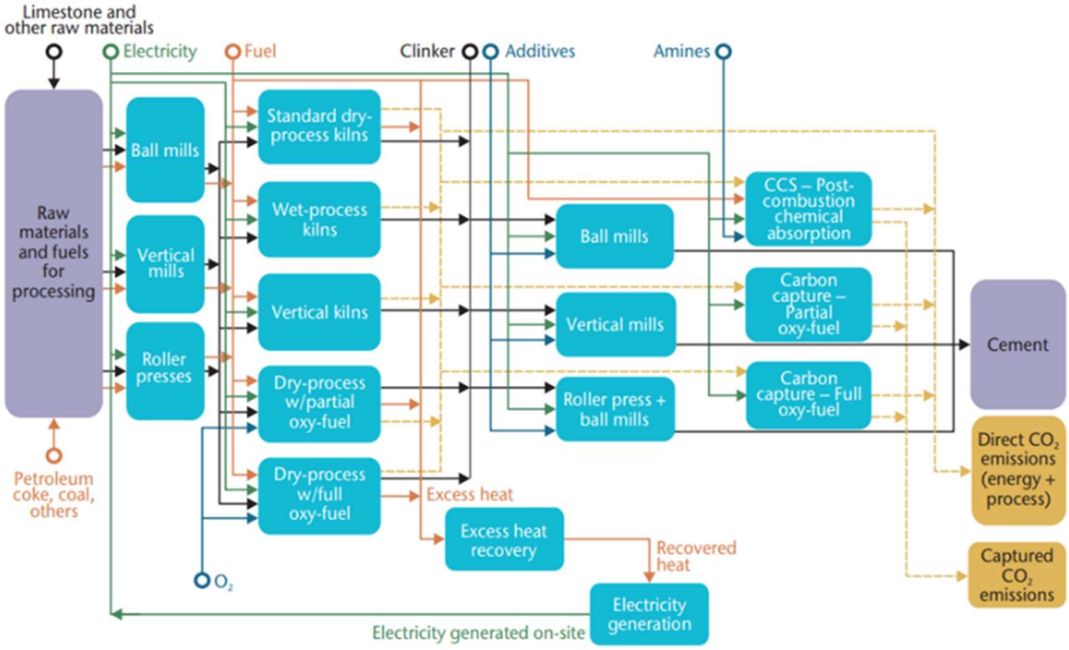

Figure 5.13 A high-level structure of the IEA ETP model of the cement sector [31]

Likewise, the cement production costs can be reduced by assuming the following optimizations of plant processes: reducing the power consumed per ton of cement produced, the stability of all operations, reducing the number of length of production downtimes, maximizing the capacity utilization, and maintaining consistency in the production quality. Furthermore, massive improvements in sustainability can be expected by incorporating alternative fuels and materials.

The primary conclusion of this study was that even though Nepal's cement sector is undergoing modernisation, inefficient and obsolete production technologies are still used, and there are energy-efficiency improvement opportunities available in the UCIL plant. Increasing energy costs and shortage of power create a threat to the production of UCIL's plant to meet the demands. Prices of Nepalese cement have shown in Figure 5.3 as compared with some countries. Market share is highly dependent upon price, and hence, cost control in production, as well as logistics, is vital. In order to meet the expanding cement demand, UCIL needs to upgrade its capacity with highly efficient technology.

5.9 Conclusion

The researcher has examined the energy and production issues at the UCIL plant in Jaljale, Udayapur, to provide an understanding of the energy efficiency, production utilization factors, and environmental pollution problems. The researcher then discussed how these issues could be improved, for instance, by adopting energy efficiency measures to reduce the production costs and improve the plant's sustainability outlooks. The study observed that many production processes currently used at UCIL do not keep up with the international and even national trends and standards. For instance, a considerable amount of heat is wasted in burning, but currently, there are no heat recovery measures adopted. A significant amount of heat is wasted in burning. Therefore, improvements can be made in this section to reduce heat loss or recycle heat. The waste heat recovery can be used to generate as much as 4-5 MW of electricity, which equates to more than half of the electricity consumed at UCIL. Other similar strategies suitable for the UCIL plant were identified, including technology upgrades as well as opportunities for the government to support the clean cement production in Nepal, for example, by investment initiatives. The government can also encourage the adoption of environmentally friendly processes and raise awareness of the sustainability issues among all the cement stakeholders, and establish the appropriate standards, for example, in the energy efficiency of cement production equipment.

The plant process optimization through data analysis and diagnostic studies seems vital as cement production costs were shooting up. The benefits that can be achieved through plant process optimization through research and development are: Reduction in power consumption per ton of cement production; Stable and sustained plant operation; Minimizing downtime (kiln stoppage); Maximum utilization of equipment; Consistency in product quality and Increase in cement/ clinker production

The chapter concludes with the identification of critical energy-efficiency technologies and measures that can be implemented in UCIL along with the recommendations for capturing the identified opportunities through policies, programs, and financing efforts.

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Chapter 6
Impact of electricity loss on the power system in Nepal

This chapter presents the work described in Poudyal et al. (2020). The goal of this chapter is to research the extent of electricity loss on the power system in Nepal, its impact, and how to mitigate the high system losses. This chapter, therefore, focuses on both technical and non-technical losses, and the most recent research papers on system loss are reviewed. In addition, it further looks at what other countries are doing their best to overcome such kind of problems. This study is linked with to mitigate the energy problem of Nepal as one of the strategies, as stated in Chapter 1 of this thesis.

6.1 Introduction

Electrical power generated in power stations travels through large complex networks like transformers, overhead lines, cables, and other equipment and reaches to the end-user. The unit of electricity generated by a power station does not match with the units distributed to the consumers. Some percentages of the unit are dissipated in the form of heat and are lost due to electrical resistance in the transmission and distribution networks. This difference in the produced and distributed units is known as Transmission and Distribution loss [1]. Losses are the amounts of electricity injected into the transmission and distribution grids that are not paid for by customers. Total losses have two components: technical losses and Non–technical losses.

Technical losses arise naturally and consist mainly of power dissipation in the electricity system, equipment used for transmission line and distribution lines, transformers, magnetic losses in transformers, and measurement systems. Non–technical losses are caused by actions external to the power system and record keeping. The uninterrupted generation, supply and distribution of electrical energy to its end-user is a significant challenge of Nepal Electricity Authority (NEA). One of the most alarming technical challenges is the poor power quality and ageing distribution lines, which is in very urgent need of expansion and upgrading with modern infrastructures. Most transmission lines and substations were constructed more than 40 years ago and are based on old technology but demands on the electric power system have increased considerably over the years. Likewise, metering problems, electricity theft, unpaid meter bills, and travel of distribution and transmission lines across long distances to rural areas are also prevalent. Altogether, these have created higher system losses in the electricity sector, a primary contributor to the rising supply-demand gap in the industry.

Non–technical losses in the energy sector are almost negligibly tiny in developed countries. Though, in contrast, many emerging market countries around the world confront widespread theft of electricity. The top 50 emerging markets lost $58.7 billion per year due to electricity theft, compared with just $30.6 billion in the rest of the world [2]. In Nepal, electricity theft leads to annual losses estimated at US$ 75.47 million according to NEA's data, whereas India losses $16.2 billion, Brazil $10.5 billion, Russia $5.1 billion, and Pakistan $0.89 billion respectively [3]. Poor people, honest consumers, and those without connections bear the burden of high tariffs, system inefficiencies, and inadequate and unreliable power supply because of electricity theft [4].

Electricity system loss in Nepal is among the highest in the region, as shown in Figure 6.3. The loss is almost double than of India and triple than Sri Lanka. Transmission& Distribution (T & D) loss of NEA was 37.5 per cent in 1975, and it slowly reduced in the region of 20 per cent during 1981 – 2005. Nevertheless, it greatly exceeded up to 32.21 per cent in 2014 [5]. The 2019 Energy Transition Index (ETI) provided scores for 115 countries spanning the many dimensions of energy transition performance and enablers. Nepal ranked 93 with the scores of 47 per cent among the 115 countries. This rank is based on the country's ability to deliver across the three imperatives of the energy triangle: economic development and growth, energy security and access, and environmental sustainability [6].

Pricing and power system loss remain the two most significant challenges that confront the country's electricity sector. The below negligible price charged on end-users in the sector has rendered NEA not able to mobilise adequate revenue in the sector. This has stifled investment in the sector, mainly in transmission and distribution lines and generation capacities.

Comprehensive studies on electric system loss exist for many countries, including India, Pakistan, Bangladesh, and Nigeria. In addition, there are some research works done around the world to improve system loss, such as [7], [8], [9].

As a matter of fact, proper assessment of technical and non-technical losses is the pathway to analyse system losses reduction and to operate electricity delivery to transmission lines at its optimum efficiency. However, to the best of the researcher's knowledge, a handful of studies have been conducted on power system loss in Nepal. Due to the lack of reliable data from the World Bank (WB), it is not possible to carry out a comprehensive analysis of system loss for recent years. NEA data is the only up to date data available for system loss, but the data itself is not trustworthy. Table 6.4 shows the comparative data between the WB and NEA from 2005 to 2014. The two-system loss data are not similar, and it might be the case that NEA data has been manipulated to flatter their performance. Because of the unavailable data since 2014 from the WB, the research process has hindered.

Nepal has the highest system loss in the region, and the country is facing a chaotic situation in energy distribution that led the researcher to do something for the betterment of the power system of Nepal. This research fills the gap by focusing on the impacts of Electricity loss on the power system of Nepal and provides the solution to improve the system loss. Though research has highlighted the negative impact of energy losses on electricity supply, for policy actions, it will be helpful to establish the impacts of system loss and how to minimise the enormous system loss.

6.2 Methodology

Varieties of materials and methods were used to collect the information required for this study. The research was mainly based on the desk study by reviewing the relevant literature and data provided. The analysis involved NEA annual reports, WECS reports, Economic survey, and national and international energy-related websites have been used. Still, several site visits, informal interviews, and interaction programs have been conducted with the Nepal Electricity Authority, Institute of Engineering's Centre for Energy Studies, and Engineering Association of Nepal.

A range of search methods was applied to ensure the identification of published and not-yet-published works. There are very few peers reviewed journals about the energy sector of Nepal; therefore, most of the literature reviews have been carried out through locally available sources. However, the 'data deficit' gap and the misleading data to show the false progress for political benefit have hindered the data collection process.

6.3 Transmission and distribution system of Nepal

The transmission and distribution system of Nepal, owned by NEA, consists of more than 78km of 400 kV, 150km of 220 kV, 2,417 circuit km of 132 kV, 511km of 66 kV, and 4,907.16 km of 33 kV power lines. Customer services are provided with 35,726.48 km of 11 kV distribution lines and 109,176.15 km of 400/240 V lines [10]. Details of the transmission and distribution system are presented in Figure 6.1 and Tables 6.1-6.5. The electrification rate among all seven provinces of Nepal is 77.82 per cent, as tabulated in Table 6.1. The highest electrification rate is in province 3 with 90.30 per cent, whereas province 6 has just 27.03 per cent. Similarly, existing and planned countrywide transmission lines, distribution lines, distribution transformers are enumerated in Table 6.1. Total existing distribution transformers in all provinces are 26271 and planned 10929. Total existing low transmission (LT) lines are 105146.70 km and planned 46055 km over the whole country. 11 kV line is existing 33603.71 km and planned 21852 km. 33 kV Line existing 4905.24 km and planned 2482 km.

The Kathmandu valley accounts for 400,000 consumers or about 16 per cent of NEA's total consumers in the country and contributes to 27 per cent of the total revenue generated from the sale of electricity. The energy consumption in the valley is rising more than 10 per cent annually, which will lead to a doubling of demand in every 7years. There are 11 distribution centres which operate distribution systems comprising 11KV primary feeders and 0.4kV lines. Tables 6.1 and 6.2 illustrated the overall picture of Nepal's power system electrification rate, transmission, and distribution lines, transformers, and sub-stations existing and planned throughout seven provinces of Nepal.

Table 6.1 Province-wise households electrification, transmission, distribution, and transformer situation of Nepal Contd…

S.N.	District	Households	Electrification (%)	33/11 kV Substation					
				Existing		Under Construction		Planned	
				Nos.	Capacity (MVA)	Nos.	Capacity (MVA)	Nos.	Capacity (MVA)
1	Province 1	1070519	75.90	32	419.95	15	73.50	18	187.00
2	Province 2	1056605	79.77	26	349.40	8	64.00	10	240.00
3	Province 3	1459858	90.30	19	136.70	27	229.20	2	32.00
4	Gandaki	601920	87.39	18	137.60	12	74.50	9	83.00
5	Province 5	984341	81.03	28	324.50	17	116.00	19	212.00
6	Karnali	339197	27.03	6	23.50	3	9.00	17	106.00
7	Sudurpaschim	523808	58.90	21	123.10	11	50.00	10	75.00
	Total	6036248	77.82	150	1514.75	93	616.20	85	935.00

Table 6.2 Province-wise households electrification, transmission, distribution and transformer situation of Nepal

Planned		33 kV Line		11 kV Line		LT Line		Dt. Transformer	
Nos.	Capacity (MVA)	Existing (km.)	Planned (km.)	Existing (km.)	Planned (km.)	Existing (km.)	Planned (km.)	Existing (Nos.)	Planned (Nos.)
18	187.00	815.54	481	6130.96	3457	16955.34	9434	4821	2308
10	240.00	682.42	215	5966.50	1665	13252.59	4210	3819	1338
2	32.00	557.32	40	7788.61	1515	26500.11	3207	7553	1523
9	83.00	623.30	306	3607.53	2126	10524.64	3491	2687	1276
19	212.00	1457.43	494	5037.78	3766	22319.67	11215	4788	2178
17	106.00	207.00	559	879.02	6171	2197.33	9624	554	1183
10	75.00	562.23	387	4193.31	3152	13397.02	4874	2049	1123
85	935.00	4905.24	2482	33603.71	21852	105146.70	46055	26271	10929

Electricity availability in Kathmandu is 400 MW, and the existing distribution system cannot cope with more than this amount without up-gradation. This became clear in 2015 when households were forced to use electricity for cooking during the shortage of LPG, which meant an additional load of 200 MW. The distribution system could not handle the resulting overload, and many distribution transformers burned out.

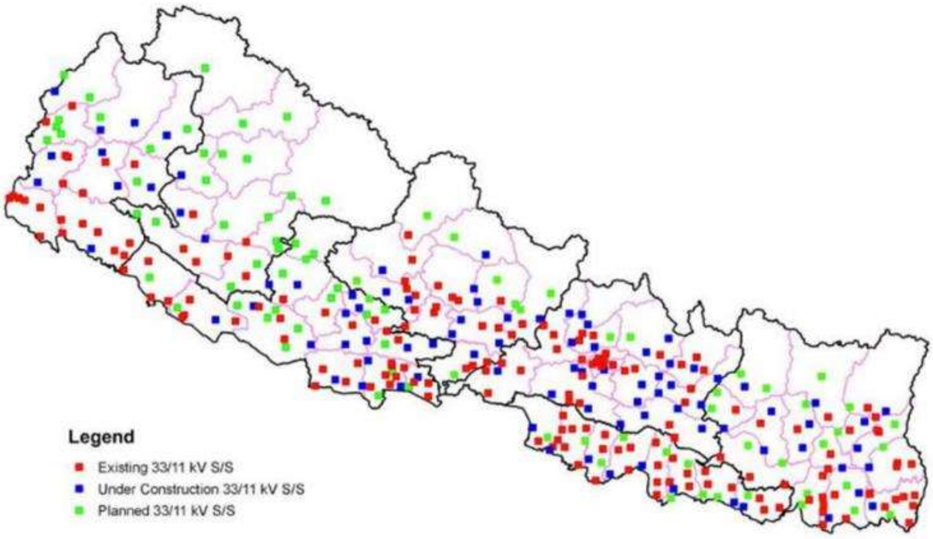

Figure 6.1 National status of 33/11kV sub-station in Nepal

According to the NEA, the number of distribution transformers in Kathmandu stands at 6,391. For safety issues, it can only flow energy at a maximum of 60 per cent capacity of the transformers. There is a must to carry out a most substantial overhaul of the distribution system in Kathmandu and need to add more equipment as the feeders which are already overloaded in the present setup. Until then, the capacity will not be able to fulfil the increasing demand [11]. Business and households from all over the valley have been set back by regular power cuts, voltage fluctuations as a surge in power demands have disclosed the cracks in the valley's decade-old and poor infrastructure.

Temporary procedures will not correct the critical situation, which intensifies, will lead to a power network failure, and both locals and other stakeholders will suffer. Amid this, the energy utility has begun exploring the likelihood of constructing a transmission ring around the river corridors of Kathmandu in a bid to reduce transmission distance and reinforce the infrastructure, but it will take a long-time for the plan to materialize [11]. Existing high voltage transmission lines are shown in Tables 6.1-6.5.

Table 6.3 Existing high voltage transmission lines - 400/220 kV

S.N.	400/220 kV Transmission Line	Configuration	Length circuit km
1	Dhalkebar- Muzaffarpur 400 kV Cross Border Line	Double	78
2	Khimti- Dhakebar 220 kV Transmission Line	Single	75
	Total		153

Table 6.4 Existing high voltage transmission lines - 132 kV

S.N.	132 kV Transmission Line	Configuration	Length circuit km
1	Anarmani-Damak- Duhabi	Single	78
2	Duhabi – Kusaha- Lahan-Mirchaiya-Dhalkebar	Double	290
3	Dhalkebar-Chandranigahapur-Pathlaiya	Double	206
4	Pathlaiya-Hetauda	Double	76
5	Pathlaiya-Parwanipur	Double	36
6	Kusaha-Katiya(India)	Single	15
7	Hetauda-KL2 P/S	Double	16
8	KL2 P/S – Siuchatar	Double	72
9	Siuchatar-Balaju-Chapali-New Bhaktapur	Double	26.9
10	New Bhaktapur-Lamosangu	Double	96
11	Lamosangu-Khimti P/S	Single	46
12	Lamosangu-Bhotekoshi P/S	Single	31
13	Hetauda-Bharatpur	Single	70
14	Bharatpur-Marsyangdi P/S	Single	25
15	Marsyangdi P/S- Siuchatar	Single	84
16	Bharatpur- Damauli	Single	39
17	Bharatpur- Kawasoti-Bardaghat	Single	70
18	Bardaghat-Gandak P/S	Double	28
19	Bardaghat-Butwal	Double	86
20	Lekhnath-Pokhara	Single	7
21	Pokhara-Modikhola P/S	Single	37
22	Butwal-Sivapur-Lamahi	Double	230
23	Lamahi-Jhimruk P/S	Single	50
24	Lamahi-Kohalpur-Lumki-Attariya	Double	486
25	Attariya-Mahendranagar-Gaddachauki	Double	98
26	Marsyangdi- Middle Marsyangdi	Double	78
27	Damak-Godak	Single	35
28	Kusum-Hapure	Single	22
29	Raxul-Parawanipur (Cross Border Nepal Portion)	Single	16
30	Kusaha-Kataiya (Cross Border Nepal Portion)	Single	13
31	Bhulbhule-Middle Marsyangdi P/S	Single	22
32	Chameliya Power plant- Attaria	Single	131
	Total		2,871

Table 6.5 Existing high voltage transmission lines - 66 kV

S.N.	66 kV Transmission Line	Configuration	Length circuit km
1	Chilime P/S – Trishuli P/S	Single	39
2	Trishuli P/S-Balaju	Double	58
3	Trishuli P/S-Devighat P/S	Single	4.56
4	Devighat P/S-hapali	Double	58.6
5	Chapali-New Chabel	Double	10
6	Chabel-Lainchaur	Single	7
7	Balaju-Lainchaur	Single	2
8	Balaju-Suichatar-KL 1 P/S	Double	72
9	KL 1 P/S- Hetauda-Birgunj	Double	144
10	Suichatar-Teku	Single	4.1
11	Suichatar-New Patan	Double	13
12	Teku-K3 (Underground)	Single-core	2.8
13	Suichatar – K3	Single	6.9
14	New Patan – New Baneswor-Bhaktapur	Single	16.5
15	Bhaktapur-Banepa-Panchkhal-Sunkoshi P/S	Single	48
16	Indrawati-Panchkhal	Single	28
	Total		514

6.4 System loss in Nepal

Energy undergoes many conversions and takes on many different forms as it moves. Every transformation that it undergoes has some associated "loss" of energy. Even though this energy does not disappear, some amount of the initial energy either turns into forms that are not usable or do not want to use. Theoretically, in broad terms, the T&D losses are of two kinds: Technical loss (i.e., related to characteristics of overhead line, distribution line, and transformer) and Non-technical loss (i.e., due to non-payment, billing errors, and record-keeping error and energy theft) as illustrated in Figure 6.2.

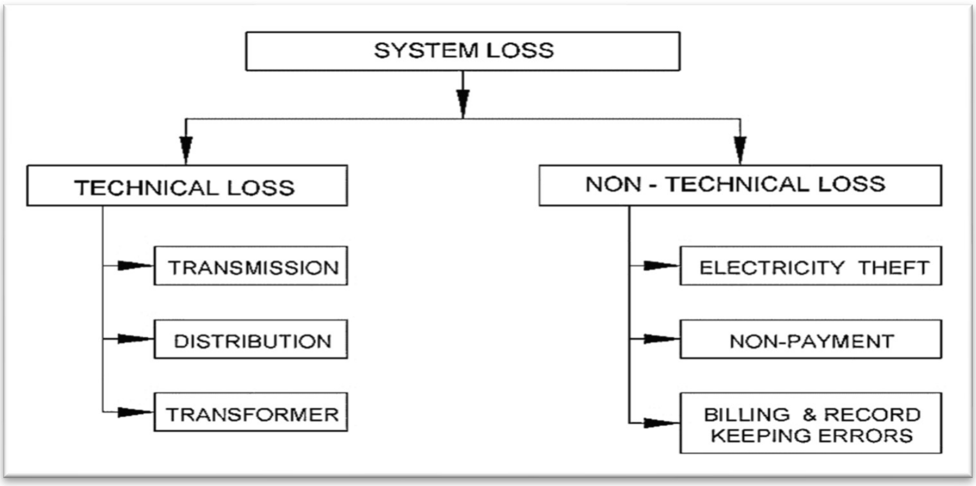

Figure 6.2 Classification of system loss

6.4.1 Technical loss

Technical losses arise naturally and consist mainly of power dissipation in the electricity system, equipment used for transmission line and distribution lines, transformers, magnetic losses in transformers, and measurement systems.

The main reasons for high technical losses in Nepal are:

1. Inadequate investment in transmission and distribution, particularly in sub-transmission & distribution. While the desired financing ratio between generation and Transmission & Distribution should be 1:1. Low financing has resulted in the overloading of the distribution system without adequate strengthening and reinforcement.
2. Random growths of sub-transmission and distribution system with the short-term purpose of extension of power supply to new zones.
3. Large scale country electrification through long 11kV and Low Terminal lines. Lengthy distribution lines.
4. Too many stages of transformations and improper load management.
5. Inadequate reactive compensation and inadequate size of conductors of the distribution line.
6. Inferior quality of equipment and bad workmanship.

On the transmission system, the percentage of system losses is lower than on the distribution system. Generally, about 1.7 per cent of the electricity transferred over the transmission system is lost, and a further 5-8per cent is lost over the distribution system. [12]. In 2018, about 5.63per cent of the electricity transferred over the transmission system was lost in Nepal, as shown in Table 6.6.

Till 2016, Nepal's energy situation was chaotic with massive power shortages. Besides the low production of electricity, the other leading cause of power outage is the sum of energy lost during the transmission and distribution process. According to the NEA Annual Report 2015/16, the average yearly system loss in Nepal's electricity is about 25.78 per cent [13]. The average power loss among 134 countries (world average) that are in the World Bank's Database is 8.16 per cent, while Nepal has 32.21 per cent in 2014, as presented in the World Bank's database [5]. Notably, T&D losses in the range of 6–8 per cent of the energy generated is considered normal.

Table 6.6 Electric power transmission & distribution losses (% of output) in Nepal by NEA

Year	Energy Input (GWh) (A)	Energy Output (GWh) (B)	Transm. Line Losses (GWh) C= A-B	Transm Losses (%) C/A*100	Total System loss %	Collection to bill %	Equiv. months of billing	Outstanding NPR million
2012	3,736.8	3,520.9	215.9	5.8	26.37	96.08	3.90	6,672
2013	3,772.9	3,574.9	198	5.3	25.11	96.67	3.69	7,950
2014	4,120.2	3,889.8	230.4	5.6	24.64	95.79	3.26	7,813
2015	4,394	4,193	201	4.6	24.44	96.76	3.73	9,475
2016	4,476.7	4,260.9	215.7	4.8	25.78	-	-	8,364
2017	4,777.53	5275.3	277.6	5.0	22.0	-	-	10,501
2018	5,560.24	5990.1	357.07	5.63	20.5	-	-	11,433

Table 6.7 Comparison of electric power transmission distribution losses (% of output) as per the World Bank data [5] and NEA data 2005 – 2014 [14]

Year	World Bank Data in %	NEA Data in %	Data Difference in %
2005	28.34	24.83	3.51
2006	29.65	24.94	4.71
2007	30.26	25.15	5.11
2008	31.86	26.52	5.34
2009	34.44	25.27	9.17
2010	34.32	28.91	5.41
2011	31.55	28.55	3.00
2012	30.26	26.37	3.89
2013	32.84	25.11	7.73
2014	32.21	24.64	7.47

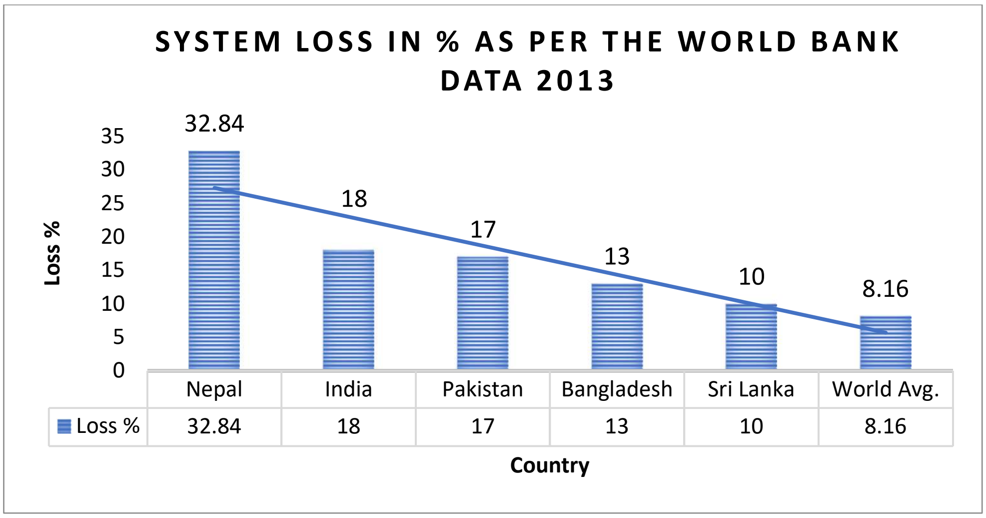

Figure 6.3 System loss in some countries [5]

According to the World Bank data 2013, the losses in some countries like India, Pakistan, Bangladesh, Sri Lanka are illustrated in Figure 6.3, which are 18, 17, 13, 10 per cent, respectively. Sadly, Nepal has 32.84 per cent while the world average is just 8.16 per cent. These losses are wasteful energy dissipated in the power system and cannot be accounted for. All these losses transform into high operating costs as well as substantial revenue losses to utilities, and consequently, they result in the high cost of electricity.

Compared data analysis between the data gathered from the World Bank and NEA is tabulated in Table 6.7. Unexpectedly, there is a difference between the two data from 2005 to 2014 (no WB data available from 2014 onwards). Hence NEA data could be taken as misleading data to show the false progress for political benefit. The data for recent years from NEA is therefore questionable and needs further investigation.

Interestingly, the story of the Chinese transformer supplier to Nepal raised a question about the quality of transformers in Nepal. Nepal's Commission for the Investigation of Abuse of Authority (CIAA) had arrested 22 senior NEA officials and 2 Chinese suppliers on suspicion of corruption on the transformer scandal. During the inspection of several transformers, the wire was found to be aluminium instead of copper, and a scam worth US$ 1.7 million was identified [15]. The total of faulty transformers in the country was 530, and 90 transformers were in the Kathmandu Valley alone. Unfortunately, the damage was beyond repair, and this has caused financial losses of NPR 150 million to NEA [16].

6.4.2 Non-technical loss

Non–technical losses are triggered by actions external to the power system and record–keeping. The three categories of losses are sometimes referred to as commercial, non–payment, and organisational losses, although their definitions differ in the literature [17]. Non–technical losses in the energy sector are almost non–existent or slightly tiny in developed economies, as most of the people can afford to pay tariffs costs of supply. However, many emerging market countries confront widespread theft of electricity around the world. The top 50 emerging markets lose $58.7 billion per year due to electricity theft, compared with just $30.6 billion in the rest of the world [2].

The only acceptable and worldwide utilised approaches for the estimation of non–technical losses are the following:

- Determination of total losses as the difference between the supplied/injected and extracted measured energies.
- Determination of technical losses with the maximum possible accuracy using the available measured energies and computational models.
- Determination of non-technical losses as the difference between the estimated at stage (1) total at stage (2) technical losses.

The mathematical description of this approach is as follows:

$$NTL = Supplied\ Energy - Extracted\ Energy - PL\ (kWh) \quad (1)$$

Types of electrical theft are:

- Bypassing the energy meter
- Injecting foreign elements into the energy meter
- Drilling holes in Electromechanical meter
- False meter reading by an employee
- Unpaid tariff by high paid profile people and organisation
- Billing irregularities made by meter readers

In Nepal, about 10 per cent of electricity is stolen by hooking and tapping the meter illegally [37]. According to NEA's data, electricity theft leads to annual losses estimated at NPR 8billion (US$ 75.47 million), whereas India losses $16.2 billion, Brazil losses 10.5 billion, Russia losses 5.1 billion, and Pakistan losses 0.89 billion [3]. The electricity theft is institutionalised by NEA senior staff by sending an engineer to top electricity consumers for meter readings and organising syndicate with them for corruption.

A few years ago, 12 NEA's employees who were engaged in tampering with electrical meters and defrauding the government for the past 12 years were arrested[18]**.** During the investigation by the Government special task force, NEA was found supplying 24 hours of electricity to high-class industrial customers by curtailing to local people as an extended hours load shedding [19]**.**

Along with electricity theft, another challenge that NEA is facing is the collection of Tariff from high paid profile people and organisation. The researcher would like to highlight the fact that most of the government ministry has not paid an amount of NPR 383.7 million (USD 3.4 million) along with penalty charges. Because of the unpaid tariffs, NEA is facing huge losses every year and is not able to build new power plants and not be able to update its infrastructure according to NEA Annual Report. Moreover, NEA also provides free electricity to its 9,500 employees that cost NPR60 million(USD 0.54 million) to NEA every year [20].

In Nepal till 2017, some industries used to get electricity from the unique feeder while the whole nation was in the dark of long hours load-shedding. These industries supposed to pay special tariffs for continuous electricity to run their business. However, with the syndicate, high-profile political linkage and corruption, they have not paid more than 10 billion NPR of their tariff, including the penalty charges, as illustrated in Table 6.8.

Table 6.8 High profile business company and their outstanding tariff [21]

S.No.	Name of the industry	Owner	NPR in Billion
1	Jagadamba Steel	Sahil Agrawal	2.5
2	Gorahi Cement	Shanghai Group	0.75
3	Arghakhaanchi Cement	PashupatiMuraraka	0.42
4	Maruti Cement	-	0.60
5	Hama Iron	B. K. Shrestha	0.09
6	Ashok Steel	-	0.23
7	Samrat Cement	Ghorahi	0.065
8	Surya Nepal	Former King	0.065
9	Hulash Steel	Shekhar Golchha	0.22
10	Everest Paper Mill	Sarraf	0.13
11	Rolpa Cement	-	0.03
12	Sanapur Cement	Dang	0.40
13	Jagadamba Synthetics	-	0.30
14	Trebeni Spinning	Shanghai Group	0.30
15	Kosmas Cement	Pradipjang Pandey	0.13
	Total	-	6.23

6.5 Effects of system loss

Losses in transmission networks cause electrical energy loss as well as occupy the capacity of transformers and lines. The increased losses at peak demand of load consumption increase losses at peak times of load consumption, which then increases the investment cost and restricts further developments detailed [8].

Poor people, honest consumers, and those without connections bear the burden of high tariffs, system inefficiencies, and inadequate and unreliable power supply because of electricity theft [4]. Due to this unreliable power supply, people and industries face many difficulties, and impacts are as illustrated in Figure 6.4.

Theft of electricity also has safety implications for customers that execute the offence as well as other individuals nearby. There is unreliable evidence of fatalities and injuries [22]. Electricity theft is a global problem that is indirectly related to electricity costs, and prices are the damages to the utilities' financial well–beings.

Because of the higher costs and lower meter reading, billing, and collection rates, the services are incurring extremely high amount of loss in their accounts.

Distorted electricity tariffs, low access rate, frequent supply interruptions, and inefficiency in operation have been the trademark of the Nepalese electricity sector along with other South Asian counties such as India, Pakistan, Bangladesh, and Sri Lanka [23]. Inevitably, in Nepal, the electricity was priced at 0.90 USD/kWh for the end-users in 2018, which is among the highest in the world. Such high costs of energy faced by developing countries require financial subsidies and put the fiscal burden in the country [24]. About NPR 8 billion (US$ 75.47 million) of the enormous debt is suffered by NEA due to system loss.

The study [25] argues that electricity prices in Nepal are too low (after subsidies) to cover all real costs, and the current rates are not based on the economic principles, but instead on the vested interests and political motives. The electricity is then supplied to end-users at highly subsidized prices distorting the market dynamics. It is one of the key reasons why NEA suffers substantial financial losses, so it cannot afford to invest the required sums of money to costly infrastructure and hydropower projects. In the absence of cost-based tariff adjustments, the financial health of NEA has worsened to the point that it is unable to invest in the new as well as existing infrastructure to respond to the energy crisis. The total financial losses of NEA have now reached 27 billion NPR despite the government already writing off the same amount in 2011.

The NEA had experienced ten repeated years of financial losses, including over US$ 100 million in 2016. Following the tariff increase and the roll-out of its financial restructuring plan, the NEA has shown improvement in 2017 and 2018. An economic feasibility action plan has been in place to keep NEA on a sustainable path, and recently NEA's system loss decreased from 26 per cent in 2016 to 20 per cent in 2018 [26].

Figure 6.4 Impact on utilities and their customers [27]

6.6 Control measures and that the lessons learned from other countries

Technical losses correspond to an economic loss for the country, and its optimisation should be performed from a nation's perspective, regardless of the institutional organisation of the region and ownership of operating electricity utilities.

Non-technical losses represent an avoidable economic loss for the utility. Although it is clear that the sum of electricity involved in non-technical losses is being consumed by customers that do not pay for them, experience illustrates that a substantial percentage of those amounts (in some cases more than 50 per cent) have reduced the demand when customers have to pay for that electricity. They regulate their consumption for their ability to pay for electricity services. That reduction in demand has precisely the same effects as a reduction in technical losses: less electricity needs to be generated. Thus, from the country's perspective, reduction in non-technical losses are also positive [28].

This section describes some typical cases of successful and sustainable reduction of total losses in electricity distribution in countries, involving both private and state-owned companies.

The lifetime of the transformer is typically around 40 years, meaning efficient transformers can have a long-lasting impact on the transmission line in the network [29].The impact of transformer losses on the overall system losses is relatively substantial between 15 per cent and 20 per cent. The current advancement in transformer technologies has yielded a considerable reduction in transformer losses. UK power network has rolled out an inferior transformer to eco-design transformers. The total losses reduction was significant, i.e., 3,225 MWh per year. The capitalized cost of this loss reduction was between £ 1.6-2.6 million. The use of copper instead of Aluminium contributes to the substantial reduction in losses with the associated drawback of more massive transformer [30].

Likewise, in the UK, Smart meters were introduced between 2019 to the end of 2020. More than fifty million new energy ‘smart meters’ were being rolled out to 30 million homes and smaller non-domestic sites [31]. Smart meters, combined with home display units, could reduce energy consumption by 2.8 per cent. The analysis showed that, correspondingly, distribution network losses would reduce by 5.5 per cent due to the decrease in consumption[30]. Furthermore, the analysis demonstrated that demand-side management, which could potentially shift 2.5 per cent load from peak to off-peak period, would lead to a reduction of losses by about 3 per cent. Similarly, UK power Networks could save 17 GWh per annum by replacing all Health index 4 and 5 distribution transformers with Eco-design units.

In Bulgaria, thefts were prevented through the replacement of electric meters and their placement at the border of owned real estates. In residential areas with increased thefts, it was` widespread to locate the electric meters at high poles. This results not only in lowering the thefts and increasing the reported electricity but also in load decrease, which reduces the losses in the grid [32].The state of government of Andhra Pradesh, India, has launched a campaign to control the theft of electricity from government-owned power supply companies and improve their revenue collection. The initiative has reduced the system loss, boosted the incomes, made observable changes in their organizational culture [4]. The Indian government has initiated the Integrated Power Development scheme to reinforce further urban distribution systems with information technology-based systems to meter distribution transformer, feeders, and public consumption. The National Smart Grid Mission works with state distribution companies and financing agencies to plan advanced communications grid projects [33].

According to reports, currently, Gujarat, Haryana, Bihar, Punjab, and Rajasthan have fulfilled 30-45 per cent of the commitments made under UjwalDiscom Assurance Yojna or UDAY. While Uttar Pradesh, Bihar, and Jharkhand required improvement with below 30 per cent progress. Jammu & Kashmir lags far behind delivering just 15 per cent of the promises made under UDAY. The implementation of state distribution companies implementing UDAY was measured on 14 operational and financial parameters, which include a reduction in technical and commercial losses reduction [34].

6.7 Loss reduction activities in Nepal

In February 2016, the government of Nepal had published the concept paper 'National Energy Crisis and the Electricity Development Decade', which was targeted a tenfold increase in production capacity to 10GW in ten years. It has also proposed a roadmap for sector restructuring and the establishment of an independent regulator and endorsed "take or pay" Power Purchase Agreements for private developers to improve the bankability of hydropower projects and recognising the need to attract private sector financing and expertise. In addition, it has proposed an action plan to reduce technical and non-technical losses in the power sector as well as measures to strengthen the environmental and social management of hydropower projects.

In 2017, the Government of Nepal increased an average tariff by 14per cent to move towards cost recovery. Similarly, the Nepalese Parliament has adopted legislation to set up an independent Electricity Regulatory Commission, and new management was installed at the NEA. Fortunately, the new administration took some immediate steps to optimise dispatch, reduce losses in the distribution system, introduce a demand management program, and increase domestic generation as well as imports. New companies were also established to manage electricity transmission, power trading, and generation [26]. Nonetheless, these activities are not meeting the expected results yet.

The following actions are adopted by NEA to reduce the massive system loss.:

- Feeder – wise loss evaluation was continued, and extra load shedding hours were set for high loss-prone feeders earlier.
- Distribution centres were assigned loss targets to achieve within the prescribed time frame.
- In many high non–technical loss-prone areas, losses are reduced using Aerial Bundled Conductor (ABC) cable.
- Upgrading of overloaded conductors and transformers.
- The electromechanical meters of the consumers of capacity 25 – 50 KVA range were replaced with electronic (TOD) meters.
- During the FY 2015/16, a total of 31,127 numbers of customers were disconnected from which NPR 328.21 million (USD 29.43 million) was recovered. Similarly, legal action was taken against 3,957 consumers for electricity pilferage, and NPR 33.58 million (USD 301049.74) was recovered from it.
- In FY 2016/17 NPR 455,640,000 (USD 4.09 million) were collected from electricity theft.
- According to Consumer and Distribution Directorate of NEA in 2016/17, USD 3.49 million were recovered among them Demand loss were USD 5875, Direct Hooking USD 158 thousand and meter misconduct USD 51723 were collected
- Removed 18,833 hookings from the customer's buildings and caught 14273 customers on a charge of stealing electricity
- Police have found dozens of NEA's staff on an allegation of Electricity misconduct with the syndication of Consumers.

Nepal has obtained a loan from the European Investment Bank to upgrade the distribution system. The bank has provided $50 million as a 32-year term concessional loan at 1 per cent interest during the eight-year grace period and 1.5 per cent interest after the grace period under the distribution enhancement project. Hence NEA is planning to bring down distribution losses to 8.5 per cent this fiscal year 2020 by strengthening the system infrastructure, including substations and transformers. In addition, NEA is planning to optimum use of sealed conductor cable in loss prone areas, upgrading overloaded transformers, and coordinating with the regional government to find cases of electricity theft and meter tampering.

Under the new leadership, NEA has shown some progress, but the works seem to be happening at a slow pace. In the fiscal year 2018-19, NEA has added more than 600km of power lines to the country's domestic and cross border electricity transmission network and has erected 30 new distribution substations[35]. Another achievement by NEA was the expansion of the long-delayed Godak-Phidim portion, which added 85 kilometres of lines in the Kabeli Corridor. Regardless of this, power lines along the Kabeli Corridor, considered as the backbone of the national grid in the eastern region, are yet to be fully commissioned as the final portion of the line remains to be completed, 10 years after the project began. Also, the construction of major transmission lines, like the 132 kV Thankot-Chapagaun, 220 kV Bharatpur-Bardaghat, 400 kV Hetauda-Dhalkebar-Duhabi and 400 kV Tamakoshi-Kathmandu, have been halted due to land compensation and forest clearance issues and delays by contractors[35].

In addition, in 3 years' time, only 6km of underground cables were laid in the new Chabel-Lainchaur power route. The remaining 250km long power lines of 11kV capacity along with 400km long 400V capacity underground cables for Maharajgunj Distribution Centre and 200 km long 11kV capacity along with 400km long 400V underground cables for Ratnapark Distribution Centre are yet to be laid before the completion date which is October 2021. Once the underground cables are laid, NEA is planning to install smart meters for 9,000 customers of both centres, which is not going to happen soon.

To reduce the system loss, NEA has issued circulars to eight distribution centres and its division offices to keep tabs on electricity pilferage, enhance the capacity of transformers and balance the system load. Despite all the positive approach, there is no actual data of system loss to back up their success. Notably, there were losses of up to 34 per cent in some years in NEA. If NEA reduced 1 per cent of the loss, it could save five corers units of electricity. Billions of NPR will be saved, and that saved energy and the money could be invested for another energy project in the future or could be used to upgrade existing infrastructure. NEA needs to implement all those positive measures and plan into immediate action. In addition, NEA must take severe action and measures to collect all unpaid bills, as listed in Table 6.8, with the help of the government of Nepal.

6.8 Discussion and conclusion

Nepal's energy situation is known for massive power shortages, which is due to the low production of electricity and a high rise in demand. The shortage of electricity is further accelerated by the amount of power lost during the transmission and distribution process. In 2014, the average annual transmission loss in Nepal's electricity market was about 32.84 per cent of total electricity generation, whereas the average power loss among 134 countries that are in World Bank's database was 8.16per cent. Surprisingly, the annual transmission loss declared by NEA for the same year was 25.11per cent, which is 7.73per cent less than the World Bank data. This has raised the reliability of NEA data, and the concern about the possibility of the data may have been manipulated to flatter their performance.

Pricing and power system loss remain the two most significant challenges that threaten the country's electricity sector. The below marginal price charged on end-users has rendered NEA not able to mobilise an adequate amount of revenue in the sector. Although the GON increased an average electricity tariff in 2017, the price is still below marginal cost. This has therefore suppressed investment in the sector, particularly in transmission and distribution lines and generation capacities.

Reducing transmission loss is very vital because the saved power can be sold to consumers and thus can generate extra revenue. It is even vital in Nepal's case since the country has not been able to produce enough electricity to meet the demand. Thus, decreasing transmission losses not only creates additional revenue, it can also be an alternative for saving capital costs from building new infrastructures.

Recent researches [36],[37],[39]have presented that high power losses contribute to high energy losses in distribution networks. It is essential, therefore, that NEA minimises power losses in the system to reduce the resultant energy losses. Other factors that contribute to increasing energy losses in distribution systems are vandalism, illegal connection to transmission/distribution lines tampering with or bypassing meters, often with the involvement of utility staff. Revenue leaks resulted from weaknesses in metering, internal control systems, billing and collection, prosecution of the disconnection policy, poor quality, use of wrong size conductors.

Energy policy, technical and administrative actions should be taken very seriously by the government of Nepal to reduce the highest rate of system loss. The top priority of

NEA should be to upgrade the existing substations and to build new transmission lines and distribution grids to reduce system loss and enhance the reliability of the transmission system throughout the national network. Further, the priority for the NEA should be to detect and to control the non–technical losses. The government of Nepal must, therefore, invest in its energy infrastructures and increase operational and management efficiencies from generation to the end-user.

The effective solution is the use of a smart electric meter, eco transformers, smart grid, a capacitor bank, and modernizing the T & D system. The modern "smart" electric meters enable sufficiently precise and valid measurement of the injected and extracted energies along all branches in the distribution grids, and calculation of the total losses by sections as a difference between the measured energies. The modern T&D system could offer substantial benefits. Costs to clients could be reduced through more competent electricity; national security could be enhanced because of the most excellent and reliable and reduce vulnerability to major disruptions; higher capacity to accommodate renewable would improve the public safety and environment would be improved. While the benefits of modernising the T&D system in Nepal are potentially tremendous - A modernised smart grid will enable a wide array of new options for load management, distributed generation, energy storage, and revenue opportunities for those who choose to participate.

Legislators and regulators have not taken an active leadership role regarding grid modernisation, nor have they adopted a clear and consistent the modern grid. There has been a significant focus in recent years on controlling electric theft. Still, less attention has been paid to developing a vision that integrates technologies, solves the various grid-related problems, and provides the desired benefits to stakeholders and society.

In Nepal, the non-technical loss is significant. About 10 per cent of electricity is stolen by hooking and tapping the meter illegally. According to NEA's data, electricity theft leads to annual losses estimated at NPR 8billion (US$ 75.47 million). Besides electricity theft, another challenge that NEA is facing is a collection of Tariffs from high paid profile people, government offices, industries, and organisation. Unexpectedly, the government ministry has not paid an amount of NPR 383.71 million (USD 34,40047.79) plus penalty charges to NEA, and some of the industries have not paid an amount of NPR 10 billion including penalty charges. Because of the unpaid tariffs, NEA is facing huge losses every year and is not able to build new power plants and not be able to update its infrastructure (NEA Annual Report 2018). Moreover, NEA is also providing free electricity to its 9,500 employees that cost NPR 60 million (USD 0.53 million) to NEA every year [20] and provides free electricity to temples and street lights. The corruption and the syndicate with a high-profile politician are the main reason for unpaid traffics. In order to recover the old debts, NEA should take police action and judicial actions and application of programs to negotiate with clients with long-standing debts or suspected of stealing electricity should be implemented.

Research and Development (R&D) is necessary to reduce costs and improve the performance of the power system. Still and all, the rate of scientific research and development in the energy sector is incredibly low compared to another sector in Nepal. Our method of collecting up to date data, literature, and lesson learned from other countries opens new opportunities for policy research, power system planning, and citizen engagement.

6.9 Recommendations

To provide an environmentally sustainable and low-cost supply of electricity, NEA must follow these recommendations:

- Vital management of metering, reading, billing, collection, disconnection-reconnection due to unpaid bills, and inspection of meters
- Formulation of policies for customer service and programs for payment of old debts and commercial regularisation
- Promoting programs aimed at creating awareness that electricity is a commercial good with a price
- Implementation of communication programs to deliver customers with transparent information on their rights and obligations.

In addition, the main technical actions NEA should follow are:

- Construction of distribution system less vulnerable to tampering and irregular connections
- Detailed analysis of network loading and correlation with feeder lengths to reduce network losses

- Smart grid technologies and systems
- Systematic field assessments for improper connections tampered or damaged consumption meters, unmetered consumers (both customers and irregular users)
- Periodic field inspections and updating mechanisms and technologies to avoid theft as well as technical loss
- Use of boxes to guarantee that the consumption meters are appropriately sealed and cannot be tampered
- Monitoring the operational condition of installed seals.
- Investments in information technology to support commercial and technical functions and shared services
- Construction and regular updates of trustworthy databases based on field activities aimed at checking its reliability with physical reality
- Use of smart meter for reading and checking consumption
- Systematic field action on improper service conditions detected.

Besides these, NEA must follow the following training and management actions:

- Continuous training to its staff and provides the provision of working tools (including safety equipment)
- Implementation of databanks including documentation of workers with immoral behaviour
- Certification of contractors based on environment, quality, and occupational health and safety criteria
- Direct and open interaction with communities, their leaders, and the authorities involved to create awareness; enhance the culture of regular payment of electricity bills, preservation of electrical infrastructure, and behaviour to avoid electrocution.
- Working together with the Government's justice departments to ensure effective action in cases of electricity theft.
- Recovery of pending debts in selected cases through police action and judicial actions; Application of programs to negotiate with clients with long-standing debts.

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Chapter 7
Conclusion and recommendations

This chapter presents a summary of findings, conclusions, and recommendations based on thorough analyses from the data gathered, the literature reviewed, long-range energy demand analysis, solar PV design, and techno-economic feasibility, energy efficiency enhancement.

7.1 Conclusions

The first chapter of this thesis provided an overview of the thesis; chapter two identified the literature of all five research chapters to find the problem of energy crises in Nepal and the solution through the adaptation of renewable energy. Chapter three further highlighted the issue of energy deficit and to examine the national energy demand of the country, by analysing long term demand analysis up to 2042 with various subsectors which are lacking in existing NEA's and National planning's study[12]. Chapter four illustrated the solar PV system design by Matlab/Simulink and further, to determine the suitability in a residential building in Kathmandu, PVsyst, Meteonorm, HOMER software were used to analyse the results with local meteo data. Chapter five highlighted the energy losses in industry and focused on the case study of UCIL, the state-owned cement industry, where energy usage is the most. It further provided the efficiency measures and sustainable solutions in producing the cement. Similarly, chapter six explained the system loss in the electric power system of Nepal, its effect, and the solution to minimise the losses. Finally, this last chapter provides a conclusion and recommendation with some technical action plan for immediate improvement that can help to mitigate the energy crisis of Nepal.

In chapter two, the researcher has analysed the literature for the country's up to date energy perspective and status of the energy crisis. The research thoroughly reviewed the current energy production and consumption profile and identified the main factors contributing to a widening gap between the energy supply and demand. These factors are delayed and overpriced hydropower projects, outdated and insufficient energy infrastructure, transmission and distribution losses, energy theft, deficient energy management, lack of energy conservation, unacceptably low efficiency of equipment, unsustainable energy pricing strategies and unsatisfying energy market regulations. Other essential factors worsening the energy crisis are the specific geographical and geopolitical situation of Nepal; it's a strong dependence on energy imports, and inadequate exploitation of vast amounts of renewable energy sources.

Analysis of the data gathered by various government sources revealed that the energy crisis could be controlled by adaptation of renewable energy such as solar PV, wind turbine, biomass, and small hydropower systematically, simultaneously with large hydropower. Energy is crucial for the socio-economic development of the country. In this regard, it is evident from the literature that most of the countries are actively switching from conventional primary energy resources to renewable and sustainable energy options to meet their rising energy demand. However, Nepal is not only lacking in meeting the total energy demand of the country but is also deficient in harnessing its vast renewable resources like solar, wind, biomass, and small hydropower, which can play a significant role in addressing the ongoing energy crisis. As an illustration, wind and solar power projects could be installed within 3 to 6 months, whereas big hydropower projects of Nepal are taking delays from 6 months to 12 years.

Further, chapter two has summarised the potential of renewable energies and how to establish the right mix of different renewable energy sources to tackle the crisis and improve the economic standing of the country. It is apparent, from the literature review illustrated in this thesis, that indigenous fossil fuel resources of the world are not only limited but, at the same time, carry adverse environmental impacts. Renewable energy resources are abundantly available in Nepal and can commercially support current energy needs and should be harnessed in full. Solar, wind, biomass, and small hydropower are, as such, the sustainable energy resources Nepal is blessed with. Nepal has 43,000 MW of hydropower, 3000 MW of wind energy, 2100 MW of solar power, and 100,000 plants of biomass potential. Further, Nepal has plenty of small hydropower potential.

Chapter three has presented the LEAP model. The objective of this research was to show the energy situation of Nepal in the hope to advocate the importance of Renewable energy adaptation and to illustrate the energy scenarios, and its long forecasting which will help to plan the future energy. In LEAP's model, by considering the environmental and techno-economic parameters, this research has investigated forecasting and balancing the electricity supply-demand situation of Nepal to show the alternative picture of what the expectations can hold for Nepal's energy sector in terms of installed capacity, generation, CO_2 emissions, and cost perspective The forecasted electricity demand for the study period is modest and comparable with other studies. In Nepal, the overall projected electricity demand has been forecasted to be 16. 983 GJ in 2042, which compared to only 10.705 GJ in 2012. This means the growth is increased by 59 per cent higher than the base year 2011/2012, with demand estimated at an annual average growth of 4.3 per cent over the study period.

It is apparent from the results that Nepal will never become a secure energy country in the future if Nepal follows current policies. However, by following suggested measures to adapt an energy mix policy, Nepal's energy sector can be turned into better energy security. This will result in reducing both costs and emissions. Energy consumption could be thought of as a leading reason for increasing demand up to 2042. In Nepal, Researchers are using the annual data based on 2011/2012 as a base year. The enormous use of energy, mostly in the residential, commercial, and industry, has directly pushed the economy.

In conclusion, for developing countries like Nepal, energy is essential for economic and social development and the improvement of life. Energy mix with renewable energy adaptation would reduce Nepal's vulnerability to fossil fuel price shocks, help build local and regional economies, and reduce global warming potential.

Additionally, the government should facilitate incentives for RET user tax exemption and VAT free facilities. Similarly, energy modelling tools should be widely used for energy planning and forecasting. For energy planning and forecasting, energy modelling tools should be used as well as establishing active collaboration between government and academia to work together for better and more promising results. From the current study, it is expected it will be beneficial for energy planners, policymakers, and government officials of other developing countries where there is insufficient knowledge of energy policy planning and energy management.

Chapter four has presented the characteristics of PV cells that have been modelled by a single diode mathematical model and has shown the affected by irradiation and temperature. It is apparent from the result that the panel performance is best at 25°C temperature and 1000W/m^2 irradiance.

Further, the values of a designed silicon monocrystalline solar module in MATLAB/ Simulink have been verified and found similar to the datasheet of the chosen PV module. The data obtained from Meteonorm showed that the horizontal yearly irradiation in Kathmandu is 1950kWh/m^2/year and has moderate temperature throughout the year, having the average maximum temperature of 25.7^{0}C and the minimum average temperature of 11.4^{0}C. This feasibility study has demonstrated that there is a very encouraging potential for solar PV systems in Nepal as the county has favourable climatic conditions in terms of both temperature and annual solar irradiation. Similarly, the simulation result in PVsyst and HOMER has proved that all three solar PV systems are technically viable in the Kathmandu valley.

In terms of installation, the Solar PV could be rapidly implemented (in a matter of weeks or months rather than the years needed to implant hydropower plants). The economic analysis has shown that the grid-connected system is best out of all. However, technically all three PV systems could be adapted to make a balance in the annual rising electricity demand. A stand-alone PV system would be beneficial for rural areas where there is no grid connection; a hybrid system would be beneficial in urban areas where there are occasional power outages and voltage inflation. Similarly, a grid-connected system would be beneficial in urban areas where there is a reliable grid system. However, considering power quality and grid stability, in the context of the Kathmandu valley, the hybrid system would be the perfect match for uninterrupted energy supply.

Given that electricity is mostly use in the residential sector for lighting purposes, excessive fossil fuel and LPG are used in cooking and in standby diesel generator. Using alternative fuels to generate electricity for the residential sector for all purposes could increase electrically available for industrial projects or export, generating significant economic benefits for the country. Additionally, it could reduce or eliminate the need to import LPG, fossil fuel, and electricity from the neighbouring country. The clean and green energy from the solar PV system not only provides the energy free of cost, but it also provides a solution for the important issues of the country's energy security, unpredictable fuel cost curve, inter-political tension, and CO_2 emission.

Concerning the cost of photovoltaic energy technology gradually decreasing as the market demand and production of PV systems increasing, the government should keep on supporting the PV system, either by providing subsidy or reducing tax or raising awareness. The government of Nepal should focus on providing specific professional training or course on solar PV systems to train competent planners and installers for the future.

In chapter five, the researcher has highlighted the imbalance between production and consumption and energy wastage in industries. The researcher has examined the status of energy efficiency in the Nepalese cement industry by undertaking a case study of state-owned Udayapur cement industry limited (UCIL). A comprehensive review of the cement manufacturing process of UCIL, the material and energy flows, process modelling, and analysis of several measures in a range of cement plants has been carried out.

Analysis of the data gathered by various government sources has revealed that cement demand is expected to grow in Nepal at a healthy pace over the years, primarily led by demand from the infrastructure segment. The demand for cement in Nepal is about 5 million MT, of which about 80 per cent is produced internally, and the remaining 20 per cent is imported. However, according to import data from the Trade and Promotion Centre (TEPC), Nepal imported clinker worth NPR30.21 billion (USD 267.63 million) in the FY17-18 and has imported cement worth NPR1.03bn (USD 9.18 million) in the fiscal year 2017-18. In addition, Nepal has imported coal worth USD 46,394.05 from India. Nepal's energy costs are determined by the price of energy products and the quantities consumed. UCIL indeed consumes more amounts, and that energy price is added to production cost. Nepal has no coal mine reserve and imports coal from India.

Contribution of cement industries in Nepal’s gross domestic production and employment seems worth mentioning; cement industries play essential roles in the national economy. Findings from the case study of UCIL has unveiled that the problem in the supply of raw materials, coal, and electricity adversely affected the operational performance and capacity utilisation factors. Moreover, the interrupted electricity and shortage of coal imposed additional costs on alternative power, damage the equipment, and halted the manufacturing process. The study has further disclosed that the production cost of a bag of cement in UCIL is nearly double in comparison with neighbouring India, and China and UCIL is facing a significant challenge to compete with the regional market. This chapter has concluded with a recommendation to follow a sustainable approach to reduce production cost by lowering the energy intake;

minimise carbon footprint by utilising locally available raw material, use alternative material and fuel, and minimising carbon emission by applying sustainable measures. It has also recommended utilising waste heat recovery process to generated electricity.

In Chapter Six, the researcher has highlighted the energy loss scenario of Nepal and have analysed the electrical power transmission and distribution losses. The researcher has discussed the main reasons for technical and non-technical losses and their effect on system loss. The factors affecting technical system losses arise naturally and consist mainly of power dissipation in the electricity system, equipment used for transmission line and distribution lines, transformers, magnetic losses in transformers and measurement systems. However, in non– technical losses are caused by actions external to the power system and record keeping. The main factor of non-technical losses in electrical theft; unable to collect tariff; unpaid tariff by high profile people and organisation; and billing irregularities made by meter readers.

Analysis of the data gathered by the World Bank and NEA sources has revealed that in Nepal, electricity system loss is among the highest in the region and stood up to 34 per cent in some years. Non–technical losses in the power sector are almost negligibly tiny in developed economies. However, in contrast, many countries confront widespread theft of electricity around the world, especially in many emerging market countries. The top 50 emerging markets lose $58.7 billion per year due to electricity theft, compared with just $30.6 billion in the rest of the world [16]. In Nepal, electricity theft leads to annual losses estimated at NPR 8billions (US$ 75.47 million) according to NEA's data. The researcher has concluded in this chapter by discussing the control measures of some countries' experience and loss reduction activities of NEA and has further recommended NEA some measures for both technical and non-technical losses.

Recently, the state-controlled NEA started to improve the dismal energy situation by adopting a series of policy and technological measures. A politically appointed position of the NEA director underlines the interdependence of energy and political matters. Some of the recent NEA achievements include expanding the electricity generation and distribution capacity and directing load shedding mainly to the most significant industrial consumers. NEA's management performance significantly improved, so it finally generates an operating surplus. However, the past poor performance of the NEA contributed to the rise of IPP providers, which changed energy markets in the country.

Based on the findings of the research, it can be concluded that the current energy crisis is harming the overall socio-economic development of the country and operations of industries. The current level of energy consumption in Nepal, with the poor harnessing of its renewable resources and increasing dependence on imported fossil fuels, is unsustainable. To narrow down the deficit of energy, Nepal needs to gradually proceed towards sustainable energy for the country in the long run. For this, Nepal must focus on the energy mix of different renewable energy sources, with suitable energy storage solutions, by following the international trend.

Despite tremendous renewable resources, Nepal is facing many obstructions to meet its energy demands. The hydroelectricity represents more than 99 per cent of electricity in the national grid; however, only about 2 per cent of the overall hydropower potential is utilised. In Nepal, hydropower plants are and will likely remain to be the dominant source of electricity. Locally, smaller-scale renewable energy sources can be used to promote the economic activity and lifestyle of communities in remote areas. However, large hydro projects are necessary to secure industrial and agricultural production in the long run.

The solar, wind, and biomass should all be considered to increase energy security, reduce GHG emissions, and to lower the dependence on energy imports and fossil fuels. In particular, the use of PV rooftop panels and wind turbines is economical, provided that the required load is less than 75 kWh/day, and the load point is more than 50 km away from the national grid. The pumped hydro storage systems can be the right solution for peak-hour load management and levelling the electricity demand more evenly over the day. The development of the hydropower-based electricity storage can significantly reduce the seasonal dependency for the flow-of-rive type hydropower systems.

The electrification rate of Nepal remains to be one of the lowest among the developing countries, while the electricity grid remains unreliable. Since developing the electric power grid and the power stations is hugely capital intensive, substantial funding and proper technical expertise both from private and public sectors are required. In order to break down policy barriers and to tackle persistent challenges of low investments and weak productivity, Nepal needs to dramatically restructure its public investment programs, intensify the level of competition in the domestic markets, especially in transport, logistics, and telecommunications, and reduce the costs of doing business, and open and steadily integrate its economy into the global world [27]. Renewable energy projects need to be promoted by the government to produce and sell electricity in the domestic and foreign markets. Even though renewable energy generation is somewhat volatile due to varying weather and seasonal conditions, the rapidly falling prices of renewable energy technologies can turn Nepal into a significant exporter of electricity to other countries.

Similarly, Nepal must increase the generation and distribution capacity urgently and improve energy utilisation to reduce the dependency on energy imports. Nepal also needs massive investments in the modern infrastructure, mitigate the T&D losses, monitor and improve energy efficiency, and raise the overall industrial production. The digitalisation of electricity distribution networks enables automation and near real-time management of electricity demands and supply. These tasks can be stimulated by international sharing of policies and best practices, including data collection strategies and by achieving a society-wide focus on conserving the energy. Smart meters and the upgrading of the smart grid are the ultimate ways to recover from colossal system loss and electricity theft of state-controlled NEA. Political interference should be ended to increase productivity and lower the theft of electricity.

Further, NEA should focus on Integral management of meter reading, billing, collection, disconnection-reconnection due to unpaid bills, and inspection of meters. It should implement policies for customer service and programs for payment of old debts and commercial regularisation. Periodic field inspections and updating mechanisms and technologies to avoid theft as well as technical loss; Systematic field assessments looking for irregular connections, tampered or damaged consumption meters, unmetered consumers can be carried out by NEA.

During the study, the researcher has noticed that the number of cement industries are increasing in Nepal as it is on the way to be self-sufficient in cement production. However, there are concerns and challenges ahead for sustainable cement production. Within the case study, it was noted that the capacity utilisations of UCIL has a low rate of 36.3 per cent on average and has high energy intensity as well as serious environmental impact. Nevertheless, few vital things are still making the plant run and be sustainable in front of those significant losses and damages. The main factors building up the sustainability of the entire industry during the past few years are no financial loss, the utilisation of the natural resources locally such as limestone quarrying, clay and silica extraction and the provision of direct employment opportunities to more than 500 people including the local workforce and the contribution to local infrastructural development and the national revenue.

Based on the finding of this research, it is concluded that UCIL has to adopt up to date technology; undertake periodic maintenance and energy audit; adopt research and development practices; use fuel and raw materials efficiently; replace high energy-consuming equipment with more efficient ones and installing energy recovery systems. This will then help to reduce thermal and electric energy consumption intake and run the state-owned factory effectively and efficiently.

Although recently, UCIL has undertaken periodic maintenance and replaced old. With new modern kilns, UCIL still needs to commit to sustainable production that meets the needs of the present without compromising the future generation.

Cement activities can have substantial impacts on the natural environment and local communities in proximity. Limestone quarries are long-lived assets, operating for 50 years. During their operational lifecycle, they have implications on the local environment, including dust, noise, and other factors, which must be managed appropriately. The removal of soil and changes in topography can affect local ecosystems and water levels. Nepal is among the countries that are most vulnerable to climate change and its effects, including more severe water-induced calamity and severe hydro-meteorological events, such as drought, storms, flooding and inundation, landslides, debris flows, soil erosion, and avalanches.

This study concluded that UCIL has to seek this sustainable side, as well as the energy efficiency measures to ensure that the cement produced, is co-processed in an ecologically safe and sound manner, safeguarding the health and safety of the staffs in the plant and people living in the neighbourhood, reducing the environmental impact of the manufacturing process and producing the affordable, high-quality final product.

During data collection and site visits of cement industries, the respondents were limited. Furthermore, only informal interviews were undertaken. Data deficiencies in the area nationwide are another bottleneck of this research.

7.2 Recommendations

Renewable energy projects need to be promoted by the government to produce and sell electricity in the domestic and foreign markets. The policies encouraging investments in the energy sectors may involve tax exemptions, and other risk-mitigating measures as well as the elimination of the administrative hurdles. The central bank of Nepal can also encourage domestic and foreign investments into the energy infrastructure. Another viable strategy is to collaborate more closely with the countries in the South-East Asian region to jointly develop systemic solutions that are not limited by the national borders. It should also be noted that the goal is to eradicate, not just mitigate the energy crisis. It is only when the energy demands are met that substantial economic and social development in Nepal can be expected.

NEA should adopt load management technologies and prioritise the demand according to the peak demand. Further, it can develop initiatives to reduce peak demand by formulating tariff structures such as peak load pricing and off-peak load pricing. The NEA would need to upgrade metering equipment that allows differential pricing across the periods of consumption. This new metering will also help to reduce system loss and electricity theft.

Most of the hydropower of Nepal is based on the ROR type. The flow of rivers depends on the seasons, so hydropower plants do not run at less than half of their capacities during a dry season. Unfortunately, the demand is very high in the dry season compared to the monsoon season. Nepal should focus on reservoir-based hydropower, and then pumped hydropower systems would be encouraged to maintain the peak load management.

There is a need to intensify efforts to create awareness for energy conservation and efficiency. The problem of demand which has outstripped supply is the cause of the energy crisis. There is an urgent need to make every effort not to waste energy but rather use it more productively. Being efficient in the use of energy can help conserve energy and thereby reduce demand pressure on the national grid. Thus, stakeholder institutions should intensify efforts to educate the public and recommend this kind of education should be included in the school’s curriculum on how to conserve energy and the use of energy-efficient appliances. Public awareness researchers have published dozens of articles in local newspapers regarding this, in both English and

Nepali. It is the new approach to make more extensive contact with more audiences for this National issue. Lists of those articles have been presented in the significant contribution of the study section in detail.

The long-term solutions to the energy crisis in Nepal have endowed it with enough renewable energy resources (solar, wind, biogas, and mini-hydro) capable of generating enough energy to augment the national energy supply. However, these renewable resources are under-utilised, and some ignored. There is the need to tap into these energy resources and desist from depending solely on hydropower. The Government of Nepal has given the passage of the renewable energy bill and joining as a member of the International Renewable Energy Association in 2017 shows some rays of hope on its mix policy. Our research further revealed that the renewable energy resources for the generation of power and heat, in an efficient and environmentally sustainable manner, would require significant effort to attract investments into this sub-sector. This would make the flexible and expedite processing involved more attractive, so potential investors are not discouraged in the energy sector. The government, as well as other Independent Power Producers (IPPs), should accelerate development projects underway in the power sector.

Thus, pipeline projects such as Tamakoshi 450 MW, Kulekhani-3 14 MW storage Hydropower, Arun-3 1200 MW, and Budi Gandaki 1200 MW, including some Solar and Wind Energy projects that have been designed and earmarked for development to augment power supply should be accelerated to end the energy crisis permanently. In other words, there is a need to increase the involvement of the government of Nepal and the private investors in the power sector of the country.

This research on the assessment of the energy system of Nepal hopes to serve the following: The communities' awareness of the causes of power outage will schedule their activities so as not to disrupt their activities by load management.

- People should be taught how to minimise the use of electricity to avoid wastage and how to make the system more energy efficient by practising efficiency measures
- The energy system of NEA and NOC will be updated for their better energy system

- Business and industries-oriented customers will be made aware of the causes of frequent brownouts so that they can do alternative plans to minimise losses in their business as well as the inconveniences.
- Energy-intensive industries like cement, pulp, and papers and sugars are encouraged by following the energy efficiency measures and applying them, such as waste heat recovery systems, to generate electricity in their plant.
- Researchers, Educators, and policymakers will be benefiting from this study.

7.3 Future research

The focus of the study was to assess the effects of the energy crisis on Nepalese people and businesses. For intelligent solutions, and for more in-depth study, there is the need for further research on the topic in other engineering areas and in the modelling of renewable energy that is suitable for Nepal's domestic and industrial needs. Nepal must focus further on data creation and renewable energy mapping, such as solar mapping, wind mapping, which will help to improve research further.

It could be seen that the battery bank requires a significant capital cost, which overall affects the PV system's economic viability. In the future, large-scale implementation of the PV system study could be done to explore the implementation of other combinations for energy storage systems along with the battery bank, e.g., wind turbine, biomass, hydrogen gas, flywheel and pumped hydro. A hybrid and cheaper energy storage system will prove helpful in harnessing clean and cheap energy. Similarly, the more in-depth study regarding the cost associated with the PV plant could be carried out in the future since almost all the cost assumptions made in chapter 4 are based on quotations provided by Chinese companies. Likewise, for future research, the primary energy consumption to implement a large-scale PV plant can be obtained, and the CO_2 savings compared to other traditional electricity-generating technology could be calculated.

Lastly, a more in-depth study could be undertaken in another energy-intensive industry, and data could be compared in terms of energy loss, capacity utilisation factor, energy conservation, and sustainable production.

7.4 Technical action plan and operation

The proposed action plans and technical operations tabulated below are recommended to implement immediately to reduce system loss and to save the energy. Table 7.1 shows the action plans to reduce the distribution and transmission loss by 10 – 15 per cent. Similarly, Table 7.2 shows the action plans to save energy by energy efficiency measures.

Table 7.1 Action plans and technical operations to reduce system loss

Strategies	Activities	Time Frame	People involved	Target output	Performance Indicators
Regular monitoring of the distribution system	Make Inspection schedule all year round	Every Four months	General Managers, Supervisors and Field Engineers	Number of the inspection schedule	One inspection schedule
	Divide the personnel into four division	Every January	Supervisors	Number of divisions to be created	Four division created
	Assign tasks to each division	Every January	Supervisors	Number of divisions to be given the assignment	Four division to be given the assignment
	Inspection of poles and lines	Every month	Engineers and Skilled Workers	Number of inspections to be done per month	Four collected reports
	Collection of reports	Every month	Supervisors, Engineers and Skilled Workers	Number of collected reports	One inspection per month Four collected reports
Replacement of the ordinary meter with smart meters	Phase wise replacement of ordinary meters to smart meters by giving the preferences to most vulnerable areas where system loss and power theft is very high	Every year	Engineers and Skilled Workers	10- 15 % reduction in system loss	Annual Report of System loss

Table 7.2 Efficient efficiency measures to save energy

Strategies	Activities	Time Frame	People involved	Target output	Performance Indicators
1.Policies on effective measures of energy efficiency improvement in industries	Make Inspection schedule all year round	Every Four months	Ministry of Energy, General Managers.	Number of the inspection schedule	One inspection schedule
	Divide the personnel into four division	Every January	Engineers and Skilled Workers	Number of divisions to be created	Four division created
	Assign tasks to each division	Every January	Engineers and Skilled Workers	Number of inspections to be done per month	Four division be given the assignment
	Inspection of poles and lines	Every January	Supervisors, Skilled Workers	Number of inspections to be done per month	Four collected reports
2.Policies on Energy efficiency measures in Households	Replace Traditional lamp to LED light	Every year	Customers	10 % of electricity save	Report annually
	Phase wise replacement of ordinary meters to smart meters by giving the preferences to most vulnerable areas where system loss and power theft is very high	Every year	NEA Supervisors, Skilled Workers	10 % of electricity save	Report annually
3 Policies of Compulsory Energy Audit provision	Make Inspection schedule all year round	Every year	Engineers and Skilled Workers	15 % of electricity save in industries	Report annually

List of publications

1 R. Poudyal, P. Loskot, R. Nepal, R. Parajuli, and S. K. Khadka, "Mitigating the current energy crisis in Nepal with renewable energy sources," *Renew. Sustain. Energy Rev.*, vol. 116, p. 109388, Dec. 2019.

2 R. Poudyal, "Energy Crisis of Nepal and Renewable Energy." *Vidyut / Electricity half-yearly journal* of State-owned Nepal Electricity Authority; Year 28, Issue 2, pp. 48-51, February 2018.

3 R. Poudyal, S.K. Khadka, P. Loskot, "Understanding Energy Crisis in Nepal Assessment of the country's Energy Demand and Supply in 2016," *IEEE Conf. 2017*, pp. 1 - 4, March 2017.

4 R. Poudyal, R. Parsajuli, P. Loskot, "Energy Efficiency Measures in Nepalese Industries." *Int. Conf. Soc. Nepal. Eng. London*, pp. 105, 2019.

5 R. Poudyal, R. Parsajuli, P. Loskot, "Innovative Technologies, and sustainable practices in the energy sector to overcome the energy crisis of Nepal." *Int. Conf. Soc. Nepal. Eng.*, *London,* pp. 54-59, 2018.

6 R. Poudyal, R. Parsajuli, P. Loskot, "Modelling and Simulation of Solar Photovoltaic Rooftop: Case of Kathmandu." *Int. Conf. Soc. Nepal. Eng. London*, p. 110. 2020.

7 R. Poudyal, "Power Outage of Nepal, Its effect and potential solution by Renewable Energy." *Britain Nepal Academic Council (BNAC) conference* 12 – 13 April 2017 Bournemouth University, UK.

8 R. Poudyal, "Understanding the link between Energy and Air pollution." *Britain Nepal Academic Council (BNAC) conference* 16 – 17 April 2018 Durham University, the UK.

9 R. Poudyal, P. Loskot, "Energy Crisis of Nepal and Sustainable solutions."*1st NRN Global Knowledge Convention,* Kathmandu, 12 – 14 October 2018.

10 R. Poudyal, "Investment opportunity in Nepal's Energy Sector." Nepal *Development Conference 4* Trade and Investment at Nepal Embassy London organised by Nepal Embassy London and Britain Nepal Chamber of Commerce 13- November- 2018.

11 R. Poudyal, P. Loskot, R. Nepal, R. Parajuli, SK. Khadka, Long-term forecast of Nepal’s energy supply and demand. *Renew Sustain Energy Rev*. 2020 under review

12 R. Poudyal, P. Loskot, “The effects of System loss on power outages in Nepal.” Under submission.

13 R. Poudyal, R. Parajuli, S.K. Lal, P. Loskot, “Assessing the opportunities for improving the energy efficiency of cement industries of Nepal- a case of Udayapur cement industry limited.” Energy Efficiency Journal Elsevier 2019 under review.

List of newspaper articles

1 R. Poudyal, "Balance of Power – small hydro, solar, biomass and wind energy are the way to end load shedding soon." The Kathmandu Post, 13-March- 2016.

2 R. Poudyal, "Light Up – could microgrids be an efficient way to overcome Nepal's energy crisis? "The *Kathmandu Post,* 15-October- 2017.

3 R. Poudyal, "Struggle for Power – New Technologies and sustainable practices are needed to overcome the energy crisis," *The Kathmandu Post*, 7- December-2018.

4 R. Poudyal, "Blessed by the Sun," *The Kathmandu Post, 17-* February-2020.

5 R. Poudyal, "Sustainable energy future: Energy mix is the key." *The Himalayan Times,* 29-March- 2018.

6 R. Poudyal, "Australia's Wildfires and climate emergency", *The Himalayan Times,* 17- January- 2020.

7 R. Poudyal, "Are we waiting for Energy Crisis again?" *Nagarik News,22-May-2018.*

8 R. Poudyal, "Hydropower is not only the option of electricity" *Nagarik News, 13-May-2018.*

9 R. Poudyal, "The future of energy in Nepal and its challenges" *Nagarik News,* 26-May-2018.

10 R. Poudyal, "Rising environmental anxiety" *Nagarik News,* 4-October-2019.

11 R. Poudyal, "Energy crisis of Nepal and delayed hydropower projects." *Gorkhapatra Daily,* 4-October-2019.

12 R. Poudyal, "Energy efficiency improvement in Nepal." *Gorkhapatra Daily,* 29- March-2019.

13 R. Poudyal, "World Anxiety over wildfires." *Gorkhapatra Daily,* 2-November-2019.

14 R. Poudyal, "Mega Dam Disaster." *Gorkhapatra Daily,* 4-October-2019.

15 R. Poudyal, "Climate and Environmental teen activist Greta Thunberg," *Gorkhapatra Daily,* 24-January-2020.

Talks and site visits

1. Hosted by Centre for Energy Studies, Tribhuvan University, Institute of Engineering, Pulchowk Campus, Nepal, on 4th July 2018: “Energy Crisis of Nepal and Energy Efficiency Measures in Industries.”
2. Hosted by Hetauda Cement Industries Limited (HCIL) state-owned cement plant of Nepal on June 2018: “Energy Efficiency measures in Nepalese cement Industries – A case of HCIL.
3. Hosted by Udayapur Cement Industries Limited (UCIL) state-owned cement plant of Nepal on June 2018: “Energy Efficiency measures in Nepalese cement Industries – A case of UCIL
4. Hosted by Nepal Engineers Association at Engineers Building, Pulchowk, Lalitpur on 5th July 2018: “Energy scenario of Nepal and its potential sustainable solutions.”
5. Hosted by Vijaya FM Radio 101.6 MHZ, Nepal as a special guest to talk about the Renewable Energy future of Nepal, the opportunities, and challenges.
6. Meeting with the official of Energy Efficiency Department, NEA, and discuss the efficiency measures of NEA. Conducted focus group discussion and data collections.
7. Meeting with official of System loss reduction Department, NEA. Conducted focus group discussion and data collections.
8. Invited Dr Mahabir Pun as a distinguished guest for talk program at Swansea University on Friday, 3rd of November 2017. Mr Pun is the acclaimed Nepalese teacher, social entrepreneur, activist, and winner of an Asian Nobel Prize award ‘Ramon Magsaysay award.’ He is actively working to provide wireless communication in the Himalayas and running Innovative Centre in Kathmandu.

Appendix A

Focus group discussion questions

Dear Respondents,

Please accomplish these questions by filling in the required data on the columns that correspond to your answers of the items. The data or information will then be used by the researcher in determining the "Energy efficiency improvement and sustainability issues in cement production in UCIL, Nepal." Your response to this research is vital for the success of this study and rest assured that this would be treated with confidentiality. Thank you for your full cooperation.

Ramhari Poudyal
PhD researcher
Swansea University, UK

Table 1 Power consumption in various sectors in UCIL

Question No	Questions	Possible answer	Respond
1	How does your firm manage electricity supply during power outages?	Deal with inconvenience Use a Petrol run generator Use a diesel-run generator	
2	Source of Power in UCIL?	National Grid in % Captive Plant in %	
3	Total power consumption in UCIL?	MW kW	
4	Water availability of the UCIL?	KL	
5	Current Problems occurred in UCIL?	Lack of maintenance Lack of electricity	
6	No. of kiln stoppages a day?		
7	Is any job training available?	Y/N	
8	Are any Energy audits and sustainable reports?	Y/N	

Table 2 The annual material and energy requirements at UCIL plant

Material	Volume and pricing	Unit	Source
Limestone		MT	
Iron ore		MT	
Clay		MT	
Gypsum		MT	
Silica sand		MT	
Coal		MT	
Furnace oil/diesel		Kl	
Water		m3/day	
Electricity		KW	
Cement bag/sag		NPR per bag	

Table 3 The average power consumption of each station at UCIL in 2017

Station	Feeder / Station	Per centage
1	Quarry - Limestone crushing & ropeway system	
2	LSS-1 - Limestone receiving, crushing& stacking	
3	LSS-2 - Raw grinding mill	
4	LSS-3 - SP and kiln + LSS-4 – APC and coal mill	
5	LSS-5 - Cement mill and packing	
6	LSS-6 – General use and colony	
	Total	

Table 4 Power consumption at various sectors

S.N.	Department	Installed Power (KW)	Actual Consumed Power (KW)
1	Raw Material Handling		
2	Raw Mill Pyro (B/Silo, Preheater, Kiln & Coller)		
3	Coal Handling		
4	Coal Handling		
5	Coal Mill		
6	Cement Mill		
7	Packing Plant		
8	Utility(Water)		
	Total		

Table 5 Electricity Consumption, Specific Heat, and Thermal Load

Month	Electric Consumption KWh/Ton Cement	Specific Heat Consumption KWh/Ton Cement	Thermal Load in Kiln in GJ/hour – m^2
Jan			
Feb			
Mar			
Apr			
May			
June			
Jul			
Aug			
Sep			
Oct			
Nov			
Dec			

Table 6 Capacity Utilisation and Cement Production

S.No	Year	Capacity Utilisation %	Cement Production Ton/Year
1	2009/10		
2	2011/12		
3	2012/13		
4	2013/14		
5	2014/15		
6	2015/16		
7	2016/17		
8	2017/18		
9	2018/19		

Appendix B

Photographs

SONE/UK conference 2019 with chief guest speaker president of Nepal Engineers Association Prof. Dr Triratna Bajracharya and proceeding editors

SONE/UK conference 2018

Presenting the paper at NRN Global Convention

Certificate received after presenting the paper at NRN Global Convention

Speaking as a guest speaker about renewable energy and efficiency measures with local Vijaya FM 101.6 MHZ

Talk program with Mahabir pun at Swansea University 2018

Talk program at the centre for energy studies, IOE, Pulchwok, campus

Talk program at the centre for energy studies, IOE, Pulchwok, campus

Meeting with NEA's official and receiving Vidyut journal together with NPRs 2000 as author contribution

With NEA's General Secretary and Vice president after the talk program


EEAAT

CERTIFICATE OF PRESENTATION

This is to certify that

Ramhari Poudyal, Shree Krishna Khadka, Pavel Loskot

presented a paper entitled

Understanding Energy Crisis in Nepal Assessment

of the Country's Energy Demand and Supply in 2016

at The 2017 International Electrical Engineering Congress (IEECON2017)

8 -10 March 2017, Pattaya, Thailand

Assoc. Prof. Dr. Athikom Roeksabutr
EEAAT President

Assoc. Prof. Dr. Krischonme Bhumkitti
IEECON2017 General Chair

IEEE Conference certificate 2017

BNAC Conference 16 - 17 April 2018 at Durham University "Understanding the link between energy and Air pollution."

https://www.slideshare.net/rhpoudyal/bnac-conference-1617-april-2018-at-durham-university

BNAC Conference 12 - 13 April 2018 at Bournemouth University

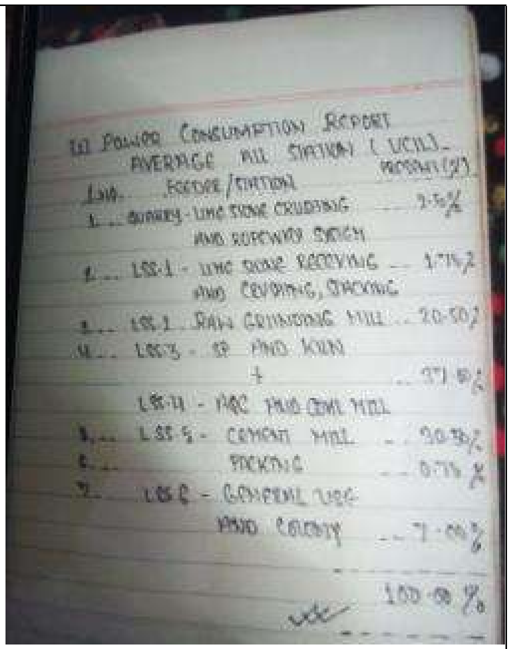
Development submit 4 at Nepalese embassy London with Excellency British Ambassador to Nepal Richard Moris, Foreign Secretary of Nepal, Nepalese Ambassador Dr D.B. Subedi

Presenting the paper in UCIL while in the case study

Presenting the paper in UCIL while in the case study

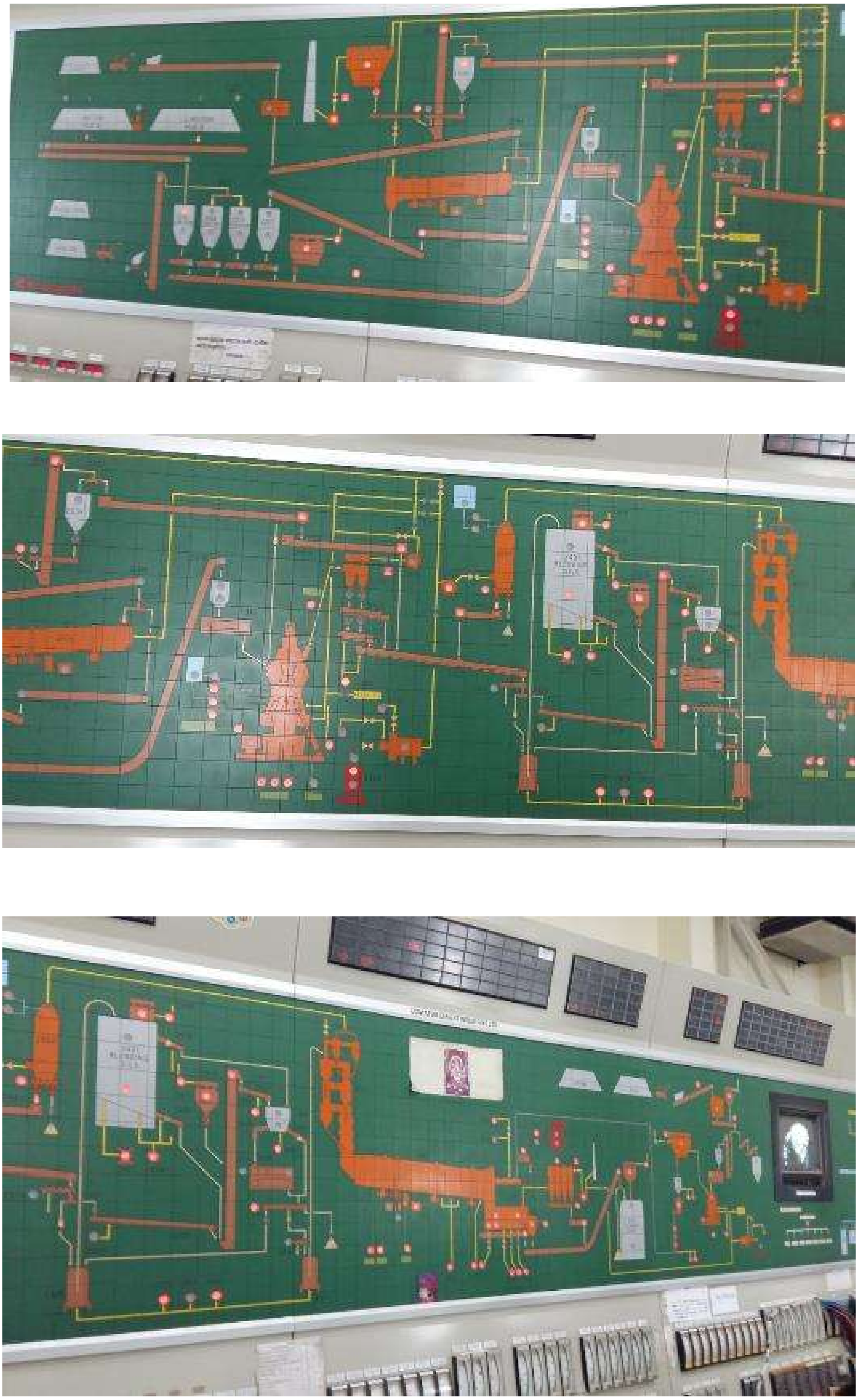
Presenting the paper in UCIL while in the case study

Control Room 2 UCIL with senior engineers Shaligram and Dan Bahadur



POWER CONSUMPTION REPORT
AVERAGE ALL STATION (UCIL
FEEDER / STATION
1. QUARRY - LIME STONE CRUSHING AND ROPEWAY SYSTEM ... 2.50%
2. LSS-1 - LIME STONE RECEIVING AND CRUSHING, STACKING ... 1.75%
3. LSS-2 RAW GRINDING MILL ... 20.50%
4. LSS-3 - SP AND KILN + LSS-4 - AQC AND COAL MILL ... 37.50%
5. LSS-5 - CEMENT MILL ... 30.50%
6. PACKING ... 0.75%
7. LSS-6 - GENERAL USE AND COLONY ... 7.00%
100.00%

Handwritten Log-book of UCIL



Process control of UCIL - Main control room 2

Site visit - UCIL

Site Visit - UCIL

बढ्दै वातावरणीय सन्त्रास

ऊर्जा सङ्कटमा आयोजनाको गोलचक्कर

Published article about " Rising Environmental pollution"

Published article about "Energy crisis of Nepal and delayed projects"

Published article about "Energy efficiency improvement in Nepal"

Published article about "Mega-Dam Disaster"

Published article about "Environmental awareness and Teen Activist Greta Thunberg"

Appendix C

Letters

Government of Nepal

Hon'ble Kumar Khadka
Minister
MINISTRY OF WOMEN, CHILDREN & SOCIAL WELFARE

Ph. : 4200280
Fax: 4200116
Website: www.mowcsw.gov.np
E-mail: mail@mowcsw.gov.np

Private Secretariate
Singha Durbar, Kathmandu

Ref No. 86

Date: May 7, 2017

To whom it may concern

I have learned about the Research effort of Mr. Ramhari Poudyal and his academic advisor Dr. Pavel Loskot from Swansea University who are starting to provide digital technology solutions for our resources constrained communities inside Nepal. It is with my Great pleasure to write this supporting statement to encourage their endeavors in improving the quality of life for Nepalese people in this remote communities where even basic necessities are precious and where must citizens had no chance to ever experiences the internet or any others digital services. I am particularly delighted to know that Swansea University in Wales, UK is engaging in these kind of activities. I will be happy to meet Mr. Ramhari Poudyal and Dr. Pavel Loskot should they visit Nepal in person and discuss with them how to maximize the impact of their project & how to best engage with the relevant institutions in Nepal.

Yours Sincerely

Hon. Kumar Khadka
Minister
Ministry of women, Children & Social welfare

मा. कुमार खड्का
मन्त्री
महिला,बालबालिका तथा समाज कल्याण मन्त्रालय

उदयपुर सिमेण्ट उद्योग लिमिटेड

(प्रधान कार्यालय-त्रियुगा नगरपालिका-०६,जलजले,उदयपुर)

UDAYAPUR CEMENT INDUSTRIES LIMITED

(नेपाल सरकारको पूर्ण स्वामित्व प्राप्त)

एक्सटेन्सन फोन नं -०३५-४११०७०,४११०७१
०३५-४११०७२(खरिद),०३५-४११०७३ (बिक्री)
e-mail info@ucil.org.np
procurement@ucil.org.np
sales@ucil.org.np, account@ucil.org.np
खानी मुकौरा,उदयपुर,फोन नं ०३५-४२१४०५

Ref. No :

Date: 04 August,2018

Subject :- <u>A Letter of Authorization to use the provided Company data in research publication.</u>

To Whom It may concern.

We hereby grant the permission to Mr.Ram Hari Paudel, PhD Student at Swansea University in the United Kingdom, to use the data sets we have provided to him about the UCIL. Cement Company in jaljale.,Nepal to perform analysis of these data, and subsequently publish in this analysis together with the corresponding data as a research publication in some reputable research Journal of his choice as part of his PhD research work.

We wish success in his academic carrier.

Yours

Surendra Kumar Paudel
Genaral manager
UCIL Nepal