Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in the Nepali Mountains

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Abstract

Nepal is a poor mountainous country with low levels of energy access and high vulnerability to climate change. Difficult geographic terrain, scattered settlements and the lack of physical infrastructure in the Nepali mountains exacerbate challenges in building modern energy infrastructure on the one hand and increase vulnerability on the other. Decentralised Renewable Energy Technologies (DRETs) have the potential to play roles in addressing both the issues of modern energy access and climate change adaptation. However, Nepal's renewable energy policy is solely guided by the goals of energy access and largely overlooks the climate adaptation potential of renewable energy technologies. In this context, this study examines the climate change adaptation benefits of DRETs in rural mountains of Nepal.

The study applies a geographical approach and draws from both social and natural science methodologies to explain local social, technological and environmental interrelationships. The sustainable livelihood approach is integrated with ideas on broadening livelihood resilience to examine the suitability of DRETs as an effective tool for climate change adaptation. The study uses both quantitative and qualitative primary data collected through a questionnaire survey of 331 households, 9 focus group discussions and 20 expert interviews to meet the study objectives. Case studies are drawn from three remote villages in the mountains of Nepal and their application of five commonly used DRETs, namely solar photovoltaics, solar-wind micro-grid, micro-hydro, improved cooking stoves and biogas.

The communities in the study sites are experiencing significant climate change. Increasing temperatures, increasing variability in monsoon onset and withdrawal, decline in water availability, increases in insect pests and invasive species, changes in flowering, fruiting and relocation of species, and changes in the frequency of natural hazards were identified as major environmental changes observed in the case study areas. Those environmental changes have a broad range of impacts on local lifestyles, production systems and livelihoods. Local communities are not effectively equipped to deal with such changes, reflecting generally poor adaptive capacities and high levels of vulnerability.

DRETs are contributing to reduced climate vulnerability by directly confronting climate risks and by improving socio-economic factors of vulnerability in the case study areas. For example direct adaptation support is offered by solar PV through the operation of early warning system to minimise losses to disasters, by solar-wind micro grid through the powering of electric fans and fridges to manage higher temperatures, and by micro-hydro

projects through irrigation to address an increasingly erratic monsoon. DRETs also contribute to improving economic productivity, education and health services, social trust and forest resources in the study areas, which help to strengthen local capacities to adapt to the observed environmental changes.

The findings of this study demonstrate that development activities can significantly contribute to climate change adaptation while simultaneously achieving socio-economic improvements. This research advances the concept of sustainable development by highlighting the need to mainstream development with responses to climate change, and demonstrating that DRETs are an effective tool to do so.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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Govinda Pathak   Date

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Acronyms

AEPC	Alternative Energy Promotion Center
CBS	Central Bureau of Statistics
CER	Certified Emission Reductions
CFUG	Community Forest User Groups
DFID	Department for International Development
DHM	Department of Hydrology and Meteorology
DRETs	Decentralised Renewable Energy Technologies
GHG	Greenhouse Gases
HKH	Hindu Kush Himalaya
ICS	Improved Cooking Stoves
IFAD	International Fund for Agricultural Development
KW	Kilowatts
kWh	Kilowatt-hour
LED	Light Emitting Diode
LPG	Liquefied Petroleum Gas (LPG)
m	Meter
m^3	meter cube
masl	Meter above sea level
MOEWRI	Ministry of Energy, Water Resource and Irrigation
MOFE	Ministry of Forest and Environment
MW	Megawatts
NEA	Nepal Electricity Authority
NGO	Non-Government Organisation
OECD	Organisation for Economic Co-operation and Development
PHC	Primary Health Center
PV	Photovoltaics
SDG	Sustainable Development Goals
SHS	Solar Home System
UNFCCC	United Nations Framework Convention on Climate Change
VET	Vocational Education and Training
W	Watt

Dedication

This dissertation is lovingly dedicated to my

mom Tara Devi Pathak and dad Keshav Prasad Pathak

who instilled in me the virtues of integrity and perseverance.

1 Introduction

1.1 Introduction

This study evaluates the potential of Decentralised Renewable Energy Technologies (DRETs) as an important measure of climate change adaptation in rural mountain communities in Nepal. In particular, the study examines the direct and indirect climate adaptation benefits of DRETs. To achieve the aim, this study analyses climate variability and its impacts on livelihood systems and assesses the role of DRETs in directly dealing with the observed and perceived climate risks and in indirectly contributing to climate adaptation by improving the livelihood systems. The study is based on case studies of five most common household DRETs: improved cooking stoves (ICS), solar photovoltaic (PV), biogas, micro-scale hydroelectricity generation schemes (micro-hydro) and solar-wind micro grids in Nepal (AEPC 2018).

Climate change is one of the most critical issues today. Increasing anthropogenic emissions of greenhouse gases (GHG) are the leading cause of significant changes in climate systems (IPCC 2018). Mitigation addresses the root cause of climate change by reducing the sources or enhancing the sinks of greenhouse gases (ibid). While mitigation may curb GHG emissions, many of those gases already in the atmosphere will continue to persist for hundreds of years (Stager 2012), affecting the current and future generations (IPCC 2013). Therefore, adaptation will be essential, as mitigation alone is not enough to deal with the consequences of climate change (Denton et al. 2014).

Climate adaptation involves actions in response to actual or expected climate stimuli to moderate harm or to exploit beneficial opportunities (IPCC 2018). Throughout history, people have adjusted to their environments and climate by developing and changing their lifestyles, practices, technologies, cultures and livelihoods (Massey 2013). However, climate change is likely to force existing societies into experiences of unprecedented changes in temperature, precipitation and extreme weather events, generating the need to explore a range of adaptation measures. Against such a background, the respective roles of different DRETs in facilitating climate change adaptation are analysed in the context of changing climate within the remote mountains of Nepal.

This chapter introduces the research problems, the rationale behind the research, outlines the research goals, and puts forward the key research questions. The problem statements present the conceptual basis for the study by providing background on DRETs and their role in facilitating energy access and achieving development goals. The identified gaps in the contemporary research are introduced to justify the study and to help frame the research objectives and questions. Finally, the last section provides the justification for site selection and the thesis structure.

1.2 Background

Access to clean, affordable, reliable and modern energy is key to meeting basic needs, social wellbeing and achieving economic growth and development (Groh 2014; Modi et al. 2005; Ouedraogo 2013; Ritchie & Roser 2019; UNDP 2015). McCulloch and Zileviciute (2017) note that the absence of electricity is a serious constraint to growth in developing countries. Duflo et al. (2008) argue that the burning of solid fuels and traditional biomass have detrimental impacts on health, well-being and the productivity of individuals. Recognising the significance of modern energy for sustainable development, the United Nations have listed "ensuring access to affordable, reliable, sustainable and modern energy for all" as one of the Sustainable Development Goals (UNDP 2015). Despite this, in 2018, around 860 million people globally still did not have access to electricity and 2.6 billion people did not have access to clean cooking fuel (IEA 2019b).

Providing modern energy access to remote communities is challenging. Among other issues, there are often: i) high costs involved in expanding energy infrastructure across difficult terrain; ii) poor abilities to pay to compensate for supply costs; and iii) a lack of well-functioning institutional structures to oversee funding, implementation, maintenance and operation of large-scale infrastructure projects (Parajuli 2011; Thompson 2017; World Bank 2018a). In addition to those potential constraints on energy development, poor countries like Nepal often face supply shortages within existing core networks (Poudyal et al. 2017; Shrestha 2010), which compel governments and businesses to first cater to meet existing demand, rather than expanding grid systems to reach new consumers in remote places.

DRETs such as solar PV, solar-wind micro grid, micro-hydro, biogas and ICS have emerged as suitable and popular options to bypass many of the barriers to centralised energy supply systems (Mainali & Silveira 2012; Oyedepo et al. 2018; Sharma 2018;

Thompson 2017). DRETs are small-scale renewable energy technologies that generate energy near the places of consumption, either by standing alone or connecting to other energy sources to share resources (Vezzoli et al. 2018). According to the description provided by AEPC (2019), solar PV is a renewable energy system that generates electrical power by converting solar radiation into direct current electricity. Solar PVs for households are generally called solar home systems. Wind energy technology produces electricity by converting the kinetic energy of wind into electrical energy. Micro-hydro, an abbreviated form for micro-scale hydroelectricity scheme generates electricity by converting the kinetic energy of running water into electrical energy. Electricity producing DRETs such as solar PV, wind and micro-hydro systems generally are also linked to inverters and batteries in order to store electric power for later use. Biogas is an eco-friendly technology that produces combustible Methane (CH_4) gas by anaerobic decomposition of household organic waste. The combustible gas provides an economical substitute to household cooking and heating fuel such as firewood, kerosene and liquefied petroleum gas. Improved cooking stoves (ICS), as the name suggests, are an efficient cooking technology with an improved design to reduce firewood consumption and indoor air pollution by increasing the efficiency of biomass combustion. A detail description of the DRETs discussed above is available in Chapter six.

DRETs have the potential to effectively supply energy for remote off-grid communities because they can be set up independently, with minimum capital and technical expertise to provide clean and reliable energy (Islar et al. 2017; Kayastha & Ale 2015; Mainali & Silveira 2013; Oyedepo et al. 2018; Surendra et al. 2011). Although in many cases, the energy supplied through electricity grids linked to large power plants is cheaper than the energy produced through DRETs (Schnitzer et al. 2014), the expense of setting up DRETs can often be less than grid expansion into remote areas (IEG 2008; Mainali & Silveira 2013; Narula et al. 2012). Sharma (2018) also suggests that in spite of the high initial establishment costs, DRETs can prove to be more competitive than traditional centralised energy distribution systems in the long run, as the fuel input and maintenance costs can be relatively low. Moreover, the cost of renewable energy technologies themselves is dropping swiftly (Chu et al. 2017; Marcantonini & Labandeira 2016), and there are strong indications that DRETs will easily compete with conventional energy sources in many places in the near future (IEA 2015b; Neuhoff et al. 2018).

The role of DRETs in addressing energy access, reducing poverty and achieving sustainable development is well documented (Colombo et al. 2013; Mulugetta et al. 2018;

Nnaji et al. 2010; Ogundipe 2018; United Nations 2018; Yadoo & Cruickshank 2012). Sharma (2018) argues that decentralised energy systems for developing countries not only empower local communities but also enhance their capabilities by facilitating infrastructure development to meet their basic needs. As a result, those technologies are considered by many scholars as the most promising model to provide sustainable energy for all (Klein 2015; Rifkin 2011; Vezzoli et al. 2018). Although there are clear and overarching benefits of DRETs in reducing poverty and addressing various dimensions of sustainable development, to date there has been little discussion on DRETs' role in local climate change adaptation. Renewable energy technology is generally viewed as a climate mitigation tool or a mechanism for energy security and development (Johansson 2013; Ölz et al. 2007). While those benefits are manifest, even in a country already experiencing climate change impacts such as Nepal, there has been little exploration of the full potential of DRETs in providing adaptation benefits and building resilience to climate change.

1.3 Conceptual basis for the study

Nepal is a lower-middle income country with one of the lowest levels of energy consumption in the world. According to the International Energy Agency (IEA), Nepal's energy consumption was only 0.41tons of oil equivalent per capita in 2015 while that of a developed country like Australia was 5.30 tons of oil equivalent per capita (IEA 2015a). Traditional biomass accounted for the majority of the Nepalese energy supply (72.8%) in 2018, followed by oil (17.5%), coal (5.95%) and electricity (3.6%) (IEA 2018b). Without any proven petroleum reserves, Nepal imports all its requirements from its southern neighbour, India. High imports of fossil fuel, combined with poor exports have contributed to the burgeoning trade deficit, which has serious implications for the national economy (Bastola & Sapkota 2015). Still, the total installed electricity generation capacity stands at only 1,182 MW for a country with a population of 29 million (NEA 2019). Reliable and adequate supplies of electricity and petroleum are still a major concern (Poudyal et al. 2019) as it continues to deter investments and diminish economic growth (Timilsina et al. 2018). Beyond those limitations, approximately 13% of the population cannot access any electricity source and 22% of the population are still not able to access the national electricity grid (NEA 2019).

Providing modern energy access in Nepal is exacerbated by difficult mountainous terrain, lack of transport infrastructure, scattered settlements, lack of capital and lack of affordability (Parajuli 2011; Thompson 2017). The changing climate and associated risks further worsen these problems. Low levels of development coupled with complex mountainous topography makes Nepal one of the highly vulnerable countries to climate change (Government of Nepal 2016; NAPA 2010; Shrestha & Aryal 2011; Wester et al. 2018). A national level study undertaken for the preparation of National Adaptation Program of Action to Climate Change (NAPA) in Nepal found 1.9 million people highly vulnerable and 10 million people increasingly at risk to climate change impacts (NAPA 2010). Climate change is expected to impact many sectors, and especially agriculture and food security (Bocchiola et al. 2019; Rasul et al. 2019); water and energy (Mukherji et al. 2018); tourism (KC & Thapa Parajuli 2015; Nepal 2011); and biodiversity conservation (Bhattacharjee et al. 2017).

In such a national context, a new approach to energy planning is crucial. An energy system that simultaneously addresses the needs of sustainable development, climate mitigation and climate adaptation is essential (Venema & Rehman 2007). There are strong arguments being presented that to achieve multiple goals, policy makers need to think beyond the least-cost options and conventional energy wisdom (Mulugetta et al. 2018). Sustainability experts and scholars are recommending a paradigm shift from top-down, conventional western style energy development models to sustainable, low-carbon and self–sufficient energy systems (Bhattacharyya 2007; Goldthau 2014; Johansson & Goldemberg 2002; Klein 2015; Nepal & Jamasb 2012; Sen et al. 2016; Sovacool et al. 2016; Vezzoli et al. 2018). Scholars have argued that an alternative must evolve to respond to the current socio-ecological risks of the Anthropocene (Bardsley 2015; Bardsley & Wiseman 2016; Beck 2010). There could be several approaches to achieve the alternative including one that involves the development of new technologies and processes to mitigate the impacts of the current unsustainable level of industrial production and consumption (Bardsley 2017).

It has been proposed that renewable energy technologies based on abundantly available hydrological and other renewable energy sources could be the best choice for sustainable energy planning, energy independence and low-carbon development pathways in Nepal (Bhandari et al. 2017; Central Bureau of Statistics 2012; Dhakal et al. 2019; Nepal & Paija 2019; Poudyal et al. 2019; Surendra et al. 2011). DRETs such as solar PV, wind turbines, micro-hydro, biogas, and ICS could be a suitable option to bypass many of the barriers to the centralised energy supply system (Mainali & Silveira 2012; Oyedepo et al. 2018; Sharma 2018; Thompson 2017). Decentralised renewable energy technologies may best serve the purpose for many communities as they can be set up independently in rural areas with low level requirements for capital or technical expertise (Islar et al. 2017; Kayastha &

Ale 2015; Mainali & Silveira 2013; Surendra et al. 2011). DRETs in remote regions have shown themselves to be more reliable and resilient than the centralised system of energy distribution (Hussain et al. 2019; Vezzoli et al. 2018). A decentralised system offers independence and energy security to local communities (Sharma 2018). DRETs are also potentially less damaging to environment because they produce either none or much fewer greenhouse gases emissions in comparison to conventional energy sources (Vezzoli et al. 2018; Wassie & Adaramola 2019). In addition to the environmental benefits, DRETs provide socio-economic benefits (Colombo et al. 2013; Vezzoli et al. 2018) and have the potential to support households and communities to adapt and build resilience to climate change (Ley 2017; Stone 2013; Venema & Rehman 2007). Thus, DRETs can be an important driver for sustainable energy planning and climate-resilient development.

Nepal's energy policy however still barely discusses the multiple benefits of DRETs. National renewable energy policy introduced in 2006 as 'Renewable Energy Policy 2006' is driven by the goal of energy access and is limited in scope mostly to rural areas (AEPC 2016; Steinbach et al. 2015). The latest update, "Renewable Energy Subsidy Policy 2016", reiterates the earlier objective of providing energy access and still falls short of acknowledging other potential advantages of DRETs. Although recent policy documents such as Nationally Determined Contributions (2016), the draft Low Carbon Economic Development Strategy (2015) and Climate Change Policy (2019) have acknowledged and prioritised DRETs for climate mitigation (Government of Nepal 2019; Shrestha & Dhakal 2019), DRETs' potential roles for climate adaptation are still being overlooked. If the comparative adaptation benefits of different DRETs could be clarified through research, the country could aim to simultaneously invest into systems that both generate clean sustainable energy and addresses climate risks that communities are already facing.

1.4 Research gap

Research on climate change impacts, vulnerability and adaptation has grown exponentially in recent years (Haunschild et al. 2016). Despite a rapid rise in 'climate change adaptation' scholarship in the past decades, there is still a notable lack of published work on effective adaptation interventions at local levels (Lwasa 2015). The literature on the potential for renewable energy technologies to support climate adaptation and generate local resilience to climate variability is even more limited (Hills et al. 2018; Ley 2017; Perera et al. 2015; Stone 2013). A systematic review by Perera et al. (2015) concludes that contemporary research demonstrating the link between energy access through renewable energy technologies and climate change adaptation is very rare. Ley (2017) also notes that the research on renewable energy technologies mainly focus on their impacts on poverty reduction and sustainable development, and largely miss examining opportunities for generating climate change adaptation advantages. Perera et al. (2015) have called for country-specific field research, especially in least developed countries, focusing on policy and institutional contexts to identify the link between energy access and climate change adaptation.

In the Nepalese context too, there is a clear lack of research discussing the role of DRETs in reducing vulnerability, building resilience and managing climate risk. While there has been an increase in the study of climate impacts and adaptation measures in recent years in different sectors such as: social-ecological systems (Pandey & Bardsley 2015), agriculture (Joshi & Joshi 2019; Khanal et al. 2019; Prasain 2018); water (Poudel & Duex 2017); food security (Poudel et al. 2017); health (Regmi et al. 2016); gender (Bhattarai et al. 2015; Onta & Resurreccion 2011); migration (Banerjee et al. 2019); forestry (Niraula & Pokharel 2016; Silwal et al. 2019); rural livelihoods (Gentle et al. 2018; Sujakhu et al. 2019) local studies on DRETs as tools of climate adaptation remain limited. Likewise research on the topic of ‘Renewable Energy’ also often focuses on national scenarios (Kayastha & Ale 2015; Parajuli et al. 2014; Surendra et al. 2011) or their suitability to address energy access (Mainali & Dhital 2015; Mainali & Silveira 2013), energy poverty (Gurung et al. 2013; Parajuli 2011) and energy crisis (Gautam et al. 2015; Poudyal et al. 2019) without discussing its implications for local climate change adaptation. Considerable research has analysed the local impacts of DRETs, however it mainly focuses on direct environmental, socio-economic and developmental impacts. For example, Meeks et al. (2019) have discussed the environmental and socio-economic impacts of biogas. Anup et al. (2011) have analysed the impacts of micro-hydro and Katuwal and Bohara (2009) have evaluated the impacts of biogas on rural livelihoods. Other studies have generally focused on developmental impacts of DRETs (Alexander 2011; Dhakal et al. 2018; Nepal 2012; Sapkota et al. 2013). While the socio-economic impacts of DRETs can be interlinked with adaptive capacities, the findings from such studies are largely generic and do not generate concrete evidence to inform adaptation policies and actions.

A handful of studies (Bajracharya et al. 2014; Gippner et al. 2013; Sapkota et al. 2014; Shrestha 2014) have attempted to demonstrate links between DRETs and climate change adaptation in Nepal. However, these studies either do not cover the broader range of DRETs or fail to establish a proper link between DRETs and climate change adaptation.

For example, Gippner et al. (2013) discuss climate adaptation benefits of micro-hydro, but do not evaluate other common DRETs such as solar PV, solar wind hybrid, biogas and improved cooking stoves. Shrestha (2014) discusses the climate mitigation and adaptation benefits of biogas only. Sovacool et al. (2016) note that there is a need to focus on a bundle of energy systems rather than one particular technology in energy-related research. Sapkota et al. (2014) discuss climate adaptation benefits of all popular DRETs in Nepal, but focus mainly socio-economic benefits with no evidence directly linking DRETs to the generation of adaptive capacity or resilience to climate change. Bajracharya et al. (2014) touched upon climate adaptation benefits in a report prepared for the Alternative Energy Promotion Centre (AEPC), which also discusses the mitigation benefits of DRETs. However, the report simply reviews previous studies from different parts of the world and does not particularly focus on the Nepalese context and climate issues. Realising the need for local research, Bajracharya et al. (2014) urge for greater knowledge creation through further studies to understand the nexus between DRETs and climate adaptation in Nepal.

The cases discussed above clearly highlight the need for a study that critically evaluates and documents the adaptation benefits of common DRETs in Nepal. To fulfil this gap, this study aims to generate scientific and empirical knowledge within the field of DRETs and climate adaptation with a focus on opportunities for climate-resilient development. The study applies quantitative and qualitative approaches to evaluate i) local climate risks and their associated impacts, and ii) the roles of DRETs in directly managing the risks and building capacity to deal with the adverse impacts of climate change in the study sites.

The findings from the study will have significant policy and practice implications in relation to climate change, sustainable energy planning and climate-resilient development in Nepal, the home country of the researcher. It is hoped that this study will inform decision-making in Nepal, as well as in other developing countries, with the potential to integrate DRETs into future energy and climate policy planning for multiple benefits. The upscaling and mainstreaming of DRETs has the possibility to lead to a paradigm shift in the energy sector not only in Nepal, but also in other developing countries looking to avoid the constraints and mistakes of the conventional, dominant, fossil fuel based energy development model (Fankhauser & Jotzo 2018). Greater integration of DRETs in mainstream energy planning could also lead to self-sustaining and low-carbon development pathways in marginal regions of the high-income countries. To achieve these goals, this study has a number of key objectives and specific research questions.

1.5 Research objectives and research questions

1.5.1 Research objectives

The main objective of this study is to evaluate and document the adaptation benefits of decentralised renewable energy technologies in rural communities in the mountains of Nepal. The specific objectives of the study are:

i. To investigate the key drivers of environmental change, and the risks and impacts of this change on local livelihoods in rural mountain communities from a socio-ecological perspective.

ii. To assess the climate adaptation benefits by evaluating the direct role of decentralised renewable energy technologies in addressing climate risks and associated impacts.

iii. To assess the indirect benefits of decentralised renewable energy technologies in climate adaptation by evaluating their impacts on livelihoods through broader changes in ecological and socio-economic conditions.

1.5.2 Research questions

In order to achieve above objectives, the study addresses the following specific research questions.

i. What is the status of local livelihoods in the study area?

ii. What is the extent of change in key climatic parameters in the study area?

iii. How are locals perceiving climatic trends and experiencing the impacts of environmental change on their livelihoods?

iv. What is the level of access to decentralised renewable energy technologies in the study sites?

v. How are decentralised renewable energy technologies directly contributing to addressing climate risks and associated impacts?

vi. How are DRETs contributing to improvements in livelihoods through broader changes in ecological and socio-economic conditions?

1.6 Justification of the focus on the Nepali mountain regions

Topographically, Nepal is broadly divided into three ecological zones from south to north: i) relatively flat plains called 'Terai or Madhes', ii) mountains called 'Pahad', and iii) the Himalayas called 'Himal' (Dahal 2010). The variation in topography results in highly varied climatic conditions and corresponding differences in rural livelihoods in the three different regions. This study focuses on rural mountain communities [see section 3.5.2] because of the following specific reasons:

i) The mountains in Nepal are characterised by terrain, which is difficult to traverse, sparse settlements, and widespread poverty, which collectively impedes the process of providing modern energy access (Cosic et al. 2017; Parajuli 2011; Thompson 2017). Poor energy access situation in the mountains has prompted the implementation of several DRET projects such as micro-hydro, solar PV, solar-wind micro-grid, biogas and ICS through the national government's "Rural Energy Policy 2006". The abundance of DRET projects provide significant contemporary case study opportunities.

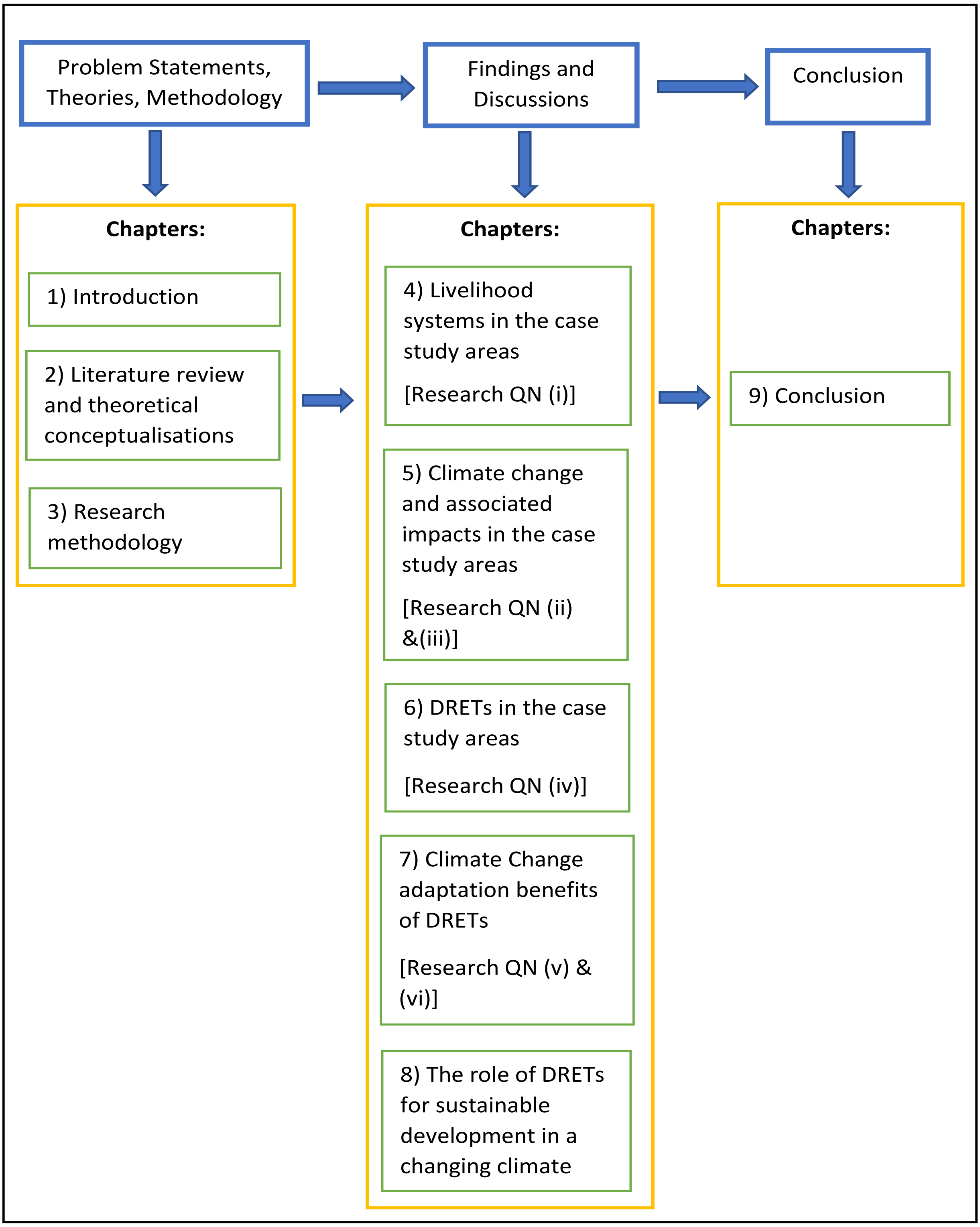
ii) Apart from energy, difficult topographic conditions hinder the development of other crucial infrastructure such as transport and public services thus inhibiting economic growth (Cosic et al. 2017; Metz 1995). The mountain region has higher poverty (42.3%) in comparison to the Terai (23.4%) (Asian Development Bank 2017). Difficult topography combined with the high incidence of poverty also makes communities living in the mountains highly vulnerable to the impacts of climate change (Government of Nepal 2016). Higher levels of vulnerabilities in the mountains provide good opportunities to undertake comparative case studies of the direct and indirect impacts of DRETs in reducing vulnerability and supporting climate change adaptation.

1.7 Organisation of the thesis

This thesis is organised into three sections and nine chapters as illustrated in Figure 1.1. The first section discusses the foundation of the study with three chapters: 1) Introduction, 2) Literature review and theoretical conceptualisations, and 3) Research methodology. This first chapter has introduced the research theme, and provided problem statements, the research gap, research goals, and the outline of the thesis. The second chapter reviews the relevant literature, discusses key theories and concepts and provides a framework for the study. Chapter three outlines the methodological approach adopted to achieve the goals set by the study.

The second section discusses the findings and implications of the study in five chapters: 4) Livelihood systems in the case study areas, 5) Climate change and associated impacts in the case study areas, 6) DRETs in the case study areas, 7) Climate change adaptation benefits of DRETs and 8) The role of decentralised renewable energy technologies for sustainable development in a changing climate. Chapter four discusses the livelihood systems by evaluating five livelihood capitals. Chapter five investigates climate variability and their associated impacts on local livelihoods using physical science (analysis of meteorological observations) and community perceptions. Chapter six provides information on the installed DRETs in the studied communities. Chapter seven discusses and provides examples of how DRETs directly address the observed environmental change and associated impacts; and how DRETs contribute to improving broader socio-ecological conditions and thereby indirectly supporting climate adaptation. Chapter eight discusses the implications of this research in relation to climate change, sustainable energy planning and climate-resilient development. Together, chapters four, five, six, seven and eight critically analyse local environmental change, the roles of DRETs in addressing climate change vulnerability and the suitability of DRETs for climate resilient development. Finally, chapter nine concludes the study by synthesising key findings and discussing the contributions of this research.

Figure 1.1 Diagrammatic representation of the thesis structure



2 Literature review and theoretical conceptualisations

2.1 Introduction

This chapter reviews the key concepts and theories relevant to the research questions and provides a conceptual framework for the analytical approach. The aim of the literature review is to critically evaluate the existing literature, deepen understanding, identify gaps and highlight areas for further research. This chapter introduces and reviews literature on energy access, development, climate change and approaches to mainstreaming climate change with development, which together form the major conceptual and theoretical components of this research. In doing so, the chapter explores how the ‘environment-development nexus’, the ‘integration of climate change with development’, and the ‘energy-poverty-development nexus’ have been conceptualised in the literature. The chapter then reviews the existing empirical knowledge of renewable energy and climate change in the Nepalese context. The chapter further explores how climate change risk has been theorised by reviewing the concept of vulnerability and adaptation to climate change. At the end, the chapter provides a conceptual framework based on the discussed theories and concepts to investigate the climate change adaptation benefits of decentralised renewable energy technologies (DRETs).

2.2 Conceptual and theoretical underpinnings

2.2.1 The Environment-Development nexus

Up until mid-twentieth century, the mainstream development theories and models focused on economic growth and rarely addressed the environmental and ecological concerns (Haque 2000). For example, development and economic growth theories such as Classical, Neoclassical, Keynesian, and Post-Keynesian theories within the conservative tradition and the modernisation theories emphasised economic growth and wealth accumulation. However such theories were largely indifferent to the environmental cost of economic production (Haque 1999; Preston 2010). Similarly, radical development theories such as Classical Marxist and Neo-Marxist theories also overlooked the cost of environmental degradation and ecological damage while primarily dealing with modes of production, production relations and class structures (Haque 2000). The development paradigm up until the end of World War II focused on the goal of economic growth, especially for achieving higher per capita income (DFID 2008; Marglin & Schor 1990). The focus was reasonable given the need for recovery after years of devastation of the western economies and the need to lift the economies of newly emerging independent countries out of decades long deprivation of colonial rule; yet the approach has had massive environmental impacts.

Since mid-twentieth century however, there has been a realisation and emergence of environmental and ecological concerns from socio-economic development. Environmental crisis like London's toxic smog of 1952 and air pollution crisis of the 1960s due to haphazard industrialisation caught the world's attention and gradually shifted perspectives on the nature and the outcomes of development (Davis 2002). The shift paralleled scholarly debate linking environment and development. With the publication of Rachel Carson's 'Silent Spring' in 1960, the debate intensified. Carson (1962) reported the potential damage of indiscriminate use of pesticides on the environment to the public. This led to a ban on DDT for agricultural use in the USA and later inspired an environmental movement that led to the creation of the US Environment Protection Agency (Paull 2013). Garrett Hardin's 'The Tragedy of the Commons' discussed degradation and depletion of resources as a result of uncontrolled access to shared natural resources (Hardin 1968). Hardin (1968) argued excessive individual activity aimed at pursuing personal gain without considering the costs of exploitative actions could risk the carrying capacity of common resources. In other words, individuals acting rationally in their self-interest are trapped in a situation where they exploit common resources until they become degraded or extinct. However, Ostrom (1990) challenged the view envisaged in the 'Tragedy of Commons' by suggesting that institutional arrangements can enable effective management of natural resources. She underscored the significance of common property regimes for livelihoods by suggesting that individuals in a community can design a livelihood system that enables them to interact with environment while ensuring its sustainability (Agrawal & Gupta 2005; Ostrom 1990; Ostrom et al. 1999).

Despite the possibility for sustainable management of the environmental commons, scholarly concern about the exploitation of natural resources for economic growth continued. Significant among them was the study from The Club of Rome entitled 'The Limits of Growth' (Meadows et al. 1972), which highlighted the potential perils of anthropogenic activities on the planet Earth (Kanninen 2013). Further concerns led to the notion that human wellbeing extends beyond economic growth and into social and political realms. Gradually, the scope of research and associated development paradigm started expanding beyond the sole focus on economic growth (United Nations 2010). Questions on the meaning and development measures were raised (Seers 1969, 1979). Amartya Sen's works on development and capability widened the scope of development discourse further (Ibrahim & Tiwari 2014; Sen 1981, 1990). Successively, the concepts of equity, capability and sustainability emerged as a means to conceptualise improvements in development as goals in themselves (Chambers & Conway 1992). The World Commission on Environment and Development identified the need to focus on sustainable development and defined it as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs as sustainable development' (Brundtland 1987, p.8). The concept of sustainable development focuses on equity, economic growth and environmental protection. As a result of this, some parts of the world started undertaking a shift in development activities away from maximising productivity, profits and income to balancing economic efficiency with social and environmental sustainability (OECD 2001). However, pursuing environmental sustainability policy goals was challenging for many governments as it generally involved trade-offs between economic prosperity and environmental protection for future generations (Romeiro 2012).

Researchers with an intergenerational justice approach focused on the use of resources in ways that generated positive outcomes for future generations. The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988. In June 1992, a comprehensive strategy to address development and environment nexus through United Nations Framework Convention on Climate Change (UNFCCC) was agreed at the UN's Earth Summit in Rio de Janeiro. The signing of the subsequent protocol to the UNFCCC at the Kyoto conference in 1997 set internationally binding emissions reduction targets for rich countries. Into the new millennium, 191 nations also set the Millennium Development Goals for 2015 at a United Nations summit in 2000. The Millennium Development Goals committed nations to a new global partnership with eight goals and 21 targets to lift populations from the abject and dehumanizing conditions of extreme poverty. The subsequent Climate Change Adaptation Policy Framework published by United Nations Development Program (UNDP) in 2004 recognised climate change adaptation at international, national and local levels as a necessary component of sustainable development. The Framework's initial focus at national and international levels was instrumental in assisting the least developed countries to prepare National Adaptation Programmes of Action (NAPA) to respond to climate change (Adger et al. 2003; Lim et al. 2004). Nepal including other 39 LDCs prepared a NAPA based on the guidelines set by

Least Developed Countries' Expert Group (LEG) with assistance from the UNDP (NAPA 2010).

In 2012, twenty years after the Rio Conference, the United Nations again convened an Earth Summit in Rio de Janeiro, Brazil. The summit took place in the context of changing consumer life-styles and increasing severe stress on environmental resources, especially in the aftermath of the global economic crises of 2008-9. It was evident that a business-as-usual approach was not the right way forward. The Earth Summit focused on a stronger framework for sustainable development, incorporating the need for green economic growth. However, it was challenging for poor countries to imagine the pursuit of development goals without exploiting cheap fossil fuels, which much of the world conceded would create unparalleled environmental concerns (Bidwai 2012). The solution to the problem was the framing of the concept of low-carbon growth, with associated processes of adaptation to changing climatic and environmental conditions. In response, the Global Commission on the Economy and Climate (GCEC) was set up in 2013 to calculate and communicate the benefits and costs of actions on climate change. The commission was instituted with the objective of finding workable solutions to simultaneously achieve economic prosperity and combat climate change.

In 2015, Sustainable Development Goals (SDGs) substituted the Millennium Development Goals. The SDGs are a collection of 17 global goals in areas including poverty, hunger, health, education, climate change, gender equality, water, sanitation, energy, environment and social justice that aim to end poverty, protect the planet and ensure prosperity for all as part of a new sustainable development agenda (United Nations 2015). Each goal has specific targets (169 targets in total for the 17 goals) to be achieved by 2030. Later in the same year, the twenty-first Conference of the Parties (COP 21) to the UNFCCC adopted the Paris Agreement. That agreement is considered to be a turning point in global efforts to deal with the climate change and chart a new path to a low-carbon, climate-resilient development (Kinley 2017) . The signatory nations agreed to hold the increase of global temperature rise for this century to below 2 ºCelsius, to pursue efforts to limit the increase to 1.5 °C, and to increase the abilities to adapt and to make finance flows consistent with a pathway towards low-carbon and carbon resilient development (UNFCCC 2016). However, the path to those goals remains very uncertain for many countries.

2.2.2 Development and climate change

The analysis of the evolution of climate change and development discourses shows that the fields operated largely independent of each other during the initial years (Ayers et al. 2014; Huq et al. 2006). Climate change was viewed as an environmental concern with little direct relevance to development policy-making and practice. Similarly, the climate change community paid little attention to development approaches as the natural sciences dominated knowledge and arguments to reduce greenhouse gases emissions (Huq et al. 2006). The Brundtland Report in 1987 was one of the first documents to introduce climate change as a potential threat to development (Keeble 1988). Climate change discourse only really entered the development arena under the wider agenda of sustainable development following the formation of UNFCCC after the Rio Earth Summit in 1992 (Weart 2008).

Subsequent work has shown that the links between climate change and development are clear (Huq et al. 2006), and in fact there are reciprocal and circular relationships between the two (Downing et al. 2003; Munasinghe & Swart 2005) . On the one hand, climate change is a stressor to development efforts that will affect current and future sustainability of development actions (Denton et al. 2014). On the other hand, the nature of development actions and their related greenhouse gas (GHG) emissions determine the magnitude of climate change and the capacity of communities to mitigate and adapt to climate change in the future (Downing et al. 2003; Olsson et al. 2014b; Roy et al. 2018).

Climate change affects the key building blocks of development such as human health, water availability and food security, thus posing serious threats to social and economic progress (Agrawala 2005; IPCC 2014b, 2018). There is also a growing consensus that climate change is substantially affecting development infrastructure, thereby undermining attempts at poverty eradication efforts and the capacity of the poorest people to adapt to the impacts of climate change (Anderson 2011; Ayers et al. 2014; IPCC 2018; Parry et al. 2007). A World Bank report highlighted that an additional 100 million people could fall into the trap of extreme poverty because of climate change in the next 15 years (Hallegatte et al. 2015). Developing countries are more likely to be disproportionately affected by climate-related disasters, which could become more destructive and derail national development objectives (de Leon & Pittock 2017; Field 2012). Climate change impacts are expected to be greatest in the primary sectors such as fishery, forestry, and agriculture upon which most developing countries’ economies rely (Adger et al. 2003; FAO 2007; Mertz et al. 2009; Pecl et al. 2017). Many therefore conclude that the less developed countries and poor communities in particular, which often possess limited economic, technical and human capacity will bear the brunt of climate change impacts (Fankhauser & McDermott 2014; Field 2012; Huq et al. 2004; IPCC 2014c; Islam & Winkel 2017; Mendelsohn et al. 2006). On the other hand, haphazard or unplanned development can exacerbate climate change and increase vulnerabilities (IPCC 2014b). For example, excessive fossil fuel based development contributes fundamentally to higher greenhouse gas emissions and human-induced climate change. Similarly, some development actions can aggravate vulnerability if they generate a heavy dependency on one activity or impose a large-scale damage and depletion of the natural resource on which the livelihoods of poor disproportionately depend (World Bank 2010). Thus, how development takes place has implications for climate change and for the vulnerability of communities (Roy et al. 2018). At the same time, addressing current socioeconomic and environmental issues through wise development interventions is likely to be critical to minimising vulnerability to future climate change impacts (O'Brien et al. 2004; Roy et al. 2018)

2.2.3 Mainstreaming development and climate change

Mainstreaming is defined as act of incorporating a social group, agenda etc. into the mainstream (Merriam-Webster 2020). Mainstreaming climate change with development is generally understood as a continuous process of integrating ideas, policies and measures to address climate change into ongoing development planning and practice (Klein et al. 2005; Persson & Klein 2008). The terms ‘integration’ and ‘mainstreaming’ are found to be used alternatively with lack of proper distinction between these terms in the literature. Yamin (2005) argues that rather than the ‘term’ it’s the ‘context’ that matters and states that “mainstreaming” is often used in the development context in the same way as “integration” is used in the environmental context. In contrast, Gupta (2010) argues ‘mainstreaming’ implies a proactive engagement with the issue and climate change responses becoming the overriding objective , whereas “integration” means a reactive approach where climate change is only being considered as an “add-on” topic brought in almost as an afterthought. In either case, the academic literature on mainstreaming or integrating climate change and development has been gradually expanding over the past years (See: Ayers et al. 2014; De Roeck et al. 2018; Klein et al. 2007; Lauer & Eguavoen 2016; Metz & Kok 2008).

The academic literature on integrating environmental concerns with development actions in the policy domain is mostly concentrated in two broad fields: Environmental Policy Integration (EPI) and Climate Policy Integration (CPI) (See: Adelle & Russel 2013; De

Roeck et al. 2018; Hogl et al. 2016). EPI is considered integral for sustainable development and is generally defined as the process of integrating additional environmental concerns beyond the traditional environmental policy domains, for example land-use planning and policies for transport, agriculture and other economic sectors (Brouwer et al. 2013; Runhaar et al. 2014). While the term 'EPI' is well established, the term 'CPI' is gradually also being adopted in the literature as a sub-set of concepts and approaches (Adelle & Russel 2013). Di Gregorio et al. (2017, p. 36) define CPI as "the integration of multiple policy objectives, governance arrangements and policy processes related to climate change mitigation, adaptation and other policy domains."

Climate policy integration primarily focuses on integrating two major areas of action namely mitigation and adaptation into development plans and actions. Metz and Kok (2008) note that the global efforts to fight poverty will be seriously hampered if mitigation and adaptation are not together taken into account. However, scholars suggest that both have primarily been addressed independently in a largely separate fashion (Adelle & Russel 2013; Ahmad 2009; Chia et al. 2015; Duguma et al. 2014; Harvey et al. 2014; Hennessey et al. 2017; Landauer et al. 2019). The initial climate change policy has mostly targeted mitigation (Ayers & Huq 2009b; Ravindranath 2007), whereas greater attention to adaptation followed only after the Marrakesh Accords in 2001 (Schipper 2004). Horstmann (2008) and Pielke Jr (1998) note that mitigation received greater attention from the UNFCCC because mitigation was assumed to be a more appropriate and applicable action and if achieved effectively, adaptation would not be required. Prins and Rayner (2007) allege that some experts deliberately suppressed the need for adaptation for fear of drawing attention away from the need to mitigate GHG emissions. While mitigation may curb GHG emissions in the future, those GHGs already present in the atmosphere will bring about substantial climate impacts (IPCC 2014b). Therefore, mitigation alone is not enough to deal with the climate challenge (Anderson & Bows 2008; Denton et al. 2014; Metz 2001; Parry & Carter 1998).

Increasingly, scholars have stressed the need to integrate climate adaptation with development (Adger et al. 2003; Fankhauser & Schmidt-Traub 2011; Hassan 2010; Schipper & Pelling 2006; Vincent & Colenbrander 2018). IFAD (2013) underscores that the linkages between development and climate change adaptation are not just vital for global climate efforts, but also essential to achieve human development goals. Mainstreaming climate adaptation into development ensures that hard-won development gains are not undermined by climate risks, and that future development outcomes are resilient to a changing climate (Vincent & Colenbrander 2018). Yamin et al. (2005) note that the current variability and climate risk is so pervasive that mainstreaming current and future vulnerabilities into development efforts is vital for the sustainability of development outcomes in developing and developed countries alike. Adaptation is, in fact, even more crucial in the context of developing countries (Huq et al. 2004; Huq et al. 2006; Klein et al. 2007; Ludi et al. 2012; Schipper 2007; Sherman et al. 2016; Tanner & Horn-Phathanothai 2014), as developing countries are more likely to be disproportionately affected by climate change impacts (Bathiany et al. 2018; Fankhauser & McDermott 2014; Field 2012; Huq et al. 2004; IPCC 2014c; Mendelsohn et al. 2006). In this respect, the 2015 Paris Agreement also highlights the need to enhance adaptive capacities of developing countries, and particularly those of the least developed countries, to deal with climate change (IISD 2016).

In spite of the increasing calls for integration and mainstreaming of development and climate change actions, scholars have also pointed out the challenges, barriers, criticism and trade-offs involved in mainstreaming of climate change with development (See: Alhassan & Hadwen 2017; Burton et al. 2007; Hassanali 2017; Huq et al. 2004; Koch 2018; Robinson 2019). Quinn et al. (2016) note that despite strong links between development and climate risk, there remains poor information on how to simultaneously address both issues. In practice, the operationalisation of mainstreaming has been slow and inefficient (Lehmann et al. 2015; Uittenbroek et al. 2013) . Robinson (2019) argues economic priorities as one of the major challenges in integrating development and climate goals. Robinson (2019) states that, in spite of known climate and environmental benefits of certain programs and actions, governments are bound to prioritise other programs and sectors that improve business performance and drive job creation and economic growth. The challenge for countries lies in balancing the achievement of higher economic growth while simultaneously addressing the challenge of climate change. Rapid economic growth traditionally demands greater exploitation of natural resources and higher energy use, which will likely increase the vulnerability of people by adding pressure on already strained natural resources and causing further changes in the climatic system (Hassan 2010) .

Sherman et al. (2016) argue that some of the current development strategies focusing on social and economic gains can potentially increase vulnerability while undermining existing traditional coping strategies. Brown (2011) notes that climate change can increase inequality and poverty not only by increasing vulnerability but through maladaptation as well. Sherman et al. (2016) and Roy et al. (2018) underscore that if development goals are unsustainable, integrating adaptation will not be effective. With respect to aid receiving developing countries, Klein et al. (2007) mention that the heavy influences of donor countries over the decision making in development and climate adaptation projects in recipient countries, often hinder mainstreaming goals and actions. Further, Robinson (2019) notes poor planning and lack of human resources as other crucial factors delaying mainstreaming goals and actions.

Thus, in spite of a clearly identified climate change–development nexus and associated frameworks in place, it can be often challenging to integrate climate change concerns with development goals. Key to this challenge is the shift from conventional to low-carbon, climate-resilient development pathways (Boyle et al. 2014; Denton et al. 2014; Fankhauser & Jotzo 2018; Rai & Fisher 2016).

2.2.4 Energy poverty, energy access and development

Modi (2005) notes that humans require at least some form of external energy to ensure their survival. Besides the provision for basic energy needs, such as for cooking food and keeping warm, humans need additional energy to support health care, education, social activities, access to safe water, agricultural & industrial productivity and in general, to advance their civilization (Goldemberg & Johansson 1995). In addition to quantitative requirements, qualitative aspects such as reliability and consistency of energy supply can be equally important (Pachauri et al. 2004; Sovacool & Mukherjee 2011).

Conceptualising and measuring energy poverty is difficult (Sovacool & Drupady 2016), as there is no single definition or set of metric of energy poverty (Culver 2017). Gaye (2007, p.4) defines energy poverty as the 'inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read or for other household and productive activities at sunset'. Sovacool and Drupady (2016) also note lack of electricity access and reliance on traditional biomass as two important indicators of energy poverty. Considering the definition above, anyone relying on traditional biomass as their primary cooking fuel and not having adequate electricity for lighting could be considered as energy impoverished. Barnes et al. (2011, p. 894) add a different dimension and define energy poverty as being below "the point at which people use the bare minimum of energy (derived from all sources) needed to sustain life." In contrast, energy consumption above this point often increases welfare and economic well-being of the consumer (Barnes et al.

2011). In the context of energy poverty, the concept of 'Energy Ladder' argues that as wealth grows, households switch from traditional, inefficient, polluting and inadequate energy sources to adequate, clean and modern energy sources, thus improving their energy access and reducing the energy poverty situation of the household (Leach 1992).

In terms of measuring energy poverty, several metrics exist. Pachauri et al. (2004) infer that an energy poverty line can be estimated scientifically based on the direct energy requirements to satisfy basic human needs within a specific location. Sovacool and Drupady (2016) note two methods can be used simultaneously, where one method tracks the minimum amount of physical energy needed for basic needs and the other looks at the energy uses of households in the lowest income quintile in a country. Culver (2017) reviews the metrics and classifies the measurement of energy poverty accounting to four different approaches namely: 1) energy access 2) energy inputs 3) outcomes of energy use, and 4) the quality of energy delivered. Energy access however, is the most commonly used proxy for energy poverty (Culver 2017).

The problem remains that like energy poverty, there is no consistency in defining energy access. Studies have stressed different factors such as the availability of modern energy generation technology, connection quality, connection reliability, adequacy of supply, affordability and consumption levels to explain and measure energy access (See: Brew-Hammond & Kemausuor 2009; IEA 2019a; Kanagawa & Nakata 2008; Pachauri & Spreng 2011; Tomei & Gent 2015; Winkler et al. 2011). Tomei and Gent (2015, p. 8) synthesize many of the above ideas to define energy access as "the ability to connect to and secure affordable, adequate, and reliable electricity supply for basic needs". IEA (2019a) describes energy access as having reliable and affordable access to both, electricity and clean and cooking facilities, which is enough to supply basic bundle of energy services initially, and then an increasing level of electricity over time. Amid a number of concepts and metrics, (Action 2010) has proposed minimum standards for six key categories of energy use to qualify for total energy access as below.

Table 2.1 Total energy access standards

Energy service	**Minimum Standard**
Lighting	300 lumens at household level
Cooking and water heating	1 kg wood fuel or 0.3 kg charcoal or 0.04 kg LPG or 0.2 litres of kerosene or ethanol per person per day, taking less than 30 minutes per household per day to obtain. Minimum efficiency of improved wood and charcoal stoves to be 40% greater than a three-stone fire in terms of fuel use. Annual mean concentrations of particulate matter (PM2.5) < 10 $\mu g/m^3$ in households, with interim goals of 15 $\mu g/m^3$, 25 $\mu g/m^3$ and 35 $\mu g/m^3$.
Space heating	Minimum daytime indoor air temperature of 12°C
Cooling	Food processors, retailers, and householders have facilities to extend life of perishable products by a minimum of 50% over that allowed by ambient storage. All health facilities have refrigeration adequate for the blood, vaccine, and medicinal needs of local populations. Maximum indoor air temperature of 30°C
Information and communications	People can communicate electronic information beyond the locality in which they live. People can access electronic media relevant to their lives and livelihoods
Livelihood generation	Access to energy is sufficient for the start-up of any enterprise. The proportion of operating costs for energy consumption in energy-efficient enterprises is financially sustainable.

Source: (Action 2010, p. ix)

Access to modern energy services and fuels is indispensable to the wellbeing of humanity in modern times. Economic growth, social inclusion and prosperity cannot be advanced without access to electricity, fuels and the range of services that they provide (Karekezi et al. 2012). In such a context, inequalities in the quantity or quality of energy supply often represent a source of social injustice (Watkins 2005). Energy impoverished communities spend a large amount of their time and physical effort on drudgeries like fetching water and collecting firewood (Karekezi et al. 2002; Urpelainen 2016), which erodes their productivity, limits their ability to move out of poverty and enhances social marginalization (Groh 2014; Ogundipe 2018). Evidently, most of the countries ranking lowest in the development index are also the countries with inadequate levels of energy access and services (Karekezi et al. 2012).

Reliable access to modern energy services enhances agricultural productivity and industrial growth, improves delivery of services, reduces poverty and contributes to the overall development of a community (Alam et al. 2018; Cabraal et al. 2005; Ogundipe 2018; Pachauri et al. 2012; Venema & Cissé 2004). Energy access facilitates improvement in education and literacy (Barnes & Samad 2018; Pachauri et al. 2004). Electricity offers the possibility of boiling, disinfecting, purifying, pumping, storing and distributing water for drinking and irrigation purposes, which further contributes to better community health, productivity and prosperity (Amin & Rahman 2019; IEA 2002). Modern cooking fuel relieves pressure on forest and other natural ecosystems, thus significantly contributing to a healthy environment (Meyfroidt & Lambin 2011). Modern cooking fuel also reduces toxic fumes and indoor pollution, which can particularly benefit women and children (Barnes & Samad 2018; Holdren et al. 2000; Rehfuess et al. 2006). In addition to hygiene and sanitation, health services can be enhanced with a modern energy supply, by allowing for the operation of medical equipment and the refrigeration of vaccines and medication (Franco et al. 2017). Energy services have a direct influence in combatting diseases and reducing infant and maternal mortality (IEA 2002; Rehfuess et al. 2006). Access to modern energy services especially benefit women by contributing to their better health, literacy, awareness and income in their households (Holdren et al. 2000; Rehfuess et al. 2006).

Thus, there is no dearth of evidence to prove the connection between energy access and development (Cabraal et al. 2005; Ogundipe 2018; Pachauri et al. 2012; Sharma 2017b; Venema & Cissé 2004). History also points to a strong connection between the two as no major poverty alleviation or development program has been successful in the recent past without the expansion of modern energy services (Saghir 2005). There exists strong correlations between energy access and indicators of development such as poverty, education, life expectancy (Legros et al. 2009). The level of energy access and energy consumption or, broadly the energy scenario in a country reflects the level of development and human welfare in the country (Alemayehou & Moss 2016; Ediger & Tatlıdil 2006). Thus, the energy-development nexus is an established paradigm in contemporary development approaches (Jingura & Kamusoko 2016). Energy access underpins socio-economic development as it is an essential pre-requisite for promoting economic growth, over-coming poverty, expanding employment opportunities, supporting the provision of social services and, in general, promoting human development (Karekezi et al. 2012; Sharma 2018). As a result, energy is an essential input for achieving many Sustainable Development Goals (IEA 2018a).

2.3 Review of empirical studies on renewable energy technologies and climate change in Nepal

2.3.1 Energy scenarios in Nepal

Nepal is a country rich in renewable energy resources (Sovacool et al. 2011). Nepal has a huge hydropower potential of 83,000 MW due to its mountainous terrain and thousands of fast flowing rivers that total a length of 45,000 km (Shrestha 2016). However, a decade long civil war from 1996 to 2006, and the ensuing political transition, combined with ongoing technical and economic challenges, have left the development of modern energy resources at a primitive stage (Bhandari & Stadler 2011; Sovacool et al. 2011).

The majority of the population still relies on traditional biomass, such as fuelwood, leaves, dung cake and rice husk for their primary energy needs (IEA 2018b; Poudyal et al. 2019). According to the IEA (2018b), traditional biomass still accounted for 72.8% of Nepal's energy supply. Modern forms of energy such as electricity and petroleum provided for only 3.6% and 17.5% respectively of the national energy needs in 2018 (IEA 2018b). Nepal is one of the least industrialised countries, with the residential sector (household lighting, cooking, heating and animal feed preparation) consuming the highest share of energy, at 48% in 2017 (Poudyal et al. 2019). Although agriculture is the backbone of the Nepali economy, its formal share of energy consumption was extremely low at just 2% in 2017 (Poudyal et al. 2019). Chhetri (2007) notes that minimal access to modern forms of energy such as petroleum and electricity, combined with a lack of mechanisation make agriculture one of the lowest energy consuming sectors despite employing most of the work force in rural Nepal. Manufacturing industries and commercial activities consumed respectively, 38% and 12% of energy in 2017 whereas the consumption in transport sector was negligible (Poudyal et al. 2019).

Kumar et al. (2015) show that many Nepalese people still do not have access to the centralised energy distribution system. According to the Nepal Electricity Authority NEA (2019), approximately 13% of the total population did not have access to electricity, 22%

of the population were not able to access the national electricity grid, and those without access to grid electricity predominantly resided in rural areas in 2018. Households with connection to the national grid also complain about inconsistent and unstable power supply with frequent blackouts and brownouts (Poudyal et al. 2019). In 2018, Nepal's total installed electricity production capacity was only 1,182 MW, for a country with a population of 29 million (NEA 2019). During the dry season, when the demand is higher, electric power production dips significantly as most of the power plants are hydroelectric, based on intermittent 'Run of the River Systems' (NEA 2016; Sharma & Awal 2013). The subsequent demand and supply gap lead to long power outages, sometimes up to 14 hours a day, frustrating households, business, industries and costing billions of rupees to the economy. One of the most prominent impacts of an inadequate electricity supply on economy has been on the manufacturing sector, as industries are forced to operate at 58% of their available capacity (Poudyal et al. 2019). Given the situation, it is not surprising that Nepal's per capita electric power consumption was only 146 kWh, per year when the global average per capita was 3132 kWh per year in 2014 (World Bank 2020).

With rapid urbanisation, the demand for electricity is increasing. According to the NEA, the electricity consumption is increasing at the rate of 7% annually, with a national demand forecast of 5785 MW for 2033 (NEA 2015). However, NEA, the sole national agency for production, transmission and distribution of electricity has not been able to meet that demand. Moreover, Nepal's electricity sector faces structural challenges such as low service standards, high transmission and distribution losses, the burden of subsidised pricing, low revenue collection and difficulties to expand the centralised grid (Nepal & Jamasb 2012). The development and expansion of a centralised grid system is exacerbated by difficult geographic terrain, scattered settlements, and the lack of capital, transport infrastructure and skilled workforce (Parajuli 2011; Thompson 2017). Even where the grid exists, disasters such as landslides, earthquakes, floods and security breaches often lead to extended power outages (Poudyal et al. 2019).

In the absence of electricity, people often opt to use petroleum to meet their energy needs. However, Nepal has no proven fossil fuel reserves and therefore all the petroleum consumed in the country is imported exclusively from India. Diesel and petrol are primarily consumed by transport, manufacturing industries, irrigation pumps and to run electric generators during power outages popularly called 'load-shedding'. Liquefied Petroleum Gas (LPG) is used for household cooking purposes. Petroleum constituted the highest share of Nepali imports in 2017, and actually exceeding the total value of all commodities exported by the country (World Bank 2018b). In 2018, Nepal imported NPR 116.8 billion [USD 1.03 billion] worth of petroleum products and the data shows an increasing trend in import and consumption at an alarming rate of 10% per annum (Poudyal et al. 2019). Apart from using a huge share of export revenues, petroleum imports are also vulnerable to political manoeuvres from the sole provider in the nation's south (Pant 2018). Nepal witnessed an economic blockade for four months in 2015, during which the import of petroleum from Indian refineries virtually stopped. Due to the blockade, social recovery from the massive earthquake in 2015 was severely hindered (Ministry of Finance 2016; Pant 2018). Moreover, the volatile international market price, air pollution and climate change resulting from the combustion of petroleum increasingly make it undesirable for Nepal to rely on fossil fuels.

The current energy situation threatens the socio-economic foundation of the nation, which is why it has become a major public concern in Nepal (Poudyal et al. 2019). To address the multifaceted challenges in the Nepalese energy sector, scholars and experts have argued for a paradigm shift from a top-down, western-style energy development model to a decentralised and self-sufficient energy systems (Bhattacharyya 2007; Nepal & Jamasb 2012; Poudyal et al. 2019). The desired energy development pathway would primarily focus on increasing modern energy access and shifting from a traditional, fossil fuel based system to a modern clean energy system (Bhattacharyya 2007; Nepal & Jamasb 2012). The government of Nepal has expressed its willingness to develop such a low-carbon development strategy, which aims at economic growth with low-carbon emissions (Ministry of Population and Environment 2016a). By 2020, Nepal plans to have a 20% share of renewables in its energy mix and increase the share of electric vehicles up to 20%. By 2050, Nepal further aims for 80% electrification through renewables and a 50% reduction in fossil fuel consumption (Ministry of Population and Environment 2016a). To meet these goals, the government has developed policies and programs to promote and upscale renewable energy technologies. The following section discusses the evolution and the current state of renewable energy policies and programs in Nepal.

2.3.2 Renewable energy policies in Nepal

Historically, the majority of Nepal's population have relied heavily on traditional energy sources such as fuelwood and other biomass to meet their energy needs (Qehaja et al. 2019). In order to expand modern energy access and to reduce the country's growing dependence on fossil fuels, DRETs became natural alternatives for the government

(Gewali & Bhandari 2005). The government of Nepal introduced renewable energy technologies as alternative energy sources into the national planning framework for the first time in its seventh national plan (1985-1990). The plan encouraged the use of renewable energy technologies especially solar, biogas and wind through the adoption of new policies. Other renewable energy technologies such as ICS, Small Water Turbines (SWT) and Improved Water Mills (IWM) were also promoted.

The eighth national plan (1990-1995) implemented after the restoration of democracy in Nepal, built upon the alternative energy agenda adopted during the seventh plan. The eighth plan focused on rural electrification through micro-hydro projects and realised the need for a national alternative energy agency for effective coordination and implementation of renewable energy projects. The ninth plan (1995-2000) recognised the importance of increase in sustainable rural energy supplies through renewable energy technologies for economic growth and livelihood improvement while maintaining environmental sustainability. The plan adopted a policy to engage the private sector, government and non-government agencies in research and development of renewable energy technologies. The plan also institutionalised the formation of the AEPC as the focal agency for promotion of alternative energy technologies in Nepal. AEPC has since become the nodal agency to promote alternative energy development, especially in the rural areas of Nepal.

The tenth national plan (2002-2007) envisioned a Rural Energy Fund and came up with targets for the deployment of renewable energy technologies. The policy for the promotion of uptake of renewable energy technologies in rural areas was released in 2006, during the tenth plan. During the next interim plan (2007-10), the Central Renewable Energy Fund (CREF) was conceptualised and the Subsidy Policy for Renewable (Rural) Energy 2009 was launched. The plan also aspired to generate financial resources by developing renewable energy technologies as Clean Development Mechanism projects. The Clean Development Mechanism under the Kyoto Protocol allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits. Each CER is equivalent to one tonne of CO_2 and can be traded to other actors towards meeting the Kyoto targets (UNFCCC 1998).

The twelfth three-year national plan (2010-2013) presented a long-term vision of increasing the contribution of renewable energy in the national energy mix. The plan adopted policies to promote renewable energy technologies in urban areas through the promotion of urban solar and waste to energy projects in municipal areas. The plan institutionalised the Central Renewable Energy Fund, promoted renewable energy based enterprise development and grid interconnection of renewable energy projects.

The thirteenth national plan (2013-2016) adopted the strategy to further research, develop and transfer technology for renewable energy. The plan also adopted the policy to operationalise Central Renewable Energy Fund. The fourteenth national plan (2016-2019) aims to provide electricity to an additional 9% of population from renewable energy technologies such as solar, micro-hydro and wind (NPC 2016). The plan also aims to add 200,000 units of biogas plants and 1.065 million units of improved cooking stoves with in the plan duration (AEPC 2018).

Currently, the following major policies and frameworks among others are in place for the promotion of renewable energy technologies in Nepal.

i) **The Constitution of Nepal (2015)**

The Constitution of Nepal (2015) ensures that the government will make policies to promote, use and protect natural resources to the benefit of its people. The constitution also directs the government to implement policies to ensure a reliable and affordable supply of energy through the development of renewable energy technologies for the fulfilment of basic needs of its citizen (CA Secretariat 2015). Thus, even the constitution mandates that government develop and promote renewable energy in the country.

ii) **Rural Energy Policy (2006)**

The Rural Energy Policy (REP) 2006 aims to provide clean energy access by reducing dependency on traditional energy and conserve the environment by increasing access to clean and cost effective energy technologies in rural areas (AEPC, 2016). The policy also aims at increasing the living standards of rural people by increasing employment opportunities and enhancing productivity through the development of rural energy technologies.

iii) **Renewable Energy Subsidy Policy and Subsidy Delivery Mechanism (2016)**

The Renewable Energy Subsidy Policy and Subsidy Delivery Mechanism (2016) details the provision of subsidies based on factors such as the capacity of renewable energy technologies, the remoteness of location and the ethnicity of consumer (AEPC 2018). The policy aims to gradually reduce and readjust the level of subsidy over time in order to shift to a lending credit model.

iv) **National Renewable Energy Framework (2017)**

The framework aims to converge the initiatives of Government of Nepal, development partners and other organisations to generate a common over-arching energy vision through an integrated framework (AEPC 2018). The framework engages stakeholders, mobilises finance and jointly coordinates and monitors results of various renewable energy projects.

v) **Biomass Energy Strategy (2017)**

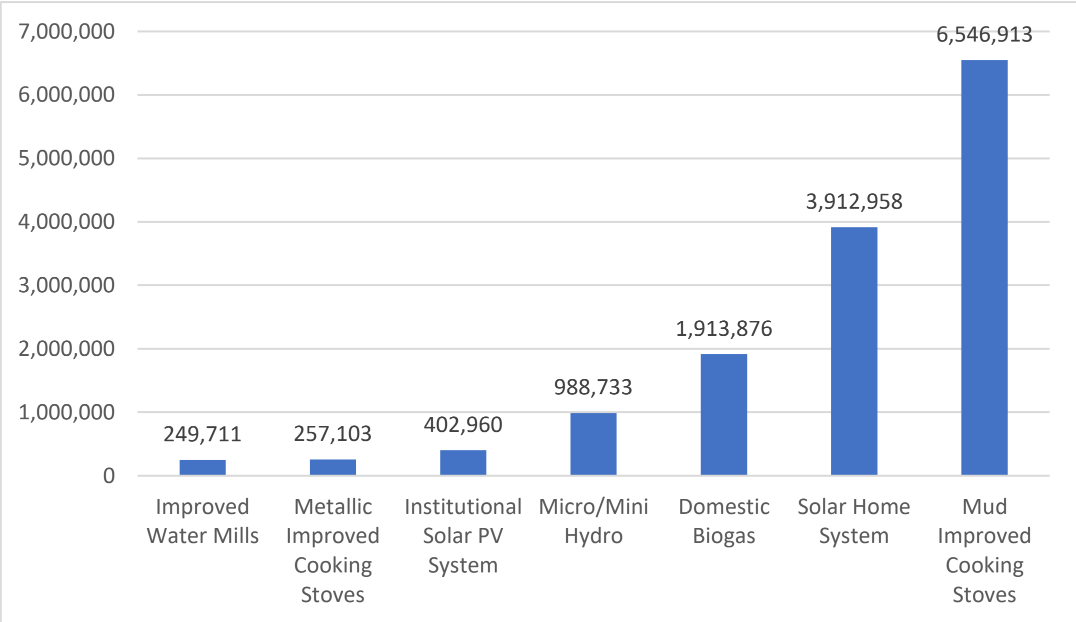
The Biomass Energy Strategy (2017) promotes biomass as a reliable and sustainable energy resource to address increasing energy demand in Nepal. The strategy focuses on increasing sustainable production of biomass by utilising agricultural and forest residues and other organic waste (AEPC 2018).

2.3.3 Current state of renewable energy technologies in Nepal

The promotion of renewable energy technologies gained momentum after the Government of Nepal recognised the positive role of these technologies in its seventh national plan (1985-1990). Since its establishment in 1996, the AEPC has implemented several projects and programs such as Rural Energy Development Program (REDP), Biogas Support program (BSP), the Energy Sector Assistance Program (ESAP), Renewable Energy Project (REP), Climate and Carbon Program, National Rural and Renewable Energy Program (NRREP) and National Renewable Energy Framework (NREF) to promote the use of renewable energy technologies in the country. Over 14 million people across the country have benefitted through the technical support, subsidy and credit schemes provided by these projects (AEPC 2018).

In Nepal’s context, promotion of renewable energy technologies has been primarily aimed at providing clean energy access to millions of households, especially in remote off-grid areas (AEPC 2016). Thus, renewable energy infrastructures in general are decentralised in Nepal (AEPC 2018). In 2018, approximately 18% of the country’s population had access to electricity through decentralised renewables such as micro and mini-hydro, wind, and solar PV (MOEWRI 2018). The combined capacity of all the micro-hydro, mini-hydro, wind and solar PV installed was around 55 MW. In the fiscal year 2017/18 alone, additional 95,000 households were provided access to electricity through solar home systems, 6,000 households through micro and mini-hydro and 900 households through solar mini-grid systems (AEPC 2018). Similarly, additional 55,000 households were provided with clean cooking fuel with the installation of biogas and ICS in fiscal year 2017/18. Figure 2.1 and Table 2.2 depict the cumulative number of DRETs and their beneficiaries since the beginning of the promotion of renewable energy technologies in Nepal to the end of fiscal year 2017/18. Renewable energy contributed 3.25% of the total national energy consumption in fiscal year 2017/18 in Nepal.

Figure 2.1 Beneficiary population based on type of decentralised renewable energy technologies in Nepal



Source: AEPC Annual Progress Report 2017/18 (AEPC 2018, p.14)

Table 2.2 Cumulative scale of decentralised renewable energy technologies installed in Nepal until fiscal year 2017/2018

Cumulative DRETs installed	Unit	Until FY2017/18
Mud Improved Cooking Stoves	Numbers	1,423,242
Solar Home System	Numbers	850,643
Domestic Biogas	Numbers	416,060
Micro and Mini Hydro	Kilowatts	30,706
Institutional Solar PV System	Numbers	1,752
Metallic Improved Cooking Stoves	Numbers	55,892
Improved Water Mills	Numbers	10,857
Urban Solar Home System	Numbers	21,144
Solar Drinking Water and Irrigation Pump	Numbers	486
Solar/Wind Micro/ Mini-Grid System	Kilowatts	413
Large Biogas Plant	Numbers	189

Source: AEPC Annual Progress Report 2017/18 (AEPC 2018, p.14)

Apart from providing energy access, the promotion of renewable energy technologies has led to the creation of a renewable energy technology industry in Nepal. At the end of the fiscal year 2017/18, more than 500 private companies and seven delivery partners were engaged in the design, manufacturing and provision of ancillary services for renewable energy. The industry directly and indirectly provided employment opportunities to over 30, 000 people (MOEWRI 2018). Promotion of renewable energy technologies has also helped to reduce GHG emission and mitigate climate change. According to AEPC, renewable energy technologies installed during the fiscal year 2017/18 alone helped in avoiding 0.13 million tons of Carbon Dioxide equivalent (AEPC 2018). The following sections review the climate change trends and impacts in Nepal.

2.3.4 Climate change trends in Nepal

Nepal is a predominantly mountainous country and lies within the greater Hindu Kush Himalaya (HKH) region. The HKH region comprises of many of the Earth's highest mountains including Mount Everest. In recent years, climatic changes are becoming more evident across the HKH (Krishnan et al. 2019; Shrestha et al. 2019). The changes are manifest through rises in the temperature, glacial retreat, shrinking snow-cover, degrading permafrost and changes in the occurrence and intensity of extreme weather events (Barnett et al. 2005; Kang et al. 2010; Krishnan et al. 2019; Pepin et al. 2015; Sarıkaya et al. 2013; Shrestha et al. 2019; You et al. 2017).

Temperatures in the mountains of Nepal are rising faster than the global average (Khatiwada et al. 2016; Krishnan et al. 2019; Nogués-Bravo et al. 2007; Salinger et al. 2014). Krishnan et al. (2019) report that even if the global warming is limited to 1.5 ºC, warming in the HKH mountains will be likely at least 0.3º C higher. A study by the Department of Hydrology and Meteorology (DHM) for the period of 1970-2014 observed a significant positive trend of 0.056 ºC per year in Nepal's annual maximum temperature, with the highest significant positive increase of 0.12 ºC per year observed in Manang district (DHM 2017). In another study for the period of 1979-2016, Shrestha et al. (2019) observed a significant increase in mean annual temperature with the more pronounced rate of increase after 2005 and with 2016 the hottest year. Winters are experiencing more warming than summers, and the high mountains are usually the most affected regions (Shrestha et al. 2015). Occurrences of extreme cold days and nights have decreased (by 0.85 days per decade and by 2.40 nights per decade) while occurrences of extreme warm days and nights have increased (by 1.26 days per decade and by 2.54 nights per decade) in the region (Krishnan et al. 2019). Shrestha et al. (2019) also observed an increasing trend of hot days and nights and decreasing trend of cold days and nights in Nepal.

Observed precipitation records, however do not show a uniform trend in Nepal (DHM 2017; Khatiwada et al. 2016; Nepal 2016). Shrestha et al. (2019) observed a significant increase in annual precipitation at the rate of 8.7 mm per year between 1979 and 2016. On the other hand, studies by Palazzi et al. (2013), Salerno et al. (2015), and Yao et al. (2012) have found a statistically significant decreasing trend. Khatiwada et al. (2016) could not find a uniform precipitation trend between individual stations while conducting hydro-climatic variability studies in the Karnali river basin in the far west region of Nepal. Similarly, the variability in the onset and withdrawal of summer monsoon, which contributes 70% - 85% of total precipitation in Nepal (Shrestha & Aryal 2011; Shrestha et al. 2000) is increasing (Kripalani et al. 2007). Panthi et al. (2015) have reported a delaying trend in the withdrawal, and Bhatta et al. (2015) and (Sujakhu et al. 2016) have reported an increasingly erratic monsoon in the mountains of Nepal.

Overall, in recent years the change in climate in Nepal as well as the greater HKH region has become more evident. There is a consistent warming trend, however, the trend in precipitation change is not uniform. The fluctuations in temperatures and water availability have substantial effects on livelihoods and communities, which are discussed in the next section.

2.3.5 Climate change impacts

Climate change has broad and far-reaching implications for natural and human systems. In Nepal, many studies are detailing the impacts and implications of climate change for various sectors; including social-ecological systems (Pandey & Bardsley 2015), water (Dahal et al. 2016; Lamichhane & Shakya 2019; Shrestha et al. 2016), biodiversity and ecosystems (Bhattacharjee et al. 2017; Lamsal et al. 2017), agriculture and food security (Bocchiola et al. 2019; Gentle et al. 2014; Poudel et al. 2017), health (Dhimal et al. 2017; Regmi et al. 2016) and natural hazards (Fort 2015; Hussain et al. 2018).

Water is the most important resource for survival. Climate change is projected to have varied impacts on water resources in Nepal. Glacial mass and snow cover are projected to decline for most parts of the mountains (Krishnan et al. 2019; Merrey et al. 2018) whereas river flows are projected to increase (Dahal et al. 2016; Immerzeel et al. 2013; Lamichhane & Shakya 2019). Although precipitation records do not show a uniform trend as mentioned earlier (Khatiwada et al. 2016; Nepal 2016), annual precipitation is projected to increase in the future (Lamichhane & Shakya 2019; Shrestha et al. 2015).

The Himalayan glaciers are likely to lose ice and glacial mass as snowfall decreases and the ablation of glaciers increases with warming (Wiltshire 2014). Carey et al. (2017) note that glacial retreat and ice loss in mountains have the potential to affect communities reliant on them by affecting irrigation, hydropower, agriculture, drinking water and recreation. Communities immediately downstream from glaciers will be most at risk to glacial change, as they will face reduced reliability of local water resources and the potential for increased hazards in the form of glacial lake outburst floods (Shrestha et al. 2015). Since most rivers in Nepal are dependent on melting glaciers and snow (Lutz et al. 2014; Wiltshire 2014), the flow in such rivers is likely to increase at least until 2050 (Immerzeel et al. 2013). Increased glacier and snow melt runoff in combination with peak monsoon flows in the rivers could potentially cause water related flood impacts downstream (Ragettli et al. 2016). Mountains, due to their fragile topography, are very prone to water induced natural hazards such as floods, landslides and soil erosions (Tiwari & Rayamajhi 2018). Changing climatic conditions are expected to aggravate this situation further in Nepal (Shrestha et al. 2015), leading to reduced livelihood opportunities and greater vulnerability to climatic risk (Khatiwada et al. 2016; Tiwari & Rayamajhi 2018). The impacts of changes in river flow will not be limited to the mountain regions, but rather will be felt downstream in Nepal and India in the form of increased occurrences of floods, habitat destruction, loss of cultivable land, loss of livelihoods, and increased pressure on resources due to in-migration from mountain areas (Hussain et al. 2016).

Agriculture is the primary source of livelihoods in Nepal. Climate change will have negative impacts on agriculture through erratic rainfall (Shrestha et al. 2015), increased pest and diseases (Paudel et al. 2014), increased invasive species (Bisht et al. 2016), reduced water availability (Bhatta et al. 2015; Poudel & Duex 2017), crop failures (Gentle et al. 2014), and extreme weather events (Kirschbaum et al. 2020; Shrestha et al. 2015). Pandey and Bardsley (2019) report a poor food security situation with the highest level of food insecurity in the mountains in Nepal. The decline in agricultural productivity due to climate change could further worsen the situation (Pant 2012; Poudel & Duex 2017). Generally, poor people who rely on dryland agriculture with limited livelihood options or adaptive capacities will be the most vulnerable to the impacts of climate change (Mertz et al. 2009).

Significant changes are happening to ecosystems and biodiversity in Nepal and the HKH region (Alfthan et al. 2018; Bhattacharjee et al. 2017). Studies have reported changes such as earlier onset of growing seasons (Shrestha et al. 2012); shifting of tree lines (Gaire et al. 2014); and, reduced regeneration capacity of local species in Nepal (Bhatta et al. 2015). Bisht et al. (2016) have discussed the growing invasive species problem in Nepal and noted the increased labour demands in agro-ecosystem, losses of crop productivity, losses of forage for cattle, losses of non-timber forest products, and the reduced forest regeneration capacity as negative impacts. Urban (2015) suggests that under current climate policies, the impact on biodiversity could be so severe that we could lose one in six species in the foreseeable future.

Changes in broad-scale climatic systems affect human health, including through morbidity and mortality from extreme heat, cold, droughts, forest fires and changes in air quality and the ecology of infectious diseases (Kinney 2018; McIver et al. 2015; Murage et al. 2017; Patz et al. 2005; Watts et al. 2015; Wu et al. 2016). In a study analysing the impacts of climate change on public health, Dhital et al. (2016) noted that climate change-induced heatwaves, disasters like floods and landslides, and vector borne diseases like malaria, dengue and kala-azar have the potential to increase illness and deaths in Nepal. Rossati (2017) argues a warming climate provides a favourable environment for disease vectors and pathogens to thrive, thus predicting increased number vector borne diseases in the future. Recent reports from various parts of Nepal, including temperate mountain regions, suggest an unprecedented surge in the reported cases of Dengue and other mosquito-related illnesses (Nepali Times 2019; The Washington Post 2019), and Bhusal and Dhimal (2010) suggest that the increasing presence of dengue carrying mosquito *Aedes aegypti* can be attributed to climate change.

The climate change impacts discussed above are certainly not an exclusive list and rather represent the findings from the primary sectors of the Nepali community. Climate change impacts are broad and manifold (Mora et al. 2018). Climate change affects the livelihood system in multiple ways (Olsson et al. 2014a). Nevertheless, the brief review of the literature confirms that the climate in Nepal, and in the mountains in particular, is changing rapidly. Such changes have wide and far-reaching consequences, challenging the sustainability of existing ecological and socio-economic systems (Mora et al. 2018). In such context, studies aimed at identifying effective adaptation measures are essential for rural Nepal.

2.4 Conceptual understanding of climate change risk

2.4.1 Vulnerability

The term 'vulnerability' has been in defined and understood in many ways (See: Adger 2006; Bankoff & Frerks 2013; Brooks et al. 2005; Cardona 2013; Chambers 1989; Dow 1992; Kelly & Adger 2000b; Liverman 1990; O'Brien et al. 2007; Oppenheimer et al. 2015; Turner et al. 2003). Numerous reviews have been conducted that detail the variety of interpretations and concepts regarding vulnerability (See: Bennett et al. 2016a; Crane et al. 2017; Cutter et al. 2009; Giupponi & Biscaro 2015; Jurgilevich et al. 2017; Lundgren & Jonsson 2012; McDowell et al. 2016b; Rehman et al. 2019; Thornton et al. 2014; Williams et al. 2018). The alternative concepts often originate from different academic disciplines and professional fields of practice, which differ in terms of frameworks, methods or unit of analysis (Ford et al. 2018; Füssel & Klein 2006; Hinkel 2011; O'Brien et al. 2007; Pearson et al. 2008; Rehman et al. 2019). Some scholars argue vulnerability is a 'pre-existing condition' of a system leading to potential loss due to the exposure to environmental hazards (Allen 2003; Burton 1993; Cutter et al. 2000; Turner et al. 2003). Some others have argued it as an 'event' or 'stimuli' that harms a system (Cuevas 2011; O'Brien et al. 2004) while some of the frameworks argue vulnerability is an 'outcome' of experiencing certain drivers of change (Birkmann et al. 2013a; Cardona et al. 2012; Oppenheimer et al. 2015).

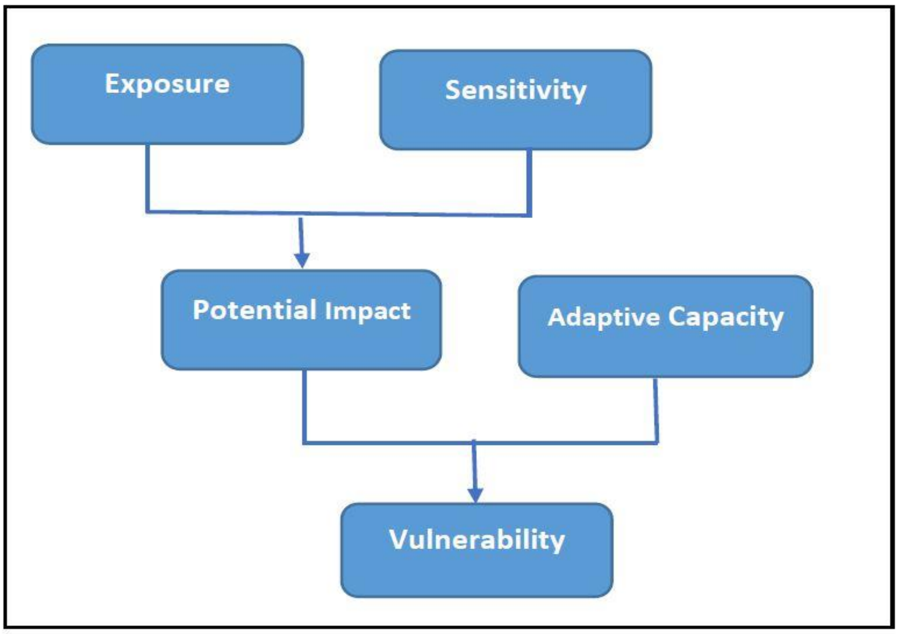
Researchers have applied the concept of vulnerability in various fields of study: Sen (1982) and Dreze et al. (1995) in food security; Hewitt (1983) in natural hazards; and Liverman (1990) and Cutter (1996) in relation to environmental change. In the field of climate change in particular, the concept of vulnerability seeks to identify why and how a human system is at risk and how it loses its ability to respond effectively to the variability in climate (Ford et al. 2018). Vulnerability in the context of climate change has been comprehensively reviewed by multiple authors (See: Adger 2006; Bennett et al. 2016b; Brooks 2003; Eakin & Luers 2006; Kelly & Adger 2000b; McDowell et al. 2016a; O'Brien et al. 2007).

The concept of vulnerability has been increasingly applied in the field of climate change particularly after the inception of Intergovernmental Panel on Climate change (IPCC), which promoted the concept to frame local risks to climate change (Jurgilevich et al. 2017). The IPCC is the leading scientific body for the assessment of climate change and

The IPCC's Fourth Assessment Report (AR4) defined vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC 2007, Glosaary, p. 89). [The IPCC's definition of vulnerability by the subsequent IPCC assessment report will be discussed later]. According to the IPCC, vulnerability in the context of climate change is a function of rate of exposure of a system to climatic variability and change, the sensitivity of the system to the change and its capacity to cope, adapt or recover from the effects of those variability and change (IPCC 2007; McCarthy et al. 2001). Thus, the vulnerability of a rural farming household in the context of climate change can be exemplified in terms of exposure to elevated temperature and erratic rainfall pattern; the sensitivity of crops to changed climatic conditions; and the ability of the farming household to adapt to the changed climatic situation and sensitivity of crops.

Despite multiple approaches and interpretations, most of the climate change literature consistently considers vulnerability of a system to be a function of three components: exposure, sensitivity and adaptive capacity (Jurgilevich et al. 2017; Smit & Wandel 2006)[Figure 2.2].

Figure 2.2 Vulnerability and its components



Adapted from Allen Consulting (2005, p. 20)

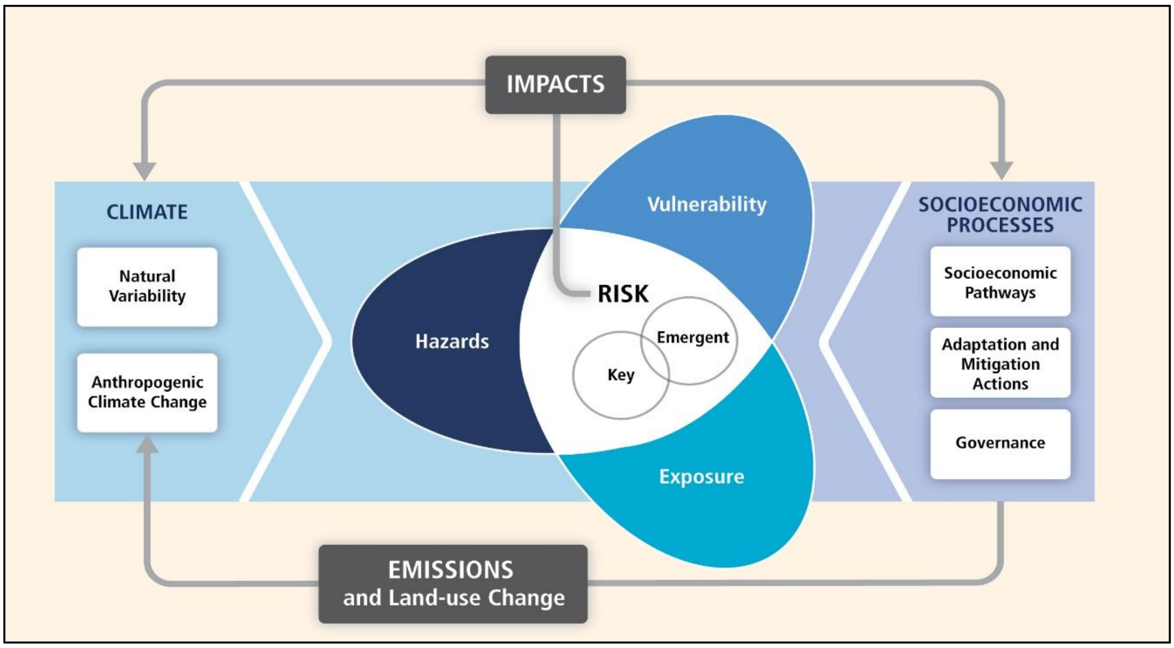
Exposure is defined as "the nature and degree to which a system is exposed to significant climatic variations" (IPCC 2001, Glossary p. 987). Exposure in the context of vulnerability is not only the extent to which a system is subjected to variation, but also the magnitude and duration of these variations (Adger 2006). For the purpose of vulnerability assessments, climatic variations can be defined as specific changes in the climate system, such as changes in temperature and rainfall (Fellmann 2012). Systems are exposed to natural climate variations, irrespective of climate change, however, climate change is expected to alter and increase the severity of exposure in the variabilities, trends and extremes in climate in the future (Lavell et al. 2012).

The sensitivity of a system to climate change is defined as, "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (IPCC 2001, Glossary, p. 993). Sensitivity reflects the responsiveness of a system to climate variability and the magnitude to which the climate change might affect it in its current form. Thus, the higher the sensitivity of a system, the higher will be the response and changes in any system.

Exposure and sensitivity together suggest the impact that the changing climate can have on a particular system. However, it has to be noted that even if a system is highly exposed or sensitive or both to climate change, the system is not necessarily vulnerable because neither exposure nor sensitivity account for the capacity of the system to adapt. The scale of the potential impact as defined by exposure and sensitivity can be mitigated by the capacity of a system to adapt, called adaptive capacity. The IPCC defines adaptive capacity as, "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2001, Glossary, p. 982). Adaptive capacity influences the vulnerability of a system to climate change by modulating exposure and sensitivity (Gallopín 2006; Yohe & Tol 2002), and is generally a desirable attribute in a system to offset vulnerability (Engle 2011). The better the adaptive capacity of a system, the higher the likelihood of the system adjusting to the impacts, making it less vulnerable to change.

Thus, the IPCC (2007) defines vulnerability on the basis of exposure, sensitivity and adaptive capacity, which implies that a system is vulnerable when the system is exposed, sensitive and has a limited capacity to adapt. On the contrary, the system is less vulnerable when the system is less exposed, less sensitive and has high adaptive capacity (Smit & Wandel 2006). Many studies have followed this formulation of vulnerability from IPCC as their starting point in their assessment (Jurgilevich et al. 2017). However, more recently the IPCC introduced the concept of climate risk that constitutes hazard, exposure and vulnerability in its Fifth Assessment Report (AR5) (Cardona et al. 2012; Oppenheimer et al. 2014). According to this framework, risk is a function of hazard, exposure, and vulnerability, i.e. Risk = f (hazard, exposure, vulnerability) [Figure 2.3], thus, the risk of climate-related impacts results from the interaction of climate-related hazards with the exposure and vulnerability of human and natural systems (Field et al. 2012; IPCC 2012).

Figure 2.3 Illustration of the fundamental concept of risk and vulnerability to climate change



Source: (IPCC 2014b, p. 1046)

Notably in this framework, vulnerability is presented separately from hazard and exposure. Vulnerability in this framework is considered as an internal property of the system, comprising particular sensitivities and adaptive capacities (Connelly et al. 2018; Sharma & Ravindranath 2019). The IPCC AR5 based on this framework defines vulnerability as, “the propensity or predisposition to be adversely affected” and further argues, “vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC 2014a p. 1775). Figure 2.4 compares the concept of vulnerability by the IPCC in 2007 and 2014.

Figure 2.4 Comparison of the concept of vulnerability by the IPCC in 2007 and 2014

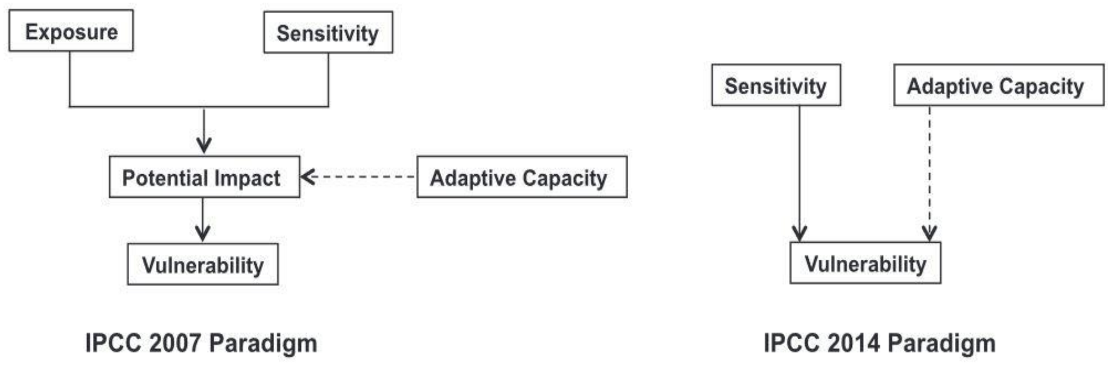


Figure 1. The concept of vulnerability as presented in the IPCC 2007 and 2014 reports. Solid and dashed arrows respectively show a positive and negative functional relationship of a component with vulnerability.

Source: (Sharma & Ravindranath 2019, p. 2)

Jurgilevich et al. (2017) argue that the IPCC's concept of "climate risk" is different from the earlier framing of "vulnerability" in following ways:

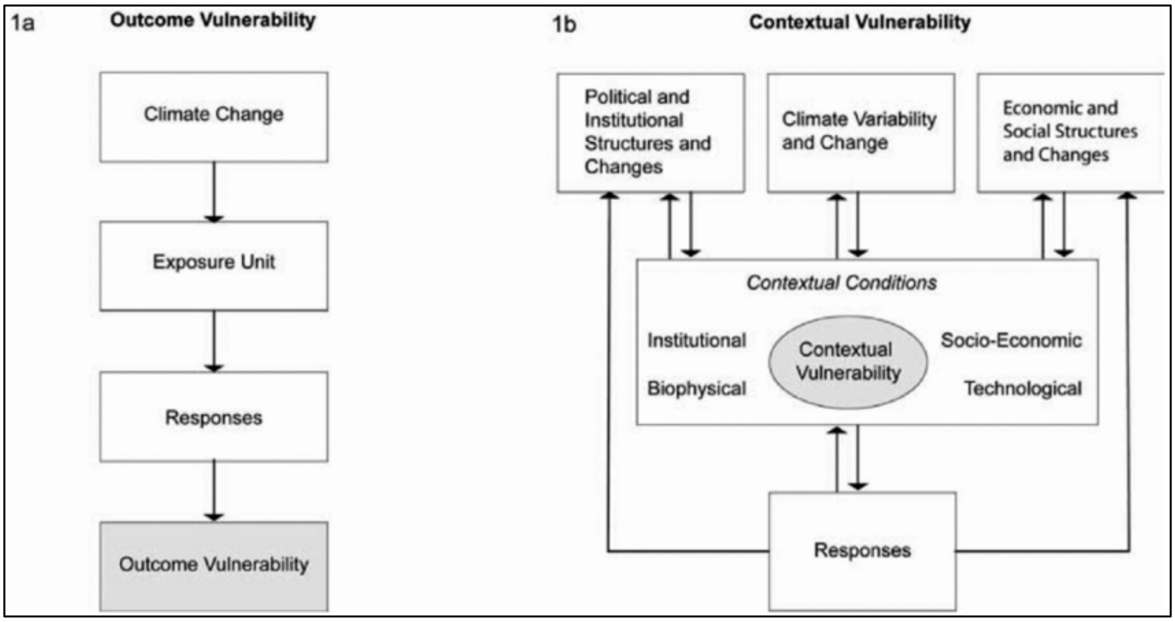
i) it links the disaster risk management and vulnerability literature,

ii) it broadens out and highlights the importance of exposure and vulnerability, and

iii) it highlights the point of occurrence of risk when all three components namely hazard, exposure and vulnerability interact.

In addition to IPCC's conceptual framing of vulnerability (IPCC 2007, 2014b), the literature provides alternative approaches and concepts of vulnerabilities (Fellmann 2012; Jurgilevich et al. 2017). Among others, two of the most prominent approaches in the context of climate change are outcome and contextual vulnerability (Fellmann 2012). The approaches differ in terms of interpreting vulnerability as either the starting-point or the end-point of analysis (Kelly & Adger 2000b).

Figure 2.5 Frameworks depicting outcome vulnerability and contextual vulnerability



Source: (O'Brien et al. 2007, p.75)

Outcome vulnerability corresponds to the "end-point" approach that considers vulnerability as the outcome, or the net impacts of climate change on a system after possible adaptation efforts have been undertaken (O'Brien et al. 2007). Thus, this approach combines the knowledge of potential biophysical impacts and socio-economic capacities to adapt to assess the vulnerability of any system (Kelly & Adger 2000a; O'Brien et al. 2007). Outcome vulnerability generally centres around hazards, focuses on biophysical drivers such as temperature and precipitation and relies on projections from biophysical models, which contain many uncertainties (Nelson et al. 2010b). Socio-economic factors are often marginalised to assess adaptive capacity and the subsequent vulnerability (Eakin et al. 2014; Fellmann 2012). The studies adopting this approach usually place greater emphasis on technological solutions for mitigation and adaptation strategies to tackle climate change (Brooks 2003; O'Brien et al. 2007). The end-point approach is often criticized for assuming humans to be passive receivers of hazards and failing to take into account human-environmental interactions to cope with such hazards (Connelly et al. 2018; Vincent 2004).

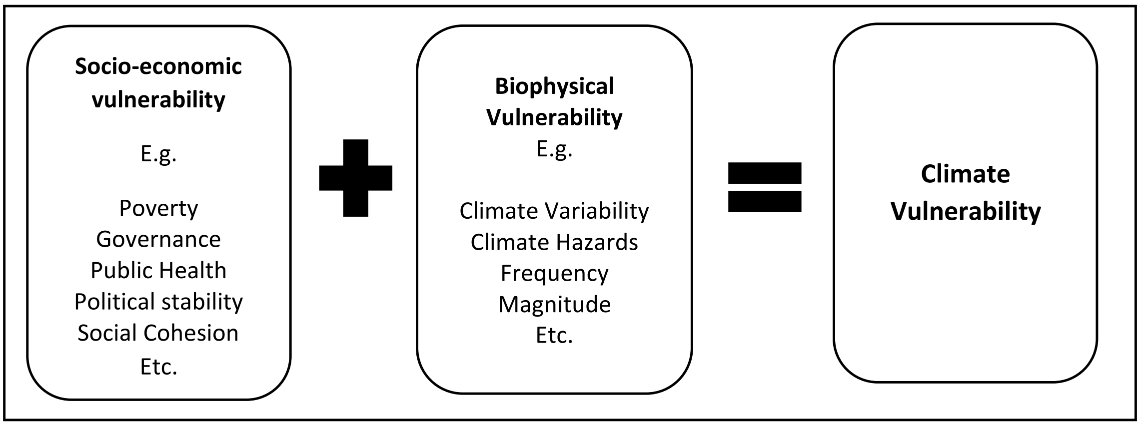
In recent years, however, studies on climate change underscore that vulnerability is not only defined by hazards, but also by human-environment interactions that enable people to cope with change (Bassett & Fogelman 2013; Piya et al. 2016; Vincent 2004). In the 'Contextual vulnerability' approach, vulnerability corresponds to the 'starting point', a state that exists within a system before it encounters a hazard (O'Brien et al. 2007).

Contextual vulnerability is considered a characteristic of a socio-ecological system that is influenced by biophysical conditions, as well as social, economic, political, institutional and technological structures and processes (Adger 2006; Bennett et al. 2016b; Fellmann 2012; O'Brien et al. 2007). Contextual vulnerability approaches generally focus on current social, political, institutional and economic determinants in the context of which both climate variability and change occur (Fellmann 2012; O'Brien et al. 2007). Specific social determinants such as inequality, resource entitlements, marginalisation, presence of institutions and financial well-being can increase or decrease a system's vulnerability (Adger & Kelly 1999; Birkmann et al. 2013b; Cardona et al. 2012) .

The conceptual interpretation of vulnerability is often different for different disciplines, purposes, times and places (Fellmann 2012; Jurgilevich et al. 2017; O'Brien et al. 2007). However, alternate and evolving concepts of vulnerability should not be considered contradictory, but rather complimentary in the context of climate change (Ford et al. 2015; O'Brien et al. 2007; Preston et al. 2011). In assessing the climate change vulnerability and adaptation planning of any complex system, a scientific approach should recognise that vulnerability is not just the result of biophysical vulnerability alone, but is also influenced by the socio-economic context in which the climatic variability and change occurs (Bennett et al. 2016b; Cardona et al. 2012; Eriksen et al. 2011; Füssel 2007b; O'Brien et al. 2007; Roiko et al. 2012). Vulnerability is thus a dynamic concept, as it is in a continuous state of flux determined by changing biophysical and social processes (Eriksen et al. 2005; Handmer et al. 1999; Leichenko & O'brien 2002). Accordingly, studies have used an integrated approach, combining socio-economic vulnerability with biophysical vulnerability for vulnerability assessments (Gbetibouo & Ringler 2009; Nelson et al. 2010a; Piya et al. 2016) and will be used in such a manner for this study [Figure 2.6].

Socio-economic vulnerability is associated with factors such as economic resources, distribution of resources, institutions, governance, cultural practices, social cohesion and other characteristics of social groups (Füssel 2007b). Social vulnerability can be defined as a lack of capability of a community to cope with and adapt to any stress placed on the livelihood and wellbeing of the members of the community (Füssel 2012; Otto et al. 2017). The biophysical vulnerability of a system on the other hand is determined by the nature of the physical hazard(s) to which the system is exposed, the likelihood or frequency of occurrence of the hazard, the extent of system's exposure to the hazard, and the system's sensitivity to the impact of the hazard (O'Brien et al. 2004). Physical hazards result from climate stresses such as increased surface temperatures, decreased or increased precipitation, sea-level rise and changes in frequency and intensity of extreme weather events (Parry et al. 2007). Socio-economic vulnerabilities and biophysical vulnerabilities interact collectively in a particular system to determine the climate vulnerability (Preston & Stafford-Smith 2009) as shown in Figure 2.6.

Figure 2.6 Relationship among different factors and climate vulnerability



Adapted from Preston and Stafford-Smith (2009, p.11)

2.4.2 Adaptation

The term 'adaptation' has been understood and interpreted in multiple ways (Bankoff 2019; Moser & Ekstrom 2010; Smit & Wandel 2006). Once again, there is no single universally accepted definition for adaptation. Generally, adaptation is considered a process of adjustment that aims to either limit harm or exploit advantages out of change that cannot be avoided (IPCC 2014b). In other words, adaptation can be referred as "managing the unavoidable" (Weir et al. 2017, p. 1020).

A review of the literature suggests that adaptation has been defined differently with a range of concepts in focus such as enhancing coping capacity, reducing vulnerability and building resilience etc. For example, Smit and Wandel (2006, p.282) lay emphasis on a system's coping capacity and note, "Adaptation in the context of human dimensions of global change usually refers to a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity". Smit and Pilifosova (2003b, p.9) focus on vulnerability reduction and define adaptation as "adjustments in socio-economic systems to reduce their vulnerability both to long-term shifts in average climate and to changes in the frequency and magnitude of climate extremes". Scheraga and Grambsch (1998, p.85) emphasize the concept of resilience and note that “adaptive actions are those responses or actions taken to enhance the resilience of vulnerable systems, thereby reducing damage to human and natural systems from climate change and variability”. In the context of climate change, adaptations are aimed at reducing the negative impacts of climate change or to realise positive impacts of the change by exploiting new opportunities (Smit & Wandel 2006). The IPCC (AR5) defines adaptation as, “The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities” (IPCC 2014a, p.1758).

There can be several ways to define climate change adaptation, framed by such elements as adaptation to what (temperature, salinity, rainfall, sea level rise), for whom (natural or human system), at what scale (community, regional, national) and for how long (Alam & Huq 2019). Adaptation responses can be diverse (Fankhauser et al. 1999). Anticipatory adaptation takes place prior to climate change impacts being observed, sometimes also called proactive adaptation. Autonomous adaptation is not planned but rather spontaneous to change. Planned adaptation is a result of a planned decision to adjust to experienced or imminent climatic changes. Despite several classifications, the common aim of adaptation activities is to reduce the vulnerability of a system (Adger 2006; Bassett & Fogelman 2013).

Adaptation is intimately associated with the concept of adaptive capacity and vulnerability (Smit & Wandel 2006), in a manner that the goal of adaptation is to enhance the adaptive capacity in order to reduce the vulnerability of the system (Adger 2006). Initially, adaptation approaches focused more on adjustments to technologies and physical structures (e.g. dams, irrigation and early-warning systems) based on the specific knowledge of climatic factors and their effects (Eriksen et al. 2007; Hammill & McGray 2018a). However, in recent years increasing numbers of adaptation studies and activities are considering a broad range of factors in addition to climatic factors in their planning and implementation (Füssel 2007a; Hammill & McGray 2018a). Non-climatic factors such as human actions and adjustments in behaviour, resource and technologies play a crucial role in shaping adaptive capacity (Adger et al. 2007). Poverty aggravates vulnerability and vice-versa, therefore poverty alleviation is equally crucial for vulnerability reduction as specific responses to climate risk (Rozenberg & Hallegatte 2015). A growing literature also underscores the importance of socio-economic factors and especially the integral role of management, institutions and governance in building the adaptive capacity of a system (Abeygunawardena et al. 2003; Adger et al. 2007; Antwi-Agyei et al. 2013; Engle 2011;

Mortreux & Barnett 2017; Piya 2019; Smit & Pilifosova 2003a; Williamson et al. 2012; Yaro et al. 2015). This study as well relies on an integrated approach to conceptualise climate change adaptation and considers adaptation measures should focus on climatic as well as non-climatic factors.

2.5 Conceptualizing the climate change adaptation benefits of decentralised renewable energy technologies

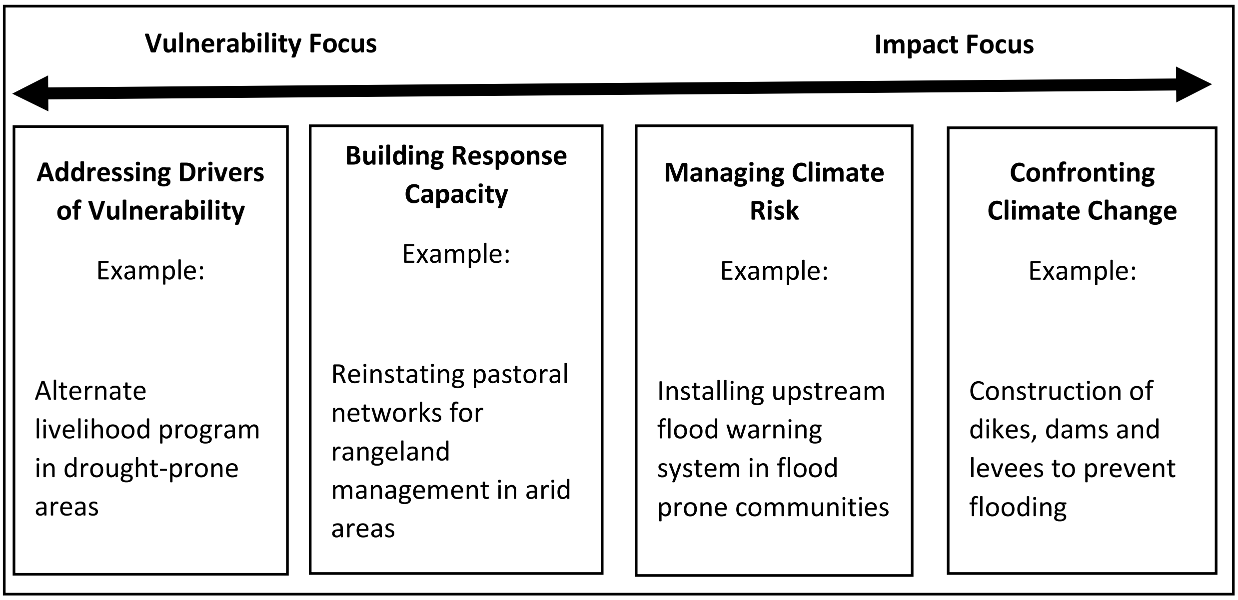
DRETs are a development tool to improve energy access and the standards of living (AEPC 2016). As introduced, modern energy access, especially electricity, is a vital prerequisite to poverty alleviation and achieving sustainable development goals (Kaygusuz 2011; Modi et al. 2005; Nkomo 2017; Sovacool & Drupady 2016; WEC 1999). Additionally, a well-designed DRET project can offer both climate mitigation and adaptation benefits. While the mitigation benefits are clear, as DRETs, by definition, are non-fossil fuel energy sources with no GHG emissions, the case for DRETs as effective measures for adaptation is less obvious (Perera et al. 2015; Venema & Rehman 2007). Therefore, this research investigates the very question about the potential climate change adaptation benefits of DRETs in rural Nepal. In the context of development activities contributing to climate change adaptation, the arguments suggested by Eriksen and O'Brien (2007) and McGray et al. (2007) about inter-linkages between development and climate change adaptation fit well for the purpose of this study.

Eriksen and O'Brien (2007) argue that not all poverty reduction measures reduce vulnerability and not all climate adaptation efforts reduce poverty, so responses that can do both, should be called sustainable adaptation measures. Such responses recognize that reducing poverty, inequality and vulnerability are all important parts of sustainable pathways to development (Cohen et al. 1998; Eriksen & O'Brien 2007; Schipper & Pelling 2006). Eriksen and O'Brien (2007) outline three different targets for sustainable adaptation; namely i) reducing climate risk, ii) addressing processes and factors leading to climate vulnerability and iii) strengthening adaptive capacity. Improving early warning and evacuation procedures to reduce climate risk, improving the collective management of natural resources to address the processes of vulnerability, and strengthening multiple sectors of the economy where poor people are engaged to improve adaptive capacity are some examples of sustainable adaptation measures (Eriksen & O'Brien 2007). Out of the above three, the first target mostly aims at reducing biophysical vulnerability, while the second and third targets aim to address socio-economic vulnerabilities. Development or poverty reduction efforts that help to achieve all three, or work independently without depleting the other two could be called sustainable adaptation measures (Eriksen & O'Brien 2007).

Ulsrud et al. (2008) used the concept to study if the development projects led by the Norwegian Development Fund could be considered as sustainable adaptation measures, and concluded that this approach can be used both as a framework to study how climate change affects people and as an analytical tool to examine adaptation efforts in a development project. Vognild (2011) also used this concept to study the climate adaptation benefits of solar power in India.

In a separate approach to defining adaptation-development linkages, McGray et al. (2007) have proposed the 'Development-Adaptation Continuum'. As a result of the significant overlap between development and adaptation strategies (Ayers & Huq 2009a; Hammill & McGray 2018b; McGray et al. 2007), it is often difficult to uniquely separate them (McGray et al. 2007). Instead, many activities undertaken to achieve development goals may also incidentally support adaptation (Adam 2015; McGray et al. 2007; Suckall et al. 2015; Ulsrud et al. 2008). McGray et al. (2007) categorise adaptation gains of development activities and targeted adaptation activities into a continuum where vulnerability and impact approaches represent two opposite extremes [Figure 2.7]. The vulnerability approach refers to adaptation measures or gains that focus on bolstering human development, reducing poverty or addressing other socio-economic factors which generate response capacity in the face of a harm; and include activities such as livelihood diversification, literacy promotion etc. (McGray et al. 2007). The impact approach on the other hand refers to adaptation measures or gains that focus on managing climate risk, confronting impacts of changing climate or addressing bio-physical vulnerability of a system; and includes activities such as installing early warning systems, draining of glacial lakes, constructing dikes etc. (McGray et al. 2007).

Figure 2.7 The Development-Adaptation Continuum



Source: (McGray et al. 2007, p.18)

The approaches suggested by Eriksen and O'Brien (2007) and McGray et al. (2007) have in common that they both suggest adaptation measures can and should extend beyond addressing climate risk alone. Bardsley and Wiseman (2016) argue that any effective intervention to deal with socio-ecological challenges in the Anthropocene needs to extend beyond direct interventions targeting particular climate change impacts. This is also the key theoretical proposition of this research, which argues that a development intervention such as DRETs, though not solely or even primarily designed to address climate risk, may still contribute to adaptation by reducing vulnerability in communities.

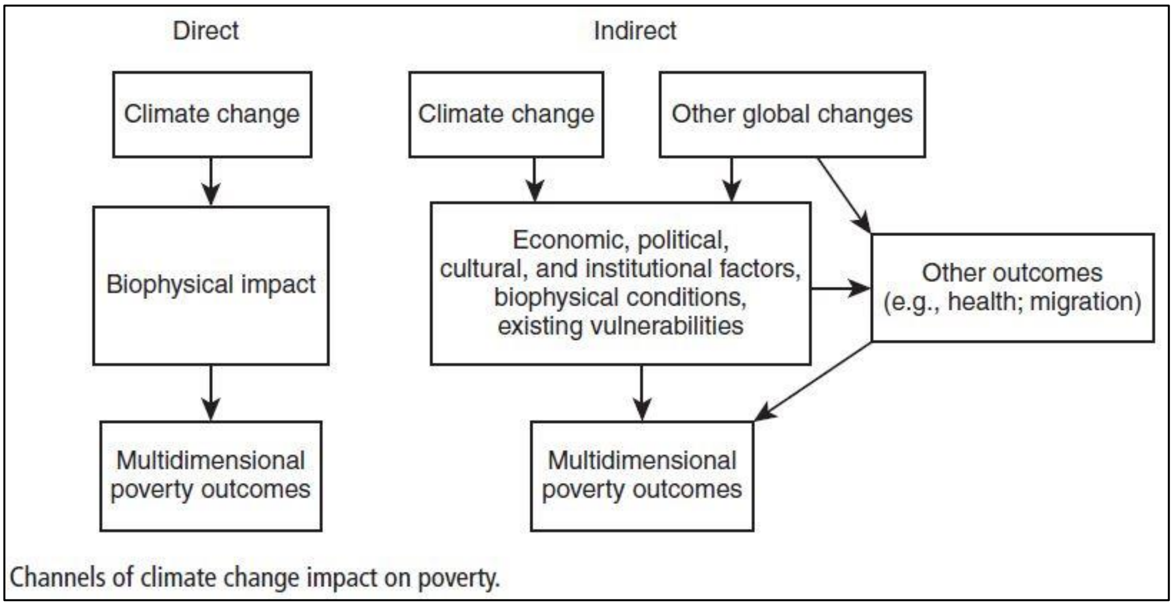
In order to examine the adaptation benefits for this study, any role of DRETs in either managing climate risks and associated impacts or addressing socio-economic vulnerabilities will be considered adaptation benefits of DRETs. Thus, DRETs’ role in reducing either biophysical vulnerability or socio-economic vulnerability or both will be considered the climate adaptation benefits of DRETs. In this research, DRETs’ direct contribution in managing climate risk and their associated impacts by facilitating activities and projects, which help in addressing biophysical vulnerability in the community are considered direct climate adaptation benefits of DRETs. DRETs’ contribution in reducing socio-economic vulnerability by addressing broader socio-economic factors such as income, literacy, access to natural resources etc. are considered the indirect or wider climate change adaptation benefits of DRETs.

This research adopted the concept of ‘direct’ and ‘indirect’ climate adaptation to enable a critical framework of analysis that would generate information that is in turn able to be disseminated in relatively simple forms to wider audiences. For example, the recent IPCC Assessment Report (AR5) presents the concept of climate risk and argues adaptation as measures that help in managing climate risk by reducing vulnerability and exposure. The adaptation focused climate risk management approaches suggested by (IPCC 2014d p.27) are highly complex and potentially confusing to end uses, particularly as concepts such as ‘vulnerability and exposure reduction’, ‘adaptation’ and ‘transformation’ have been presented as three different overlapping risk management approaches, which is not the way that they are being used by many scholars or practitioners. In just one example of the potential confusion, the intervention of ‘early warning systems’ appears as an example in all three approaches (IPCC 2014d p.27). Such a complex presentation of information can be confusing, especially for the non-expert readers, but even practitioners in the field have criticised this approach. Barkemeyer et al. (2016) and Mach et al. (2016) highlight the poor readability of the IPCC reports. Harold et al. (2020) have highlighted the complexity in understanding IPCC visuals and note that high quantity of information in IPCC’s assessment reports is leading to comprehension difficulty. Similarly, Howarth and Painter (2016) argue that the vast amount of evidence presented by the IPCC can be overwhelming to non-expert readers. Black (2015) notes that IPCC reports are ill-suited for non-expert audiences because of the use of terms that people will not be familiar with and a failure to distil the main conclusion into short summaries. So even though the IPCC’s assessment reports are widely regarded as the most authoritative publications (Howarth & Painter 2016), the IPCC has been criticised for its failure to effectively communicate with wider audiences and especially with the decision makers at the local level (IPCC 2016).

Stirzaker et al. (2010) note that decision makers and practitioners often complain about complex and fragmented information from science and therefore call for a simplified information that is useful at the scale of implementation. Howarth and Painter (2016) recommend that the vast amount of evidence and complex information presented by the IPCC needs better targeting and framing of the summaries from a local perspective to maximize engagement with local stakeholders. It is within such a context that this research uses the concepts and terms ‘direct’ and ‘indirect’ in order to present adaptation research output in simple forms. Actually, this is also how many respondents in Nepal were conceptualising the concept of climate change adaptation for themselves.

The concept of 'direct' and 'indirect' climate impacts and adaptation have also been used by a broad range of scholars (Islam & Winkel 2017; Leichenko & Silva 2014; Mertz et al. 2009; O'Brien et al. 2008). Islam and Winkel (2017), Leichenko and Silva (2014), and Mertz et al. (2009) refer to the concept of 'direct' and 'indirect' climate change impacts, or channels, and state that biophysical impacts are direct, and socio-economic impacts are indirect impacts of climate change (See Figure 2.8).

Figure 2.8 Direct and indirect channels of climate change impacts on poverty



Source: Leichenko and Silva (2014 p. 545)

Mertz et al. (2009) and O'Brien et al. (2008) refer to the concept of 'direct' and 'indirect' climate adaptation. Mertz et al. (2009) mention interventions to deal with biophysical impacts such as dike building to prevent flooding, and building of dams to expand irrigation as direct climate adaptation interventions. In another study, O'Brien et al. (2008) discuss direct and indirect climate adaptation and mention indirect adaptation as measures which are not specific to the impacts or risk of climate change, and rather are a by-product of some other livelihood support or coping mechanism that increases resilience to climate hazards.

Despite the specific conceptual framing of adaptation benefits in this study, the concept of 'direct' and 'indirect' climate adaptation can still be well-associated with the adaptation focused climate risk management approaches suggested by the IPCC (AR5). As stated earlier, the IPCC has proposed three overlapping approaches namely 'vulnerability and exposure reduction', 'adaptation' and 'transformation' (IPCC 2014d p.27). In that conception, the 'vulnerability and exposure reduction' approach generally includes measures such as human development, poverty alleviation, livelihood security, disaster risk management, ecosystem management and spatial or land-use planning. The 'adaptation' approach generally consists of physical/structural and institutional measures. The 'transformation' approach includes measures that aim at bringing social, personal, practical and political changes. Since the indirect climate adaptation benefits here refer primarily to improvements in livelihoods through improvements in income, education, health, infrastructure etc., the indirect adaptation benefits could also be identified as DRETs' contribution for vulnerability and exposure reduction. Similarly, the direct climate adaptation benefits, which refer to DRETs direct role in managing climate risk such as heatwaves, drought, floods etc could be referred to as DRETs' contributions to structural/physical adaptation.

In this study, the direct climate adaptation benefits of DRETs are evaluated on the basis of the observed cases of direct DRET contributions in managing climate risks. The indirect climate change adaptation benefits or, in other words, the DRETs' roles in reducing socio-economic vulnerability are assessed by analysing the impacts of DRETs on five livelihood capitals based on the sustainable livelihood approach (Carney 1998; DFID 1999; Ellis 2000). The sustainable livelihood approach focuses on several factors and processes that either enhance or constrain livelihood opportunities and the ability of people to live in an ecologically, economically and socially sustainable manner (Bennett 2010; Chambers & Conway 1992; Serrat 2017). These factors and processes range from global or national trends and structures over which individuals have little control to more local norms and institutions and the assets to which the households or individuals have direct access. The idea of livelihood assets is central to the sustainable livelihoods approach as the assets are the basis on which livelihoods are built and, in general, a greater and more varied asset base means a more sustainable and secure livelihood system (Burton et al. 2003). The sustainable livelihood approach identifies five types of capitals or assets upon which livelihoods are built, namely natural capital, physical capital, human capital, financial capital and social capital (DFID 1999).

Table 2.3 The Livelihood Capitals

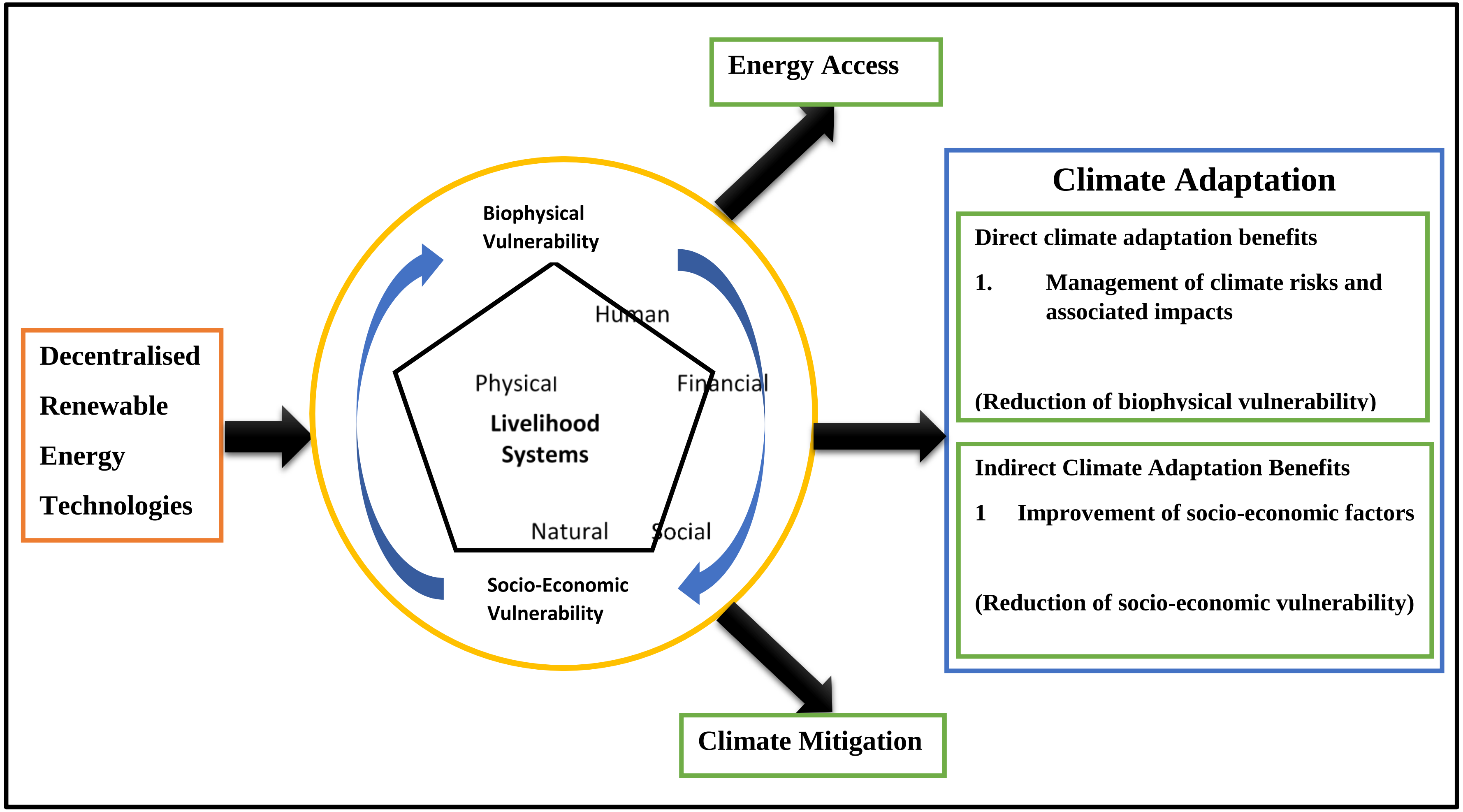
Capitals	**Description**
Human	Education, health, skills, knowledge, physical capability, confidence
Social	Family links, support networks, groups, conflict, influences over political decisions
Financial	Cash, savings, sources of income, debt, access to credit, assets that can be sold, financial services
Natural	Natural resources stocks and environmental services-soil, water, forest, environmental assets
Physical	The built environment, infrastructure and equipment-houses, schools, clinics, roads, dams, canals, farm machinery

Adapted from (DFID 1999)

The suitability of the 'Sustainable Livelihood Approach' for assessing vulnerability and adaptive capacity has been supported by several scholars (Carr 2014; Clay 2018; Jacobs et al. 2015; Lemos et al. 2013). Dasgupta et al. (2014) note that the concept of livelihoods, particularly in relation to assets and adaptive capacity has become the most common approach to analyse climate change vulnerability. On many occasions, scholars have argued that the improvement in livelihood capital enhances livelihood outcomes and adaptive capacity, and thereby reduces vulnerability (See: Bebbington 1999; Block & Webb 2001; DFID 1999; Li et al. 2017; Moser & Satterthwaite 2010; Nelson et al. 2010a; Paul et al. 2016; Su & Shang 2012; Thulstrup 2015). This study considers the improvement in livelihood assets namely (Natural, Human, Social, Physical and Financial) as outcomes that strengthen adaptive capacity and reduce vulnerability and thus as an indicator to measure indirect climate adaptation benefits of DRETs.

The conceptual framework for this study is graphically presented on Figure 2.9.

Figure 2.9 Conceptualisation of the climate adaptation benefits of decentralised renewable energy technologies (DRETs)



Source: Researcher's own construct based on concepts adapted from Sustainable Livelihood Framework approach (Carney 1998; DFID 1999; Ellis 2000), Eriksen and O'Brien (2007), and McGray et al. (2007)

2.6 Conclusion

This chapter reviewed the key concepts on energy access, development and climate change. It is noted that past development models have generally focused on economic growth and rarely fully addressed environmental and ecological concerns. However, more recently, there has been a realisation and emergence of environmental and ecological concerns around socio-economic development. Currently, the dominant development paradigm is more centred around “Sustainable Development’, which focuses on equity, economic growth and environmental protection. Climate Change and development are intricately linked with each other. Development actions affect the climate system and climate change affects development outcomes. In spite of such reciprocal and circular relationships, both fields have operated largely independent of each other in thoughts and action. Of late, however, scholars and practitioners are showing greater interest in integrating climate change concerns with development. Most of the academic literature around integration comes under the domain of climate policy integration, which calls for the greater integration of climate mitigation as well as adaptation into development policy making and practice.

The review of empirical studies suggest that the energy situation is very poor in Nepal with the majority of the population still relying on traditional biomass to meet their energy needs. In order to address the energy access problem and to promote economic growth, the government of Nepal has promoted renewable energy technologies in remote off-grid areas of Nepal. While the country is already one of the poorest and least developed, the changing climate is making the situation even worse. Nepal is experiencing rapid changes in climate, especially in the mountains, manifested through rising temperatures, glacial retreat, shrinking snow-cover, degrading permafrost and changes in rainfall patterns and the occurrence of extreme weather events. Since local lifestyles and livelihoods in Nepal are deeply linked with climate and the local environment, any changes in the climatic system and the environment are having profound impacts on existing ecological and socio-economic systems. This makes the generally poor rural communities highly vulnerable to climate change.

The literature review on vulnerability suggest that there are multiple approaches to conceptualise and measure the concept. Each approach has its own strengths and weaknesses. The biophysical or hazard approach focuses on the nature of climatic hazards, their frequency, intensity and impacts on a system. The socio-economic vulnerability approach is associated with factors such as economic resources, institutions, cultural practices, social cohesion and other characteristics of social groups, which are essential to cope with or adapt to any stress placed on the livelihoods of a community. For the purpose of this research, the vulnerability of a system is considered as the combination of socio-economic and biophysical vulnerabilities. Therefore, adaptation to climate change is defined as measures that reduce climate change vulnerabilities by addressing either socio-economic or biophysical vulnerabilities or both. The conceptual framework adopted for this study is based on the above conceptualization of vulnerability and adaptation and defines the climate adaptation benefits of DRETs as any direct or indirect impacts of DRETs in reducing climate change vulnerabilities by addressing either socio-economic or biophysical vulnerabilities or both. The ‘Research methodology’ chapter continues to explain the methods and systematic processes applied to meet the objectives of this research.

3 Research methodology

3.1 Introduction

This chapter discusses in detail the research approach and methods adopted to achieve the stated research objectives for this study. This study evaluates DRETs as one of the suitable measures of climate change adaptation in the Nepali mountains. For this, mixed methods, a combination of qualitative and quantitative approaches has been employed. The chapter begins with the philosophical foundations of the research design, followed by an explanation for the choice of mixed methods as a strategy of inquiry. The study areas are introduced and their brief geographic and demographic descriptions are provided. Further, tools and techniques of sampling, data collection, analysis and interpretation are discussed. Finally, the chapter discusses the ethical considerations and limitations of this research.

3.2 Epistemological foundation

Research design refers to the set of tools and procedures used to address the research problem (Creswell 2013). The philosophical positioning of a researcher is an important factor in research design, as the researcher's inclination towards a particular dictum influences the formulation of research problem, plan of actions and the use of research tools (Bailey 2008). While there are several methods available to address a particular research question, it is advised that the method that best matches the researcher's philosophical inclination be adopted. A method in this context refers to the technique or the way of proceeding to gather evidence, while research methodology refers to the underlying theory and analysis of how research does or should proceed (Kirsch & Sullivan 1992).

The term 'epistemology', often defined as the 'theory of knowledge' describes a researcher's position on what can be regarded as acceptable knowledge in a discipline (Bryman 2016). In epistemological considerations, 'positivism' and 'interpretivism' are two popular doctrines that influence social sciences research (Bryman 2016). The positivist approach advocates the imitation of tools and principles used in natural sciences to study social realities. The approach affirms the importance of application of 'scientific' methods and quantitative techniques for data analysis and hypothesis testing. Interpretivism, on the other hand in contrast to positivism, respects the differences between people and objects of natural sciences and posits itself as a strategy that explores the subjective meaning of social action (Bryman 2016). Accordingly, this approach emphasizes qualitative techniques over quantitative techniques. The interpretivist approach aligns closely with an alternative philosophical approach called constructivism, which also relies heavily on qualitative methods to conduct research (Andrew et al. 2019).

This research primarily lies within the social sciences domain, however, the study also has some components of quantitative analysis, which predominantly come under the natural sciences. Thus, this study draws from both the social sciences and natural sciences to investigate the climate change adaptation benefits of DRETs in Nepal. In this context, both interpretivist and positivist approaches are used in this research. In particular, the interpretivist approach is applied to understand the broader situation of local socio-ecological systems, their transformation due to climate change and their relationship with DRETs in Nepali mountains. For example, open-ended questions and in-depth interviews are used to explore how communities perceive and experience environmental and social change, how they are affected by the changes, and how DRETs contribute to respond to the changes.

In addition to the interpretivist approach, the positivist approach is essential for holistic understanding of the socio-ecological setting and its interaction with DRETs and climate change. The positivist method of statistical analysis is used to study inter-variable relationships and the differences between groups. For example, statistical averages are used to compare the perception of impacts of climate change between communities and the impacts of DRETs between different user groups. Additionally, weather records are analysed using positivist approach to understand trends in variability and to quantify the scale of changes. The findings from the quantitative analysis are then compared with local perceptions of the changing climate.

Overall, the combined use of the positivist and interpretivist approaches in this study complement each other to generate a holistic understanding of the local situation. Thus, this research uses two dominant epistemological doctrines together to construct a narrative on the risks of a changing climate and the role of DRETs in dealing with such risks in the Nepali mountain communities.

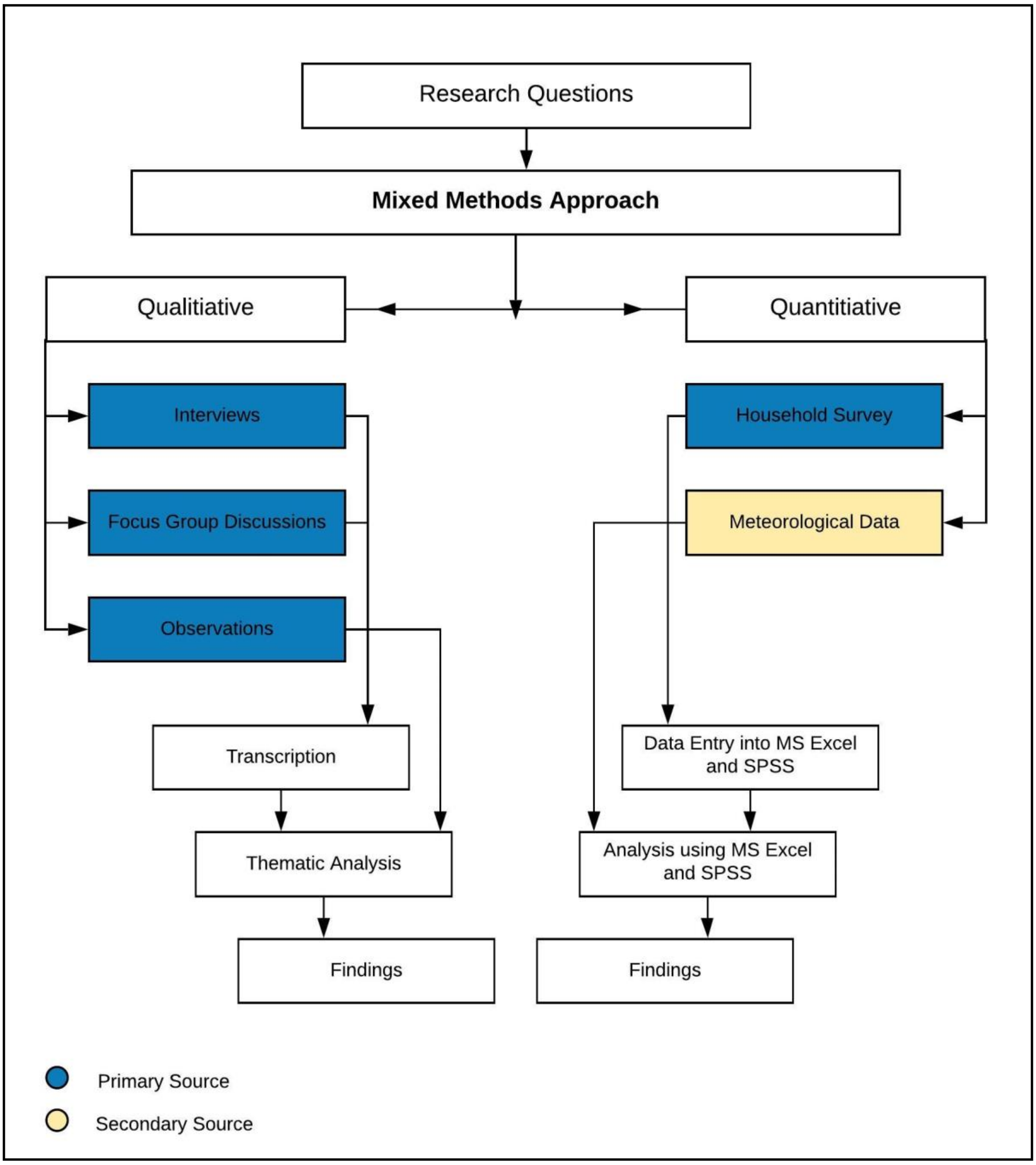
3.3 Mixed methods as the strategy of inquiry

Strategies of inquiry that guide research design can be generally classified into either quantitative or qualitative (Creswell 2013). The quantitative approach incorporates the practice and the norms of the natural scientific model, and positivism in particular (Bryman 2016). Thus, various statistical methods and mathematic models are applied to collect and analyse data, and to test the robustness of the hypothesis through a quantitative method of inquiry. In contrast, qualitative method refers to an alternative research strategy that focuses on seeking answers to why or how a particular phenomenon may occur, rather than how often it occurs (Lune & Berg 2016). The qualitative method uses descriptions and textual interpretations to explore perceptions and to find meanings from social actions, behaviour and expressions (Neuman 2005).

When the research strategy combines both qualitative and quantitative forms, it is called a 'mixed methods' approach (Creswell & Creswell 2017). Over time, the mixed methods approach has become a distinct research methodology and a strategy for inquiry in its own right (Clark & Creswell 2008). Bryman (2016) notes that qualitative and quantitative methods can be conflicting in their epistemological position, however, not necessarily in the methodologies applied. In recent years, there has been calls for the greater use of the mixed methods design in the implementation of the research (Landsverk et al. 2012; Palinkas et al. 2011; Proctor et al. 2009). In the study of energy systems in particular, scholars such as Broto et al. (2017), Lema et al. (2015), Pachauri and Spreng (2012), and Sovacool et al. (2016) have highlighted the need for interdisciplinary and mixed methods research strategies.

The mixed method strategy is appropriate in this study for two reasons. First, it allows the author and the readers to view a set of phenomenon from different angles using different data types and thus providing rich information through a deepening and widening of knowledge about the issue or its context (Olsen 2004). Second, qualitative data can be supported by quantitative data, and quantitative data can often be explained through qualitative insights, which together enhances the validity of the research (Creswell & Creswell 2017). This research uses the mixed methods strategy with an emphasis on qualitative approach. While the researcher acknowledges the potential subjective bias of that approach and limitations in generalising the findings and challenges in replicating the results in qualitative techniques, such an approach is necessary to understand and appreciate the complexity of socio-ecological interactions (Eyisi 2016). The role of mixed methods approach in ensuring the validity of this research is discussed later in section 3.8 of this chapter.

Figure 3.1 Overall research framework using mixed methods approach



Source: Author

3.4 The case study as a methodological strategy

This study employs case studies as a methodological strategy to identify answers to the research questions. The use of case studies is a well-established strategy to analyse complex phenomena in the social sciences (Yin 2014). Creswell et al. (2007) note that case studies have been commonly used in understanding local communities and studying local services and initiatives in diverse fields of social sciences. As one of the tools of empirical enquiry, a case study 'investigates a contemporary phenomenon within its real-life context' (Yin 2003, p.110), and it is suitable for answering the 'how' and 'why' questions (Baxter & Jack 2008). The case study approach for this research is appropriate, as it aims to understand how environmental, social and technical changes affect households, specifically in relation to the roles of DRETs in rural mountain communities. Feagin et al. (1991) further suggest that case studies are useful for understanding the actions, motives and larger social complexities of actors in their everyday settings.

The strategically selected cases of five different DRETs in three communities in Nepal are expected to provide sufficient information to understand the stated research problem. Through these case studies, the author aims to examine the changes within specific local contexts and gain a holistic understanding of how various factors and actors interact with one another in rural Nepal, which then can be used to generalise in similar contexts elsewhere (Flyvbjerg 2006; Patton 1990).

3.5 Introduction to study area

Nepal is a landlocked country situated in the central Himalayas between 26º22ʾN and 30ºʾ27ʾN latitudes and 80º40ʾE and 88º12ʾ E longitudes (Uddin et al. 2015). It has an area of 147,181 square kilometres with boundaries to India in the east, west and south, and China in the north. Despite being a small country, Nepal has a diverse geography and climate primarily due to wide variation in altitude (Lillesø et al. 2005). The altitude varies from 60 meters above sea level (masl) in the south to 8848 masl at the highest point in the north, which is also the highest point on Earth (Mount Everest) (Uddin et al. 2015).

Nepal's climate is influenced by the high Himalayas, the South Asian monsoon circulation and the westerly circulation (Shrestha et al. 2000; Shrestha et al. 1999). Local climatic conditions vary enormously with topography and as a result, Nepal experiences a wide range of climates from sub-tropical in the south to an alpine type in the northern mountains, all within a span of less than 200 km (Lillesø et al. 2005). The tropical monsoon generates up to 80% of the annual rainfall, falling during the summer months (Shrestha 2000; Singh 1985). Winter is relatively dry with occasional rainfall and snow, because the westerly wind generates occasional cold fronts (Karki et al. 2016). Although the winter precipitation is not as significant as summer monsoon, it is vital for generating water flows for agriculture during winter, especially in the north-west region of the country (Shrestha & Aryal 2011). On average, Nepal receives an average annual rainfall of 1768 mm (Shrestha et al. 2000), with a varying range of precipitation from less than 200 mm in Mustang to over 5000 mm near the Pokhara valley (Karki et al. 2016).

Topographically, Nepal is broadly divided into three ecological zones from south to north (Dahal 2010). Detailed classification divides Nepal further into eight physiographic divisions namely: *(1) Terai (2) Siwalik or Churai Range, (3) Dun Valleys, (4) Mahabharat Range, (5) Midlands, (6) Fore Himalaya, (7) Higher Himalaya, and (8) Trans Himalaya*. Each of these divisions has unique altitudinal variations, slopes, relief characteristics, and climatic patterns (Dahal 2010). The flat plains or "*Terai*" is a narrow strip of relatively flat and fertile land situated in the southern part of the country south of the middle mountains. The "*Terai*" region constitutes 17% of the national area and houses 50.3% of national population (Central Bureau of Statistics 2012). Its elevation ranges from 60 masl to 300 masl (Lillesø et al. 2005). The *Terai* has a warm tropical climate. The mountains or "*Pahad*", lie in the middle between *Terai* and *Himal* with complex mountains, slopes and river valleys and are the site of the case studies for this research. The mountain region is sometimes referred to as the Hills also. The mountains cover 68% of the national area and house 43% of population (Central Bureau of Statistics 2012). The altitude ranges from 600 masl to 4,877 masl. The mountain region has the cool temperate climate. The Himalayas "*Himal*" region lies in the northern part of the country with snow-capped mountains year round. The Himalayas is also sometimes referred to as the high mountains. The Himalayas covers 15% of the national land area and house only 6% of the national population (Central Bureau of Statistics 2012). The elevation in the Himalayas ranges from 4,877 masl to 8848 masl at the highest point in the north. The Himalayas has a cold alpine climate.

3.5.1 The Mountains

The mountains lie between the high snow-capped Himalayas in the north and the flat plains in the south. Two major mountain ranges, commonly known as the *Mahabharat Lek* and *Churia Range* occupy the region. The steep slopes on the southern *Churia Ranges* are nearly uninhabited and act as buffer between the Terai and the Mountains (Dhital 2015). The Mountain region has difficult terrain with complex slopes, river basins and valleys (Dahal 2010). The soil is generally semi-fertile and because of the steep slopes, the topography does not favour agriculture as much as in Terai.

The region has a cool temperate climate, with four distinct seasons: spring/pre-monsoon (March-May), summer/monsoon (June-September), autumn/post-monsoon (October-November) and winter (December-February). During the summer/monsoon, moisture laden air masses build up over the bay of Bengal and then sweep in to the mountains to deposit up to 80% of total annual rainfall (Shrestha et al. 2000), whereas the winter is relatively dry (Karki et al. 2016). The mountain region receives an average annual precipitation ranging from 275 mm to 2300 mm, and has a mean annual temperature ranging from 10ºC to 20ºC (WECS 2005).

The difficult terrain has slowed infrastructure development and overall socio-economic growth (Cosic et al. 2017; Metz 1995). Despite its relative geographic isolation and limited economic potential, the region has always been the political and cultural centre of Nepal. Kathmandu and Pokhara are some of the biggest urban centres, with Kathmandu also being the national capital. Hindu *Paharis*[1] such as Brahmin, Chhetri and indigenous Janajati groups such as Newars, Gurungs, Magars and Tamangs, predominantly inhabit the Mountains (Central Bureau of Statistics 2012). Up until 1991, the mountain region had the highest share of the national population, however, heavy out-migration to the Terai in recent decades has led to a population decline (Central Bureau of Statistics 2012).

The sections below discuss individual case study locations in the mountains.

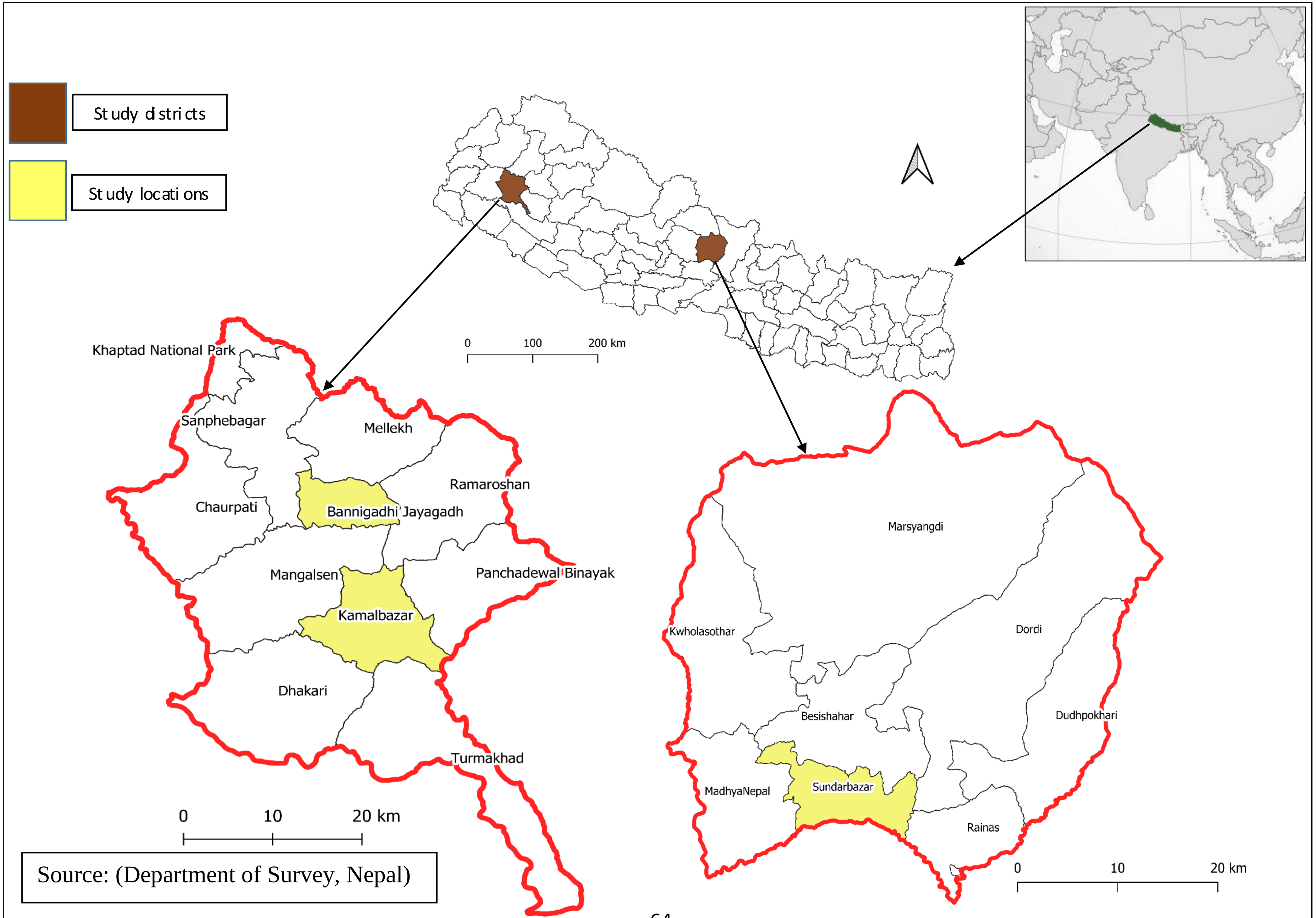
3.5.2 Study sites: Kamal Bazaar, Darna and Sunder Bazaar

This study employs a case study design to evaluate the climate change adaptation benefits of five DRETs in three different communities of Nepal. The study sites were purposively selected for the study. Patton (2014) notes that such purposeful sampling is a widely used technique in qualitative research to identify and select information-rich cases for the most effective use of the limited resources. To achieve an effective selection of case-study locations, significant prior evaluation of the national programs were undertaken. Based on the national classification (NAPA 2010), two highly vulnerable districts namely Achham in far west and Lamjung in central Nepal were selected. After arriving in Nepal for fieldwork, the researcher consulted with renewable energy and climate change experts at AEPC in Kathmandu to help to select potential study sites within those districts. The AEPC provided a list of locations with access to DRETs. Out of the list, Kamal Bazaar and

[1] Mountain dwellers

Darna village from Achham district and Sunder Bazaar village from Lamjung district were selected because these villages had have high uptake of DRETs.

Figure 3.2 Case study locations in Nepal



Source: (Department of Survey, Nepal)

3.5.2.1 Kamal Bazaar

Kamal Bazaar village is located in Kamal Bazaar local council in Achham district in the Sudur Paschim province in the far west of the country. The study was conducted in Ward 1 and 2 of the local council area. Kamal Bazaar is connected to the district headquarters with a seasonally motorable road and has no access to the national electricity grid. According to the local council records, Kamal Bazaar lies within the *Mahabharat Range* and has a distinct mountainous topography with steep slopes and deep basins (Kamal Bazaar Council 2018). The elevation for Kamal Bazaar local council ranges from 680 masl to 2200 masl. The study site is located at an elevation of approximately 1900 masl. Analysis of long-term weather records from the nearest meteorological station [Pusma Camp (DHM Station Index No. 0401, Elevation: 950m)] by the author shows average maximum temperatures of around 33ºC in the month of May and average minimum temperatures of around 8ºC in the month of December [see section 5.2]. The average annual rainfall is about 1740 mm [see section 5.2]. Some locations at higher elevations also receive snowfall during the winter season.

According to a survey conducted in 2017, Kamal Bazaar council has a population of 30,400 in 4,574 households (Kamal Bazaar Council 2018). Out of the total population, 49.5% are females, 50.4% are males and the entire population in Kamal Bazaar follows Hinduism. People of different castes such as Chhettri, Brahman and Dalits live in Kamal Bazaar with majority being Chhetri followed by Dalit and then Brahmin. Of the total population aged 5 years and above, 59.5% are literate. Agriculture, external remittances and wage labour are the primary sources of livelihoods. The majority of the population identify agriculture as their primary occupation. Rice, maize, wheat, barley and oil seeds are the major crops grown in Kamal Bazaar. Citrus fruits such as oranges, limes and lemons are also widely grown in the region.

A more detailed description of the ecological and socio-economic situation about Kamal Bazaar has been developed from the fieldwork data and is available in Chapter four.

3.5.2.2 Darna

Darna is a village located in Bannigadhi Jayagadh local council in Achham district in the Sudur Paschim province. The study was conducted in Ward 6 of the local council area. As Darna and Kamal Bazaar lie in the same geographic and administrative region, both have many similarities. For example, like Kamal Bazaar, Darna lies within the Mahabharat range and therefore has a distinct mountainous topography and climate (Bannigadhi Jaya Gadh Council 2018). Darna and Kamal Bazaar have similar climatic features [as described in section 3.5.2.1]. Like Kamal Bazaar, Darna has one seasonally motorable road and has no access to the national electricity grid. The aerial distance between Kamal Bazaar and Darna is only around 14 km, however, if travelled by road, a distance of around 65 km has to be covered through the mountains. The elevation of the Bannigadhi Jayagadh local council ranges from 691 masl to 2100 masl and the study site in Darna is located at an elevation of approximately 1215 masl.

According to the local survey conducted in 2018, Bannigadhi Jayagadh council has a population of 21,629 in 3,373 households (Bannigadhi Jaya Gadh Council 2018). Out of the total population, 48.6% are females and 51.3% are males. Like Kamal Bazaar, the entire population in Bannigadhi Jayagadh follow Hinduism and are of Chhettri, Brahman, Dalits and Janajatis castes. Majority of the residents are of Chhetri caste followed by Dalits, Brahmins and Janajatis. Darna has a literacy rate similar to Kamal Bazaar at 57.7%. Agriculture, remittance and wage labour are the primary sources of livelihoods with majority identifying agriculture as their primary occupation. Rice, maize, wheat, barley and oil seeds are major crops grown in Darna. Citrus fruits such as oranges, limes and lemons are also widely grown in the region.

A more detailed description of the ecological and socio-economic situation about Darna is available in Chapter four.

3.5.2.3 Sunder Bazaar

Sunder Bazaar is a village located in Sunder Bazaar local council in Lamjung district, Gandaki province in the central part of the country. The study was conducted in Ward 2 of the local council area. Unlike Kamal Bazaar and Darna, Sunder Bazaar is well connected to other parts of the country through all-weather metalled roads and has access to the national electricity grid. The powerhouse of one of the major hydropower stations, Mid-Marshyangdi Hydropower-70 MW (Megawatts) is located in Sunder Bazaar. Like Kamal Bazaar and Darna, Sunder Bazaar also lies in the mountainous region with landscape of rugged topography (Sunder Bazaar Council 2018). The elevation of Sunder Bazaar local council ranges from 600 masl to 1480 masl. The study site in Sunder Bazaar is located at an elevation of approximately 700 masl. Analysis of long-term weather records from the nearest meteorological station [Khudibazaar station (DHM Station Index No. 0802, Elevation: 823m)] by the author shows average maximum temperature of approximately 30.5ºC in the months of May - June and average minimum temperature of around 6.5ºC in the months of December [see section 5.2]. Although the average minimum and maximum temperatures are similar, the average annual rainfall of around 3300 mm is much higher in comparison to that of Kamal Bazaar and Darna.

According to the latest records, Sunder Bazaar local council has a population of 26,864 in 7,199 households (Sunder Bazaar Council 2018). Out of the total population, 43.8% are females and 56.2% are males. In Sunder Bazaar, 97% follow Hinduism and the remaining 3% follow Buddhism. People of different castes such as Brahman, Chhettri, Janajatis and Dalits live in Kamal Bazaar with majority being Janajatis followed by Dalits, Brahmin and Chhetri. Sunder Bazaar has a higher literacy rate at 70.8% in comparison to Kamal Bazaar (59.6%), and Darna (57.7%). Agriculture, salaried job in military and police, external remittance and wage labour are the primary source of livelihoods. Like Kamal Bazaar and Darna, agriculture is the primary occupation for majority of the households. Rice, maize, wheat, mustard and pulses are major crops grown in Sunder Bazaar. Farmers grow potatoes, vegetables and fruits as minor crops.

A more detailed description of the ecological and socio-economic situation about Sunder Bazaar is available in Chapter four.

3.6 Data collection

Irrespective of philosophical standpoints and research methods, research generally involves the gathering of large amount of data (Sutton & Austin 2015). The data could come through primary or secondary sources. While primary data represents original and unique data collected directly from a first hand source or study object, secondary data is obtained through published studies and articles, reports and periodicals. This research relied on both primary and secondary sources of data.

3.6.1 Primary Data

Primary data represents original and unique data gathered directly first hand. Primary data were collected at the study sites in Achham and Lamjung districts and in the national capital, Kathmandu from May 2018 to October 2018. Both quantitative and qualitative data were collected. Household surveys were used to collect quantitative data. Focus group discussions (FGDs) and expert interviews were designed to generate in-depth qualitative responses from participants. The Primary data collection techniques are graphically presented in Figure 3.1.

3.6.1.1 Sample selection

A sample is defined as a finite part of a statistical population whose properties are studied to gain information about the whole (Merriam-Webster 2020). As the definition suggests, sampling is essential in most research as studying everyone, everywhere or everything is rarely feasible. Several sampling techniques are available for the purpose. Such techniques can be generally categorised into probability sampling and non-probability sampling (Taherdoost 2016). The probability sampling is a method in which all the members of the population has a pre-specified and an equal chance of being chosen as a representative sample, whereas, in non-probability sampling there is no specific probability that any given person will be in the sample set (Bryman 2016).

This research adopted both probability and non-probability sampling techniques. For quantitative data collection, the probability sampling technique adopted aimed at providing a close to representative sample for the study sites. For household surveys, a sample size of (n = 331) was determined from the total households of (n=2351) in three study sites [Kamal Bazaar -822 (35%), Darna-823 (35%) and Sunder Bazaar-706 (30%)]. The sample size was calculated using the sample size calculator tool available at Australian Bureau of Statistics website[2]. The total sample size calculated was then proportionally divided between individual study sites [35% of 331 for Kamal Bazaar, 35% of 331 for Darna, and 30% of 331 for Sunder Bazaar]. Thus, the actual sample size for individual study sites was 116 for Kamal Bazaar, 116 for Darna and 99 for Sunder Bazaar [Table 3.1].

[2] Sample size calculated at 95% confidence level and 0.05 confidence interval using 'Sample Size Calculator Tool' available at: https://www.abs.gov.au/websitedbs/d3310114.nsf/home/sample+size+calculator .

Table 3.1 Household survey sample population by location and gender

Study Sites	Male		Female		Total	
	Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Kamal Bazaar	84	72.4%	32	27.6%	116	35%
Darna	77	66.4%	39	33.6%	116	35%
Sunder Bazaar	54	54.5%	45	45.5%	99	30%
Total	215	65%	116	35%	331	100%

Source: Field Survey, 2018

For qualitative data collection through FGDs and expert interviews, non-probability sampling techniques such as purposive and snowball sampling were used. The purposive sampling method for this study involved identifying and selecting individuals who had rich knowledge and experience in the field of decentralised renewables and climate change (Cresswell & Plano Clark 2011). The snowball sampling involved taking suggestion or referral from the existing research participant to recruit another potential participant (Yin 2015). Despite the relevance of purposive and snowball sampling for this research, it should be noted that unlike probability sampling technique, it is impossible to determine the possible sampling error and make generalisations from the sample to the population as such samples should not be considered to be representative of the population being studied(Sharma 2017a). Additionally, the purposive sampling can be highly prone to researcher bias. Table 3.2 provides site wise details of FGDs and expert interviews conducted for this research.

Three FGDs were conducted at each study sites, altogether nine FGDs were conducted. Out of three FGDs, two FGDs included both men and women participants and one separate FGD included women only participants. The participants for FGDs were the adult members of the communities and came from households who had not participated in surveys. Local resource persons, Community Forestry User Groups (CFUG) and Mothers' groups at the study sites were approached to suggest FGD participants for this research. Phone calls were made to prospective participants to request their participation at FGDs. Once they arrived for the FGD, proper details were provided through participant information sheet and their approval was sought before starting the FGD. The participants for each FGDs ranged from seven to fifteen persons. The FGDs lasted from 1.5 hours to 2 hours. The FGD included 20 questions and the researcher sought a common response to the questions from the group. If the group agreed to a response from any individual in the group, the researcher moved ahead with next question. The researcher provided enough time for counter arguments and collected information, which majority believed to be true. For expert interviews, national experts and experts at the study sites with rich knowledge and experience in the field of decentralised renewable energy technologies, climate resilience and disaster risk management were approached personally via phone and email for the expert interview. After the experts allowed time for a meeting, the researcher visited them at locations convenient for them and provided details about the research through participation information sheet and sought their approval before starting the interview. Twelve expert interviews were undertaken at the study sites and eight expert interviews were undertaken in Kathmandu, the national capital. Altogether, 20 expert interviews were conducted, where seven experts were women.

Table 3.2 Site wise number and participant size of focus group discussions (FGD) and expert interviews

Sites	FGDs (Women Only)		FGDs (Mixed)		Expert Interviews
	No.	Participants	No.	Participants	
Kamal Bazaar	1	9	2	16	4
Darna	1	11	2	25	4
Sunder Bazaar	1	10	2	17	4
Kathmandu	-	-	-	-	8
Total	3	30	6	58	20

Source: Field Survey, 2018

3.6.1.2 Household surveys

The survey is a common tool for data collection in social sciences research (Walter 2006). The survey method involves gathering quantitative or numeric information about frequency, characteristics, trends, behaviours, attitudes and opinions of people from a sample population based on a standard set of questions (Creswell & Creswell 2017). One of the main advantages of survey is that it allows the collection of information on a big scale from a large section of a population. However, when the surveys are self-administered, there is no room for probing into details based on initial responses. In the context of Nepal, self-administered surveys are not always feasible as there are many practical barriers to access. One key limitation is that poor physical mail delivery systems and a lack of internet and email services in remote parts of the country make delivery and retrieval of survey packages very challenging. Moreover, a significant percentage of adults, especially in rural areas are still illiterate and thus cannot respond to surveys. Therefore, for this research, the researcher visited individual households to conduct surveys. The researcher facilitated the process by first informing about the research then by explaining survey questions and taking note as participants provided their responses.

A total of 331 household surveys; 116 in Kamal Bazaar, 116 in Darna and 99 in Sunder Bazaar were conducted. The households for the surveys were randomly selected from a list of DRET connected households. Survey respondents were usually the head of the households and above 30 years of age. The 30-year age limit was followed so that the respondent could report the changes observed in their environment in the last 2-3 decades. If a suitable respondent was not available because of reasons such as the house was locked, the respondent was below the age of 30, or the respondent did not wish to participate, then an adjacent household was approached.

The household survey employed a questionnaire schedule (Appendix 1), which was based on the review of existing literature. Pre-test of the questionnaire was carried out to check its efficacy and necessary changes were made accordingly before the start of the survey. The questionnaire was designed in line with the research questions for this study and was divided into six sections: i) Questionnaire Details, ii) Demographic details, iii) DRET details, iv) Climate change and associated impacts, v) DRETs' direct role in addressing the observed climate risk and vi) DRETs' impact on livelihood capitals. Such classification facilitated a deeper understanding on the issue that was being studied. The questionnaire included both open and close-ended questions, which enabled simultaneous collection of quantitative and qualitative data. While the questions on DRETs, demography, the scale of changes in environment, and the level of DRETs' impact on livelihood capitals were generally close-ended and quantitative in nature, the questions on the experiences of climate variability, the role of DRETs in directly dealing with climate risks and the impacts of DRETs on livelihoods were open-ended and qualitative. Local perceptions on the scale of change were quantified on a scale of 1 to 5, where 'No Change' = 1, 'Not Sure'= 2, 'Some Change' = 3, 'Change' = 4 and 'Considerable Change' = 5. Similarly, local perceptions on the level of DRETs' impacts on livelihood capitals were quantified as 1= 'Very Negative', 2= 'Negative', 3= 'Neutral', 4= 'Positive' and 5= 'Very Positive'. The close-ended questions provided ready-made response options for participants, which ranged from 'YES' or 'NO' to multiple-choice answers. The responses for the close-ended questions were marked on the questionnaire itself for quick data taking and efficient processing. The open-ended questions sought further in-depth information from the participants. Although the questionnaire was drafted in English, the researcher translated the questions into the Nepali language with dialects and terminologies common to the study sites with the help of field assistants. The researcher himself conducted the surveys with assistance from two local field assistants, who were well oriented before the start and supervised during the course of the survey. On average ten surveys were conducted in a day during the months of July, August, and September in 2018. The researcher contacted and sought constant feedbacks from research supervisors throughout the survey period.

3.6.1.3 Focus group discussions (FGD)

Focus group discussions (FGD) are useful tools to collect information from large numbers of people in a limited time and expense (Longhurst 2003). A focus group refers to a group of people gathered in a formal setting to discuss about a particular topic set by the researcher (Longhurst 2003). A total of nine FGDs, three at each study sites were conducted. The participants for FGDs were the adult members of the communities and came from households who had not participated in surveys. Local resource persons, Community Forestry User Groups (CFUG) and Mother's groups at the study sites were approached to suggest FGD participants for this research. The participants for each FGDs ranged from seven to fifteen persons.

The researcher moderated the FGD process, while research assistants assisted with note taking. All focus group members were given an equal chance to provide their views either in support or in contradiction to the views of other members. However, in such settings, group dynamics can profoundly affect the direction of discussions in a certain way. Stewart et al. (2007, p.116) note that elements of 'desirability influences, pressure to conform to group thinking, or the persuasive effects of a dominant group members' should not affect the outcome of the discussion. Therefore, the researcher as the moderator had to guide the direction of the discussion with a focus on extracting relevant information needed for the research without giving way to unreasonable or irrelevant distractions. For example, the researcher had to intervene when the discussion about the role of political parties in initiating solar-wind micro project in Kamal Bazaar became unpleasant.

At each study site, one FGD had women only participants and the other two had mixed participants. Topics discussed during the focus groups were similar to those covered in the surveys, except that the FGD sought answers at community level while surveys targeted responses at the household level. The FGD schedule (Appendix 2) was used to guide the discussion process and to make sure all the topics were covered. FGDs were conducted in public spaces convenient to participants and were audio-recorded with prior permission from the participants.

The FGD as a tool for data collection offered several advantages for this research. In addition to qualitative data collection, FGDs facilitated data triangulation as the information gathered through FGDs were crosschecked with the information obtained from other collection methods such as surveys and interviews to confirm the validity of the data.

The FGDs also allowed the opportunity to observe social interactions of individuals from varied castes and economic backgrounds in a community setting.

3.6.1.4 Expert interviews

An interview involves a one-to-one discussion between two individuals, an interviewer and an interviewee, to generate information on a specific topic (Harrell & Bradley 2009). Interviews are useful tools in gaining information about opinions, events and experiences to fill gaps in knowledge and to investigate complex behaviours and motivations (Dunn 2000). Expert interviews were necessary for this study for two important reasons. First, experts who are high-level officials or figures are usually busy and do not always respond to surveys. In such cases, interviews can be an effective tool to gather particularly valuable information from such individuals especially in relation to questions of governance and policies. Second, interviews as a data collection tool offer greater opportunity to probe, thus enabling a deeper insight and understanding of the topic.

A total of 20 expert interviews, eight with national experts in Kathmandu and 12 with local experts at the study sites were conducted. Interviews were conducted with the experts in the field of renewable energy technologies, climate resilience and disaster risk management; and were approached via phone, email or meeting in person. The national level experts were affiliated to organisations such as AEPC, Ministry of Energy, Water Resource and Irrigation (MOEWRI), Ministry of Forest and Environment (MOFE), multilateral development organisations, non-government organisations (NGOs), universities and research organisations. At the local level, the experts included representatives from the local councils, NGOs, DRET management committees and disaster risk management committees. The researcher himself conducted all the interviews so that the range of responses can be treated in the same manner.

During the interview, the national experts were asked about climate change and associated risk at national and regional level, policies around DRETs and climate change, the impacts of such policies, and the potential and observed impacts of DRETs on climate risk and on broader development goals. Similarly, the local experts were also asked about local climate variability and associated risk, local DRET projects and their impacts on climate risk and development. The interviews usually lasted for one hour and were audio recorded with prior permission from the participants. An interview schedule (Appendix 2) was used to guide through the process. Five interviews were conducted with national experts in

Kathmandu prior to the start of surveys in study sites. Twelve expert interviews were conducted in study sites together with surveys. The remaining three expert interviews were conducted in Kathmandu after the completion of the surveys. The information obtained from expert interviews was useful in providing greater insights and in comparing and triangulating information obtained through FGDs and surveys.

3.6.1.5 Observations, informal conversations and photographs

Observation is one of the important ways to generate rich primary data as it helps to capture details that may not be reported by other data collection methods (Yin 2015). Observation over a long period leading to greater understating of the study sites improves rigour and validity of research (Bryman 2016).

The researcher spent considerable amounts of time in the study area to understand key behaviours, actions and interactions in the community. In order to engage and build trust, the researcher spent many days interacting with community members, participated in community events and meeting community members for tea and lunch when invited. Apart from formal surveys and interviews, the researcher engaged in informal conversations during community events and other casual meetings. Being a Nepali and having a fluent command of Nepali language helped the researcher easily connect with the community members. Additionally, the researcher’s previous experience as a field researcher proved useful in the observation process.

The information obtained through observation and informal conversations were gathered in the form of field notes, sketches and photographs. Observations help researchers in recreating images of the studied phenomenon (Yin 2014), and photographs in particular can jog the memory and allow researcher to recall detailed information during the time of data analysis. Photographs relevant to research were taken when and where necessary with prior permission from the community members. Photographs and information from observations and informal conversations have been incorporated wherever relevant in the findings chapters of this study.

3.6.2 Secondary data

Secondary data refers to data that is collected by someone other than the researcher for some other purpose (Allen 2017). The secondary data provide readily available resources to examine characteristics of populations or particular hypothesis (Vartanian 2010).

Weather data is an important component of this research, primarily used to analyse the trend in temperature and precipitation change at the study sites. The weather data consisting of daily minimum and maximum temperatures and precipitation records for past three decades were collected from the Department of Hydrology and Meteorology (DHM) in Kathmandu. As weather stations were not precisely located at the study sites, the stations close to study sites were chosen for weather data collection. Daily temperatures recorded at Pusma Camp station [DHM Station Index No. 0401, Elevation: 950m] and precipitation recorded at Sutar station [DHM Station Index No. 0404, Elevation: 1231m] were analysed to determine the extent of any trends in Kamal Bazaar and Darna in Achham district. Similarly, daily temperatures and precipitation recorded at Khudi Bazaar station [DHM Station Index No. 0802, Elevation: 823m] were collected to analyse the trend in Sunder Bazaar in Lamjung district.

Additionally, secondary sources of data such as peer reviewed articles, reports, policy documents, working papers and local council profiles were consulted for this study. Such secondary sources informed the researcher about recent context of climate variability, their impacts and coping practices in the region. The secondary sources also provided greater insight into local policies and programs around climate change and decentralised renewable energy technologies. Policy documents on decentralised renewable energy technologies and climate change adaptation were sourced from the websites of Alternative Energy Promotion Centre (AEPC), Ministry of Energy, Water Resource and Irrigation, and Ministry of Forest and Environment in Nepal. Reports on the progress of energy access in the study areas were obtained from AEPC and Nepal Electricity Authority (NEA). Reports on the progress of climate adaptation plans and actions were obtained from National Climate Change Support Program (NCCSP) and local NGOs operating in the region. Population and other demographic data were obtained from the website of the Central Bureau of Statistics and offices of the local councils during the field visits.

3.7 Data analysis and interpretation

Data gathered during the research process requires categorization, analysis, organisation and interpretation to explore the meaning out of the data (Marshall & Rossman 2014). This research used various tools and techniques, based on the data type and the questions to be answered to analyse the data. Quantitative data from household surveys were analysed using MS-Excel (Microsoft Excel- 2016) and IBM SPSS (Statistical Package for Social

Sciences-Version 25) as they are recognised tools for quantitative data analysis software in social sciences (Bryman & Cramer 2011).

The data collected through the household survey were carefully coded and entered into SPSS. The household survey data were then analysed mostly through the use of the descriptive statistical analysis tools such as frequencies, measures of central tendency and variability. Descriptive statistics and chi-square (X^2) tests were performed in SPSS to summarise information and to make meaningful comparison between study sites. MS-Excel was used to draw graphs. The meteorological data obtained from the Department of Hydrology and Meteorology (DHM) in Kathmandu was analysed using MS-Excel and SPSS to understand the changing trend in temperature and precipitation at study sites. Linear regression analyses were performed on SPSS to test the level of significance of the detected change. Linear regression analysis is a non-parametric test to determine whether a linear relationship and trend exists between variables with a 95% confidence interval (Haan 1977). For the level of significance, a P-value less than 0.005 (typically ≤ 0.05) was considered to be statistically significant.

Qualitative data for this research were collected through interviews, focus group discussions (FGDs) and observations. Audio recorded interviews and FGDs were first transcribed and then analysed using the thematic analysis. Thematic analysis refers to identifying, analysing and reporting implicit as well as explicit ideas or themes with in data (Braun & Clarke 2006; Guest et al. 2011). It is a commonly used approach for qualitative data analysis (Castleberry & Nolen 2018).The process of thematic analysis followed five steps suggested by Renner and Taylor-Powell (2003). The first step was to become familiar with the data by reading and re-reading it. The second step was to focus on the analysis by identifying key questions that were to be answered. The third step was to categorize the information coherently by identifying themes or patterns. The fourth step was to identify patterns and connections within and between the categories. Finally, the fifth step was to interpret the data by using themes and connections to explain the findings. In line with the thematic analysis process stated above, raw data in the form of audio recordings were listened to several times and the transcription and the field notes were thoroughly read to identify themes and sub-themes. An inductive coding process was applied where the themes and sub-themes were determined based on research objectives and the questionnaire prepared for the research. A matrix table with themes and sub-themes was used to enter information and quotes extracted from the transcripts. Field notes and photographs were also categorised on the basis of identified themes and used for interpretation. The qualitative data was then analysed and interpreted to derive meaningful conclusions.

Following the essence of the mixed methods research design, the findings from both quantitative and qualitative approaches have been integrated in the analysis and discussion of the results. Results obtained through the quantitative method were compared and combined with qualitative findings to triangulate and to increase the validity of the research. The quantitative results are communicated through the use of charts, graphs and tables, while the qualitative results have been presented descriptively. Photographs and quotes from research participants are used to enhance richness and the validity of the information provided. Table 3.3 summarises research questions, corresponding data collection methods and data analysis techniques adopted to answer the research questions for this study.

Table 3.3 Summary of the data collection and analysis techniques

Research questions	**Data needed/ Data type**	**Methods of data collection**	**Data analysis**
What is the status of local livelihoods in the study area?	Demographic Quantitative	(Primary) -Face-to-face household surveys, observations (Secondary sources) -Census and local council data	- Comparative percentage, frequency and descriptive statistical analysis of quantitative data
What is the extent of change in key climatic parameters in the study area?	Meteorological data Quantitative	(Secondary) -Department of Hydrology and Meteorology (DHM)	Descriptive and Inferential statistical analysis of quantitative data
How are locals perceiving climatic trends and experiencing the impacts of environmental change on their livelihoods?	Description of observed changes, experiences and impacts of changing climate Qualitative, Quantitative	(Primary) -Face-to-face household surveys, interviews, FGDs, observations	-Thematic analysis of qualitative data - Comparative percentage, frequency and descriptive statistical analysis of quantitative data based on survey respondents' perceptions

What is the level of access to DRETs in the study sites?	DRET features Quantitative Qualitative	(Primary) -Face-to-face household surveys, interviews and observations	- Comparative percentage, frequency and descriptive statistical analysis of quantitative data -Thematic analysis of qualitative data
How are DRETs directly contributing to addressing climate risks and associated impacts?	Description of the direct impacts of DRETs in addressing or reducing climate risk Qualitative	(Primary) -Face-to-face interviews, FGDs, observations	-Thematic analysis of qualitative data
How are DRETs contributing to improvements in livelihoods through broader changes in ecological and socio-economic conditions?	Description of impacts of DRETs on livelihoods Qualitative Quantitative	(Primary) -Face-to-face household surveys, interviews, FGDs, observations	-Thematic analysis of qualitative data - Comparative percentage, frequency and descriptive statistical analysis of quantitative data based on respondent's perception

3.8 Research validity and reliability

Validity and reliability are important aspects of research to determine accuracy and consistency (Golafshani 2003). Validity is concerned with the meaningfulness of research components (Drost 2011). Joppe (2000 p. 1) explains, "Validity determines whether the research truly measures that which it was intended to measure or how truthful the research results are." In other words, validity ensures that the means of the measurement are accurate (Golafshani 2003). Similarly, reliability is defined as, "the extent to which results are consistent over time….and if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable" (Joppe 2000 p. 1). In simpler terms, reliability refers to whether the research result is replicable or not (Golafshani 2003).

This research paid great attention towards validity and reliability. Different strategies were adopted to maintain validity, reliability and trustworthiness of the study. Triangulation is one of the strategies to improve the validity and reliability of research and to evaluate findings (Golafshani 2003). Patton (1990 p. 247) promotes the use of triangulation by noting, “Triangulation strengthens a study by combining methods. This can mean using several kinds of methods or data, including using both quantitative and qualitative approaches.” This study also applied a mixed methods strategy to enable a triangulation approach, which has enabled knowledge generation from different perspectives to inform a complex discussion. Further, to capture a complete picture and varying perspectives on the issues of interest, the researcher communicated with people from different backgrounds in formal as well as informal settings. While the participants for household surveys were randomly selected, participants for FGDs and expert interviews were purposively selected to ensure the collection and comparison of diverse perspectives. Additionally, the researcher’s own observations enhanced the richness of information and study’s credibility (Lincoln & Guba 1985) and validity (Bryman 2016).

Special attention was paid to the process of data collection. The researcher himself collected, edited, compiled and analysed primary data from the study areas. Field assistants employed to help researcher were well oriented, supervised and monitored by the researcher. Research supervisors provided constant feedbacks throughout the study period. All such measures have contributed in maintaining quality, validity and reliability of the research.

3.9 Ethical concerns

Special attention was paid to ethical concerns during the course of the research. Intellectual integrity and professional ethics call for the right acknowledgement of the scientific work. Respecting this notion, the authors of scientific as well as grey literature, whose works and ideas have been discussed in this study, have been duly acknowledged.

With regards to primary data, data collection for the study began after approval from the University of Adelaide’s Human Research Ethics Committee (APPROVAL No: H-2018-018, Appendix 10). The researcher strictly adhered to the key principles of research ethics, which included clearly explaining the purpose of the research, ensuring voluntary participation, informing data collection, storage and access protocols and obtaining participant’s informed consent prior to engaging them in any part of the study.

During the recruitment phase, the researcher provided clear details to participants about the project through ‘Participant Information Sheet’ (Appendix 3, 4, 5) printed in local vernacular. The position of a researcher and that of participants have significant influence on social inquiry (Scheyvens et al. 2003; Sultana 2015). Therefore, as a person who has lived and had experiences from the region, the researcher made his position and professional background clear to the participants prior to the start of the research. The researcher clearly explained the motivation to undertake the study. The message that the participants would not be paid and the study would not instantly benefit participants was clearly conveyed alongside the possibility of indirect benefits in future in the form policies and program based on the findings of the study. The fact that findings of the research could be published in academic journals and presented at conferences was also mentioned. In order to clear doubts, participants' queries were responded openly and honestly. Ample time was provided to participants to consider their decision to participate in the study. Participants' permission was sought on a 'Participant Consent Form' (Appendix 6, 7, 8) prior to the administering of the field instruments.

Development research often entails a 'confrontation between the powerful and the powerless, a relationship fraught with possibilities of misunderstanding and exploitation' (Beazley & Ennew 2006). In the above context, the researcher tried his best to maintain a sensitive attitude towards all participants at the study areas. Participants comfort and convenience was the guiding factor in determining the time and location for surveys and FGDs. Participants were provided the right to stop participating mid-way during activities and to destruct their provided information in case they wanted to. Confidentiality and anonymity of participants have been sincerely maintained in this study. Participants' prior permission was sought before disclosing their identity in the findings. The ethical dimension of research pertaining to principles of 'Do no harm' and 'Do good' was ensured by assuring participants that the information they provide would only be used for the purpose of the study. Even though the proposed study posed negligible risks to participants and the researchers, due care was taken through out to ensure the safety and the health of the researchers and participants. The primary information obtained has been kept confidential as per the University of Adelaide's data management plan.

3.10 Research limitations

A limitation of a study design refers to the systemic bias that the researcher did not or could not control and, which could inappropriately affect the research outcome (Price & Murnan 2004). This study experienced some limitations as well. Meteorological data obtained for the analysis of the change in temperature and precipitation at locations close to study sites were not sufficient. Precipitation and temperature data for the study sites in Achham (Kamal Bazaar and Darna) could not be obtained from the same weather station because no nearby single station had the records of both temperature and rainfall. On top of that, the obtained weather records were incomplete. Weather records for a few years were missing. Such limitations prevented this research from making firm claims for the results obtained through the quantitative analysis of the weather records. The researcher has therefore mostly relied on qualitative data or local perceptions obtained through interviews and FGDs to discuss the observed climate variability in the study areas. Additionally, due to time and scope imitation, a detailed vulnerability and DRETs' impact analysis based on demographic characteristics such as age, gender and ethnicity could not be performed. Rather the research focused on identifying detailed impacts of DRETs on five livelihood capitals.

3.11 Conclusion

This chapter provided an overview of the research approach and described the methods adopted for this study. At the beginning of the chapter, the philosophical foundations of research design were discussed. This was followed by an explanation for the choice of mixed methods as a strategy of inquiry. The chapter provided arguments for combining both quantitative and qualitative methods to answer the research questions. Then a brief geographic and demographic description of the study sites were provided. Further, various qualitative and quantitative data collection techniques, sampling methods and data analysis techniques adopted for this study were discussed in detail. Finally, the chapter also discussed about research validity and reliability, ethical concerns and the limitations of this study. The following chapters discuss the key findings and the results of this study.

4 Livelihood systems in the case study areas

4.1 Introduction

This chapter discusses the livelihood systems in the study sites and in doing so uses the sustainable livelihood approach. The sustainable livelihood approach focuses on five types of capitals upon which the livelihoods are built, namely natural capital, human capital, social capital, financial capital and physical capital (DFID 1999). This chapter discusses the status of each of the five livelihood capitals based on primary data obtained through household surveys and secondary data obtained from local councils and Central Bureau of Statistics (CBS) in Nepal.

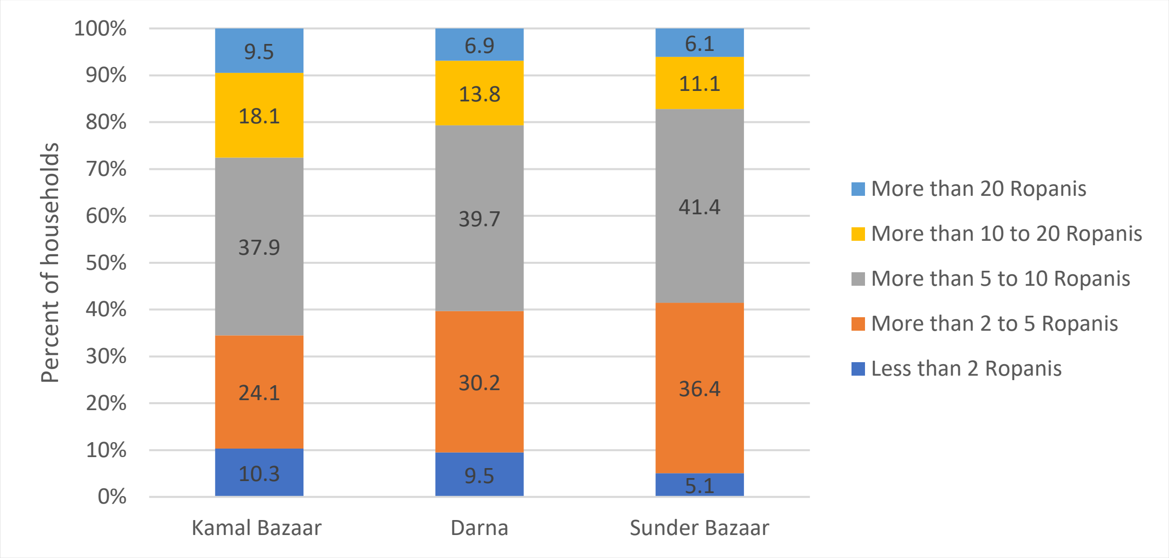
4.2 Natural capital

Natural capital constitutes a wide range of tangible and intangible goods and services provided by nature on which users depend for their livelihoods (Pandey et al. 2017). Poor populations rely disproportionately on natural resources for their livelihoods (Adger 2003; Lee et al. 2009). Farming (Gioli et al. 2019) and forest resources (Ali 2018; Angelsen et al. 2014; Karki et al. 2018) are crucial for livelihoods and in ensuring food security in rural areas in developing countries generally. In Nepali mountains, farming and forest resources form an integral part of livelihood systems (Acharya 2006; Neupane & Thapa 2001; Pandit et al. 2014; Piya et al. 2019; Yadav 1992). Farming provides continuous employment for unskilled labour to tend crops and livestock, which produces food year round and forests supply timber, fuelwood, food, fodder, medicines and leaf litter (Yadav 1992). In order to assess the natural capital in the study sites, this study focused on households' land holding size and access to forest resources.

4.2.1 Land

Land is the most important form of natural resource in rural Nepali communities as it is the main source of production, income and employment (Bhandari 2004; Deere & Doss 2006). Possession of land signifies power, class and status in Nepali society (Avis 2018; Dhakal 2011; Rawal & Agrawal 2016). Li and Deng (2017) report that around 25% of Nepal's land, or an area of 36,901.96 km2, is used for farming. Although the increasing population has been placing a rising pressure on land resources and land ownership in Nepal, none of the survey respondents reported that they possessed no land [Figure 4.1]. The unit of land size measurement can be different across different parts of Nepal. However, "Ropani" [one 'Ropani'= 508.74 sq. m. or 5476 sq. ft. or 0.0508 hectare] was the common unit of measurement across study sites. The household survey result shows that 5-10 Ropanis of land is the most common land size possession in the study sites. There is no significant spatial variation in terms of land holding size between study sites [Chi-square, P= 0.471].

Figure 4.1 Percentage of surveyed households based on land holding size



Source: Field Survey, 2018

The uniform nature of land holding size across study sites is probably because the study sites share similarities such as, i) all the study sites are in the same geographic zone and ii) farming is the most common occupation in all the study sites. Farming across Nepal is characterised by small landholdings and often fragmented smaller plots with low farm labour productivity (Gauchan & Shrestha 2017; Lamsal et al. 2018b). The land ownership by women is particularly low in the study areas. In Kamal Bazaar, only 0.9% and in Darna none of the surveyed households had female land ownership. The case is slightly better in Sunder Bazaar where 14% of the surveyed households had female land ownership.

Land in Nepali society is generally divided into different categories based on their productivity potential and uses. The standard of land classification is similar across study sites and is often classified as either 'Khet' or 'Baari' or 'Paakho' or 'Ghaderi'. One of the experts in Darna elaborated on the classification of land and said:

"Khet is usually flat with good access to water and therefore is a productive piece of land. Baari has less access to water and is less productive. Paakho is a steep slope of land which

has very low productivity, and Ghaderi is a piece of land that is well connected to roads, utilities and is suitable for building houses and business."

Although 'Khet' gives the highest agricultural yield, "Ghaderi" can be the most prized piece of land for local residents as 'Ghaderi' commands higher market value. Focus group participants in Kamal Bazaar said that they were interested in giving up their 'Khet', 'Baari' and 'Paakho' in exchange for a good 'Ghaderi' either in the town or in Terai. This has led to a national trend in underutilisation of farm lands as more farmers are giving up their prime agricultural lands for non-agricultural uses such as housing, infrastructure and industries, a process fuelled by rapid urbanisation and rural-urban migration (Gauchan & Shrestha 2017).

Table 4.1 Percentage of the type of land ownership

Land holding type	Kamal Bazaar (%)	Darna (%)	Sunder Bazaar (%)
Baari	62.1	55.2	47.5
Khet	16.4	27.6	36.4
Ghaderi/Built House	11.2	7.8	10.1
Paakho and Others	10.3	9.5	6.1

Source: Field survey, 2018

Table 4.1 above shows that the percentage share of 'Khet', the most productive land type is lowest in Kamal Bazaar, slightly higher in Darna and highest in Sunder Bazaar. This could be because Kamal Bazaar is situated on a hilltop with little provision of water to their fields apart from natural rainfall, which makes most of the land their less productive in comparison to the other areas. On the other hand, settlements in Darna and Sunder Bazaar are not located on top of a hill, which allows rain water from hill top to accumulate in farm lands below. Moreover, the rivers like 'Kailash Khola' in Darna and 'Paudi' in Sunder Bazaar facilitate irrigation to nearby fields through canals.

4.2.2 Forest

The forest is an important resource for households in the study areas. All surveyed households in the study sites had access to forests in their locality. The level of access is dependent on the rules set by local community forest user groups (CFUG). Chhetri et al. (2013) refers CFUGs as recognised user groups that develop, protect and manage local forests for collective benefits. Interactions with local residents at the study sites revealed that they rely on forest for kitchen fuel, timber, cattle forage, medicinal plants and edible products.

Survey participants in Kamal Bazaar mentioned that their forests predominantly have "Khote Sallah" or Chir pine trees (*Pinus roxburghii).* Forests found at lower elevation in Kamal Bazaar have 'Saal', (*Shorea robusta*), Sishoo, (*Dalbergia sissoo*) 'Khaiar' (*Senegalia catechu)*, 'Amala' (*Phyllanthus emblica)*, 'Harro' (*Terminalia chebula*) and other species. Like Kamal Bazaar, forests in Darna also have predominantly "Khote Sallah" or Chir pine trees. According to survey respondents in Darna, apart from Chir pine, other commonly found plant species in their forests are Saal', Sishoo, and 'Khaiar'. Survey participants in Sunder Bazaar mentioned 'Saal', 'Saaj' (*Terminalia elliptica)*, 'Harro' and 'Katush' (*Castanopsis indica)* are common tree species found in their forest. Households in Kamal Bazaar and Darna reported that they use Chir pine trees for building houses and as fuel in their kitchen. 'Saal' trees are highly prized for their good timber value and are generally used in house building and making furniture in Darna, Kamal Bazaar and Sunder Bazaar.

In addition to fuel wood and timber, households collect edible products, ornamental plants and medical plants from their forests. Focus group participants in Kamal Bazaar and Darna mentioned that they collect plants with medicinal value such as 'Rittha' (*Sapindus mukorossi*), 'Timur' (*Zanthoxylum armatum*) 'Amala', 'Bojho' (*Acorus calamus*) and 'Kaulo' (*Machilus macrantha*) from their local forests. Survey respondents in Sunder Bazaar collect medicinal products from plants such as, 'Harro', 'Amala' and 'Bojho' from their forest. Households in the study sites use medicinal plants to treat headache, body aches, fever, cold and gastro-intestinal problems. In addition to medicinal plants, survey participants in all the study sites mentioned that they collect flowers, mushrooms, 'Kafal' (*Myrica esculenta*), bamboo shoots and leafy vegetables from their forest for their household consumption.

The forests in the study sites have wild animals that contribute to rich biodiversity of the place. Focus group participants in all the study sites reported wild animals such as monkeys, deer, bears, wild boars, jackals, porcupines and rabbits as common animal species and 'Kalij" (*Lophura leucomelanos)*, 'Chyakhura' or Chukar (*Alectoris chukar),* dove, pigeon, eagle, vulture and owl as common bird species found in their forest. While the animal species in the forests had almost disappeared in the past, focus group participants informed that they have noticed a gradual increase in the numbers of monkey, wild boar and leopards in recent years.

Figure 4.2 Forest in Darna (left) and forest in Sunder Bazaar (right)

Source: Field Survey, 2018

4.3 Human capital

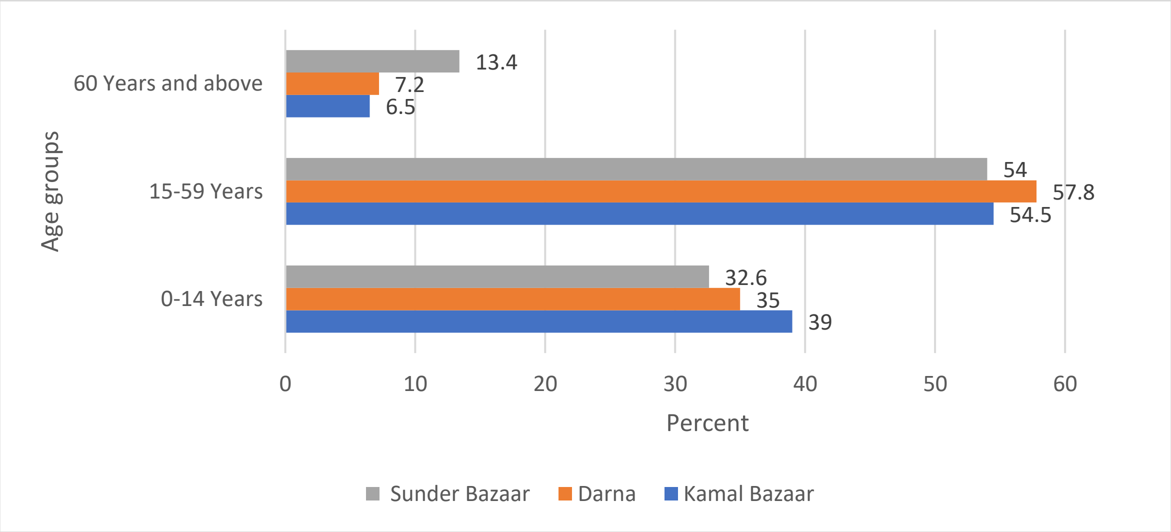
Human capital refers to knowledge, productive skills, ability to labour and good health of the people, which are essential to gain access and to make use of other capitals to pursue livelihood activities (Burton et al. 2003). Good health and a good level of education increase access to available livelihood opportunities and enhance adaptive capacity (Dulal et al. 2010). In the case of households, human capital includes both, quantity-the number of productive individuals as well as quality-the level of knowledge and skills in the individuals (Burton et al. 2003). In order to assess human capital, this study focused on the proportion of economically active population, literacy rate, level of education in households and the access to health and educational services in the study sites.

4.3.1 Economically active population

The Central Bureau of Statistics in Nepal defines children (aged 0 to 14) and people older than 60 years as economically inactive or a dependent population (Central Bureau of Statistics 2012). The population between age group 15-59 years is considered economically active or an independent population. A higher ratio of working age population is a demographic dividend for a country as it is particularly favourable for economic growth and development (Miller et al. 2016). The availability of greater labour force also strengthens the adaptive capacity of a household (Yeh et al. 2014).

According to the local council records, the percentage of the economically active population is slightly higher in Darna (57.8%) in comparison to Kamal Bazaar (54.5%) and Sunder Bazaar (54%) [Figure 4.3]. Sunder Bazar has the highest share of old age population, which indicates an improving life expectancy in Sunder Bazaar in comparison to other places.

Figure 4.3 Percentage of population by age groups in the study sites

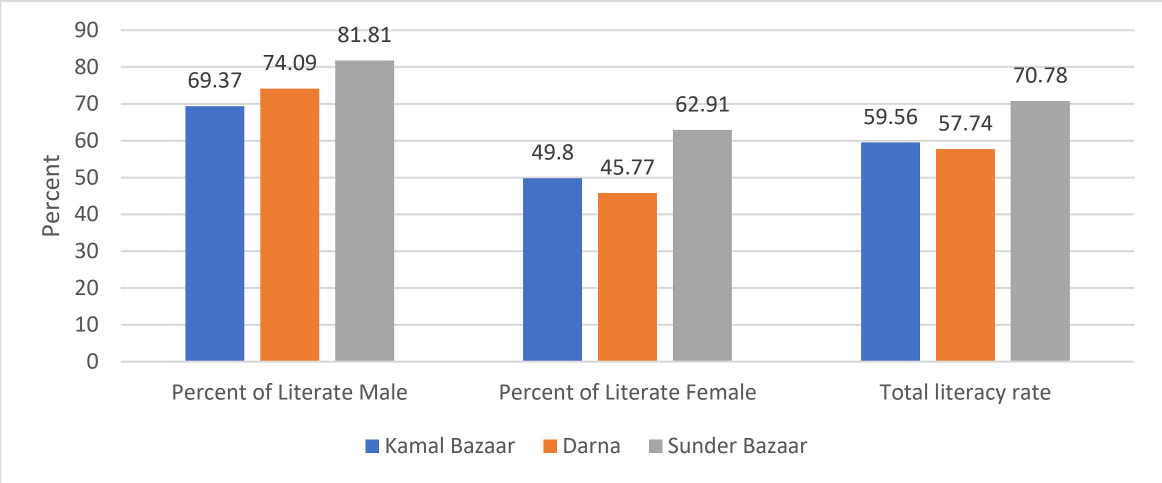


Source: Local council records (Bannigadhi Jaya Gadh Council 2018; Central Bureau of Statistics 2014; Kamal Bazaar Council 2018)

4.3.2 Level of education

A higher labour force might lead to a better productivity. However, education and skills are equally important for higher economic output (Crespo Cuaresma et al. 2014; Krishnamurty & Kumar 2015). The level of educational attainment is one of the key factors in explaining productivity and income growth (Crespo Cuaresma et al. 2014). Government records indicate that Sunder Bazaar has the highest literacy rate among three study sites. Of the total population aged 5 years and above, 70.8% population are literate in Sunder Bazaar. Kamal Bazaar and Darna have similar, lower levels of literacy rate at 59.6% and 57.7% respectively [Figure 4.4].

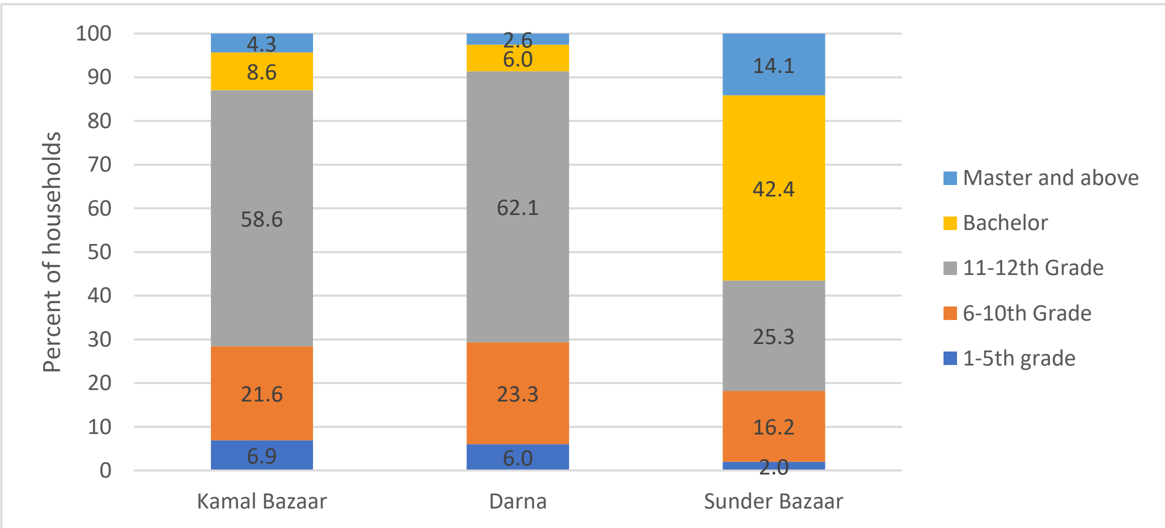
Figure 4.4 Percentage of literate population aged 5 years above in the study sites



Source: Local council records (Bannigadhi Jaya Gadh Council 2018; Central Bureau of Statistics 2014; Kamal Bazaar Council 2018)

In addition to literacy rate, survey respondents in Sunder Bazaar reported a greater percentage share of the population with higher education in comparison to the other study sites. Of the total surveyed households, 42% reported Bachelor and 14% reported Masters as the highest qualification obtained by at least one member of their household in Sunder Bazaar. In Kamal Bazaar, only 9% mentioned Bachelor and 4% mentioned Masters as the highest qualification in their household. In Darna, just 7% households mentioned Bachelor and 2% households mentioned Masters degrees as the highest qualification in their household. There is a significant difference in terms of the highest household qualification between the study sites [Chi-square, P= 0.000].

Figure 4.5 Percentage of households in terms of the highest household qualification



Source: Field Survey, 2018

The difference in the literacy rates and the level of education in households is perhaps explained by the difference in the number of available higher educational facilities at individual study sites [Table 4.2]. For example, Sunder Bazaar, which scores highest for literacy rate and households with higher degree qualifications, also has the highest number of higher education institutions. Sunder Bazaar council has four university colleges that teach undergraduate and postgraduate programs. Kamal Bazaar, which scores second in the ranking, has one university college to study university programs. Darna with the lowest ranking has no educational institution to teach any university programs.

4.3.3 Access to education and health services

Education and health both are important components of human capital (Appleton & Teal 1998). Access to better health and education services enable people to remain healthy and learn important skills to be productive. Based on the local council data, the residents of Sunder Bazaar have access to greater number of health and educational facilities in comparison to other study sites [Table 4.2].

Table 4.2 Access to health and educational facilities in the study sites

	Number of facilities within the local council								
	Medical Facilities					**Educational Facilities**			
	Hospital	Primary Health Centre	Health Post	Ayurveda Hospital	Private Clinic	Primary Schools(up to 5^{th} grade)	Secondary Schools (6^{th}-12^{th} grade)	Vocational Schools	Undergrad and Post graduate colleges
Kamal Bazaar	0	1	9	0	0	37	11	2	1
Darna	0	0	6	0	0	25	6	0	0
Sunder Bazaar	3	1	7	2	2	29	13	0	4

Source: Local council records (Bannigadhi Jaya Gadh Council 2018; Kamal Bazaar Council 2018; Sunder Bazaar Council 2018)

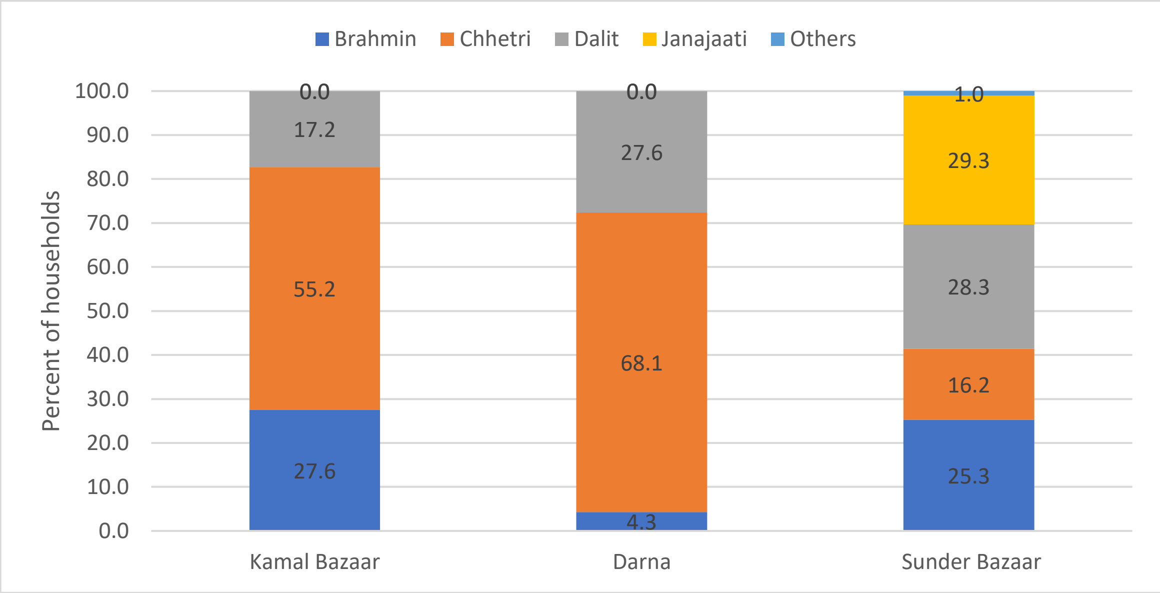
4.4 Social capital

Social capital is the range of social relationships and networks that are important in the operation of livelihood activities and that can be determining in terms of getting access to credit, markets, government services and other factors of production (Burton et al. 2003). Studies suggest communities with rich social capital are likely to be more adaptive and resilient to environmental changes and shocks (Adger 2003; Pelling 2012; Pelling & High 2005). Social capital constitutes both tangible and intangible social elements of a society such as contact networks, groups, memberships to organisations, kinships, friendly relationships, trust etc. (Burton et al. 2003). However, measuring social capital is difficult due to the lack of consistency of the unit of aggregation (Engbers et al. 2017). For this study, social capital is examined through the assessment of social or ethnic homogeneity and the presence of community-based organisations or self-help groups in the communities.

4.4.1 Ethnic (Caste) homogeneity

Individuals within the same religious or ethnic or caste groups share bonding ties (Pelling & High 2005). They generally follow similar values, cultures and participate together in community events of sorrow and joy. Such strong bonding helps in recovery from disasters and conflicts (Mishra et al. 2017; Pelling 2012). The survey results show that in terms of ethnicity (caste), Darna had the lowest and Sunder Bazaar had the highest diversity [Figure 4.6] [Chi-square, P= 0.000]. In Darna, all of the surveyed households followed Hindu religion with “Chhetri” and “Dalit” being two major caste groups making more than 95% of the surveyed households. In Sunder Bazaar, 98% of the surveyed households followed Hinduism and the remaining 2% followed Buddhism. In terms of caste groups, Sunder Bazaar had the most diverse mix with similar proportion of households of “Brahmin”, “Chhetri”, “Dalit” and Janajatis” castes. In Kamal Bazaar, all the surveyed households followed Hindu religion with “Chhetri” and “Dalit” being two predominant castes.

Figure 4.6 Percentage of households based on caste in the study sites



Source: Field Survey, 2018

4.4.2 Community-based organisations and self-help groups

Affiliation to community-based organisations and self-help groups increases the scope of social relationships and networks beyond kinships and ethnic linkages. Nayak (2015) concludes that greater participation in self-help groups helps its members to accumulate higher social capital. Story et al. (2018) found that the members associated with women-led village savings and loan program group in Ethiopia had higher social capital then the others who were not associated with the group. Survey respondents for this study reported to have received financial and other assistance, such as counselling, labour and material support from the community based organisations and fellow members at a time of crisis.

Households in the study sites are associated with multiple community-based organisations, committees and self-help groups [Table 4.3]. While most of the committees and self-help groups are informal and sometimes ad hoc, some committees and organisations are more formal in nature and are set up either by or with assistance from local government bodies. Women savings groups and mothers' groups are informally set up and are common across study sites. Focus group participants in the study sites reported that they also form ad hoc committees whenever any community-level task needs to be undertaken. For example, organising committees are set up every year to celebrate major festivals at the community level. In addition to informal and ad hoc committees, survey respondents and focus group participants reported that they are engaged in several formally registered community-based organisations such as Community Forest User Groups , multi-purpose cooperative, disaster management committee, ward citizen forum and citizen awareness centre.

Table 4.3 Number of community based organisations and self-help groups in the study sites

	Community Forest User Groups	Cooperatives	Mothers and Women Saving Groups	Disaster Management Committee	Ward Citizen Forum/ *Wada Nagarik Manch*	Citizen Awareness Centre/ *Nagarik Sachetana Kendra*
Kamal Bazaar	4	3	16	1	1	1
Darna	6	4	18	0	1	1
Sunder Bazaar	3	4	11	1	1	1

Source: Field Survey, 2018

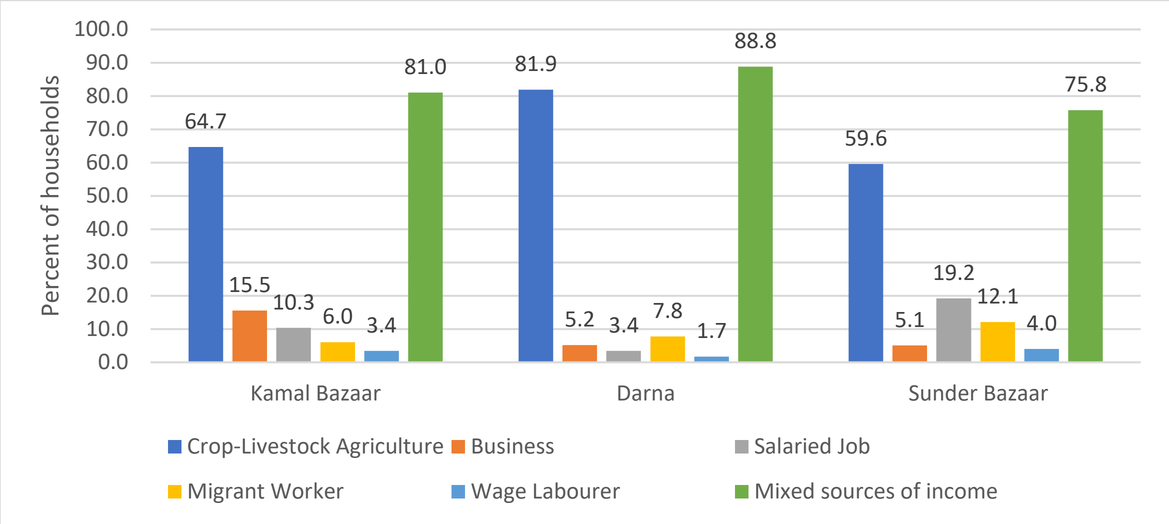
4.5 Financial capital

Financial capital constitutes financial resources such as income, remittances, savings and access to credit etc., which are necessary for the pursuit of any livelihood activity (Scoones 1998). Financial capital is essential as a means of production and for responding to the effects of different vulnerabilities (Burton et al. 2003). In order to assess financial capital, this study focused on the primary sources of income, annual household earnings and access to formal financial institutions in the study areas.

4.5.1 Primary occupation

Primary occupation of a household represents the occupation that gives the highest income to a household. The survey results show that the mix of primary occupation in the study sites is not uniform [Figure 4.7] [Chi-square, P= 0.000]. Crop-livestock agriculture was reported as the most common primary occupation. Of all the surveyed households, 64.7% in Kamal Bazaar, 81.9% in Darna and 59.6% in Sunder Bazaar identified crop-livestock agriculture as their primary occupation and the main source of income.

Figure 4.7 Percentage of households by primary occupation



Source: Field Survey, 2018

Although, the majority of the survey respondents identified crop-livestock agriculture as the primary occupation, experts at the study sites expressed a contradictory opinion. Experts mentioned that remittances have now become much more important source of income than agriculture for many households in the study areas. In Kamal Bazaar and Darna, seasonal migration to India as a temporary worker is very common. One of the experts in Kamal Bazaar said:

"On average, at least one adult male per household goes to India to earn money during off-agricultural season. Without the income from India, most of the households here would not have enough to eat from their fields."

According to an expert in Sunder Bazaar, migration to Gulf countries for income is also quiet common in Sunder Bazaar.

It is interesting to observe that very few households in the study sites reported 'migrant worker' as their primary occupation, while expert opinion and the author's own observation suggest that remittances play a much greater role in providing financial security than other income sources in the study areas. When inquired about the discrepancy, one of the experts in Darna said:

"It is very typical of Nepali households to report farming as primary occupation despite farming contributing lower share of their household income. This is probably because the other sources of income such as remittances are not permanent and guaranteed for life.

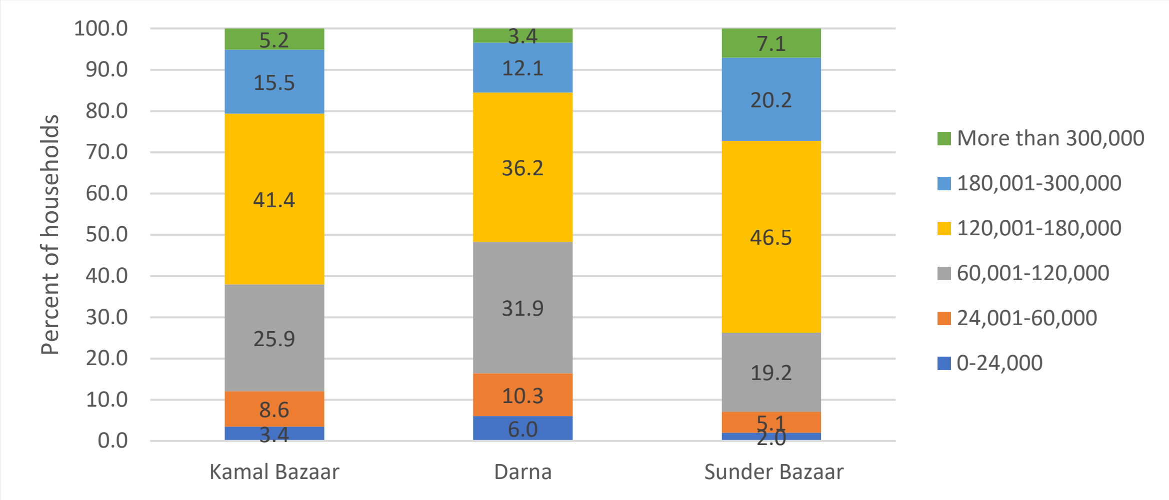
However, if you have a piece of land, you can always go back to farming without any formal qualification and skills. Farming is permanent. Moreover, farmers get various assistance and subsidies from government and non-government agencies. Therefore, in hope of some freebies also households tend to identify farming as their primary occupation.”

Most of the survey respondents in the study sites agreed to have multiple sources of income. The survey results show that 88% households in Darna, 81% households in Kamal Bazaar and 76% households in Sunder Bazaar reported to have multiple sources of income [Figure 4.7]. A study by the International Fund for Agricultural Development (IFAD) also notes that more than 50% of income in rural farming communities in developing countries come from non-farm sources (IFAD 2010). Having multiple sources of income or diversified livelihood strategies enables households to have better incomes, increase agricultural production by smoothing capital constraints, enhance food security and to better cope with environmental stresses (Bezu et al. 2012; Chambers & Conway 1992; Hoang et al. 2014; Liu et al. 2008).

4.5.2 Annual income

The annual household income represents the cumulative income from all sources in one year. According to survey results, the majority of the surveyed households have an annual income between NRS.60, 000 to NRS.180, 000[Figure 4.8]. The average annual income for households in Kamal Bazaar, Darna and Sunder Bazaar are NRs.131,586, NRs.124,323 and NRs.166, 426 in respectively. There is no significant variation in household annual income between the study sites [Chi-square, P= 0.254].

Figure 4.8 Percent of households by annual income



Source: Field Survey, 2018

It is interesting to observe that Darna, which has the highest share of households engaged in agriculture also has the lowest average annual household income [see Figure 4.7 and 4.8]. This indicates that agriculture in general appears to be the lowest earning occupation in the study areas. This is possibly because most of the farming in Nepal is still subsistent in nature (FAO 2019). Although subsistence farming leading to minimal monetary income suggests poor financial capital, the landholding associated with farming represents a strong financial asset for the households. Land itself can be a source of income through renting. Land can be used as a collateral to obtain credit from formal and informal financial institutions at a time of crisis. In Nepali society, land is considered the safest form of savings and hence the possession of land signifies wealth, power and a social safety net (Dhakal 2011). Household land ownership based on size and type of land have been already discussed in section 4.2.1.

4.5.3 Access to financial institutions

Access to credit through financial institutions is also one of the influencing factors for designing better livelihood strategies (Paudel Khatiwada et al. 2017). Research participants mentioned that the availability of formal financial institutions in their locality increases their access to inexpensive credit. According to an expert in Kamal Bazaar, while the credit obtained informally from individuals has high interest rates and short payback period, the credit obtained formal financial institutions such as bank, co-operative and micro-finance has lower interest rate and longer payback period. In addition to credit, formal financial institutions facilitate remittance services in the study areas. According to an expert in

Kathmandu, the provision of remittance services offered by formal financial institutions is as important as providing credit services in rural areas. The expert said:

"Obtaining credit is a lengthy, difficult and expensive process. Earlier, people had no options other than seeking loans when necessary. However, these days, people ask their family members working abroad or in the other parts of the country to quickly send the financial help. The remittance services have thus facilitated a quick and easy availability of funds."

According to the latest council records, households in Sunder Bazaar have access to the highest number of formal financial institutions in comparison to the other study sites [Table 4.4].

Table 4.4 Number of formal financial institutions in the study areas

Study Sites	'**A**' Class Commercial Banks	'**B**' Class Development Banks	'**C**' Class Finance Companies	'**D**' Class Micro-finance Finance
Kamal Bazaar	1	0	0	2
Darna	0	0	0	2
Sunder Bazaar	5	3	0	3

Source: Local council records (Bannigadhi Jaya Gadh Council 2018; Kamal Bazaar Council 2018; Sunder Bazaar Council 2018)

4.6 Physical capital

Physical capital is the set of basic infrastructure for transport, accommodation, communication, energy, water management etc. that enable people to pursue their livelihoods (Burton et al. 2003). Physical capital includes both, those that are owned by individuals such as houses or those that are owned by public such as roads, dams and utilities. Access to reliable infrastructure promotes local economic activity and livelihoods (Ghosh 2017; Sahoo & Dash 2012), which further enhances the adaptive capacity of communities (Adger et al. 2007). In order to assess physical capital, this study focused on the status of transport, telecommunication, housing and toilets, electricity and drinking water infrastructure in the study sites.

4.6.1 Transport

Transport refers to the movement of humans, animals and goods from one place to another. Good transport infrastructure is essential for economic growth and development (Simon 2002). Kamal Bazar does not have a good transport infrastructure and connectivity to the rest of the country. An 8.5 km dirt road is the only modern transport infrastructure that connects the town to national highway 'H18'. The dirt road is seasonal and not accessible during rainy season because of water logging and frequent landslides. A few private jeeps and bus operators provide limited, irregular and expensive transport services on this road. Focus group participants in Kamal Bazaar said:

"Private jeeps or buses operate only in the mornings and evenings and sometimes they do not operate at all if they think that they are not going to get enough passengers to fill the seats. There is no service during the rainy season. Moreover, operators charge random and exorbitant fares."

There are no public transport services with in Kamal Bazaar as there are no motorable roads. In order to address the issue, the local council office has now started opening tracks for motorable roads. One of the local council staff stated that there were 13 different road projects of at least 5 km length each in construction at the time of this study. Kamal Bazaar has an airstrip, which provided air transport for few years before shutting down during the Maoist civil war. According to an expert in Kamal Bazaar, the airstrip has remained non-functional for the last 18 years.

Figure 4.9 Dirt road at the onset of rainy season in Kamal Bazaar

Source: Field Survey, 2018

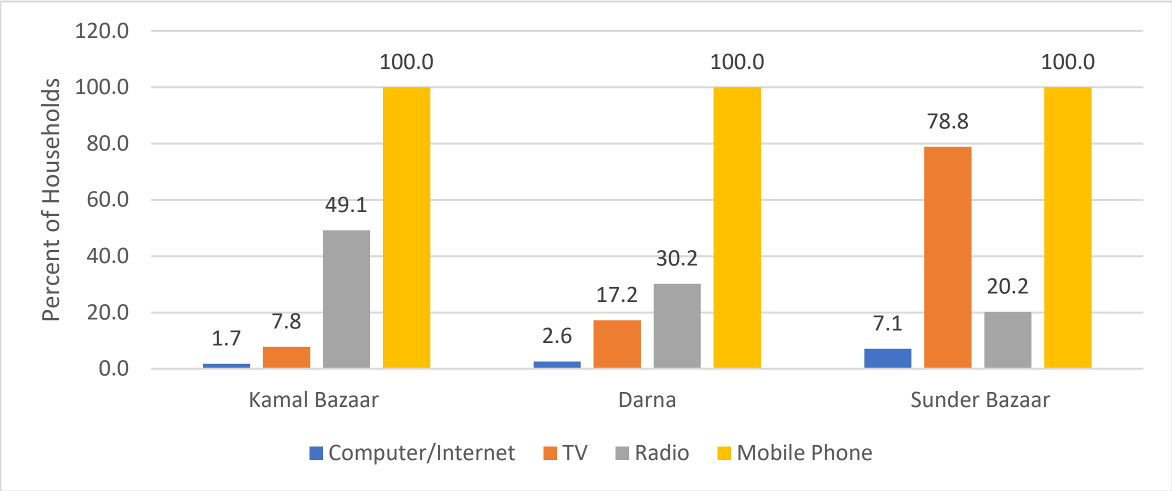
Like Kamal Bazaar, Darna also has a poor transport infrastructure. Except for few human trails and a recently built 16.2 km dirt road, there are no other modern transport infrastructure in place. The dirt road is seasonal and is not accessible during the rainy season because of water logging and landslides. Focus group participants in Darna defined the transport services in their village as irregular and expensive, and expressed discontent about exorbitant price of day-to-day products due to the lack of proper transport services in their community. Like Kamal Bazaar, Darna is investing in the construction of new road tracks. One of the local council staff mentioned that there were six different road projects of at least 5 km length each in construction at the time of this study in Darna.

Sunder Bazaar has a better transport infrastructure and connectivity in comparison to Kamal Bazaar and Darna. An all-weather 25 km metalled road connects Sunder Bazaar to a national highway 'H04'. Sunder Bazaar has multiple transport options to district headquarters, and to major cities such as Pokhara, Naryanghat and Kathmandu. In addition to the outbound services, there are public transport services with in Sunder Bazaar. According to the local council records, there were 11 km of blacktopped road, 45 km of gravel road and 120 km of new road tracks under construction in Sunder Bazaar at the time of this study (Sunder Bazaar Council 2018).

4.6.2 Telecommunication

Telecommunication infrastructure promotes economic growth and prosperity (Roller & Waverman 2001). Radio, television and mobile phones are the most common means of telecommunication in the study sites. According to survey, mobile phones have the highest penetration (100%) in all three-study sites [Figure 4.10]. Every households in the study sites owned at least one mobile phone. In many cases, family members owned multiple mobile phones in the same household. TV ownership was highest in Sunder Bazaar and lowest in Kamal Bazaar with significant spatial variation [Figure 4.10] [Chi-square, P= 0.000]. Radio ownership was highest in Kamal Bazaar and lowest in Sunder Bazaar with significant spatial variation [Figure 4.10] [Chi-square, P= 0.000]. The computer and internet access was highest in Sunder Bazaar and lowest in Kamal Bazaar with no significant spatial variation [Figure 4.10] [Chi-square, P= 0.085]. The higher ownership of computer and television in Sunder Bazaar and the lower ownership in Kamal Bazaar is probably due to the quality of electricity available at respective places. Kamal Bazaar is still off-grid and relies on basic electricity from intermittent renewable energy sources; however, Sunder Bazaar gets stable electricity from the national electricity grid.

Figure 4.10 Percentage of households with access to different means of communication



Source: Field Survey, 2018

4.6.3 Housing and toilets

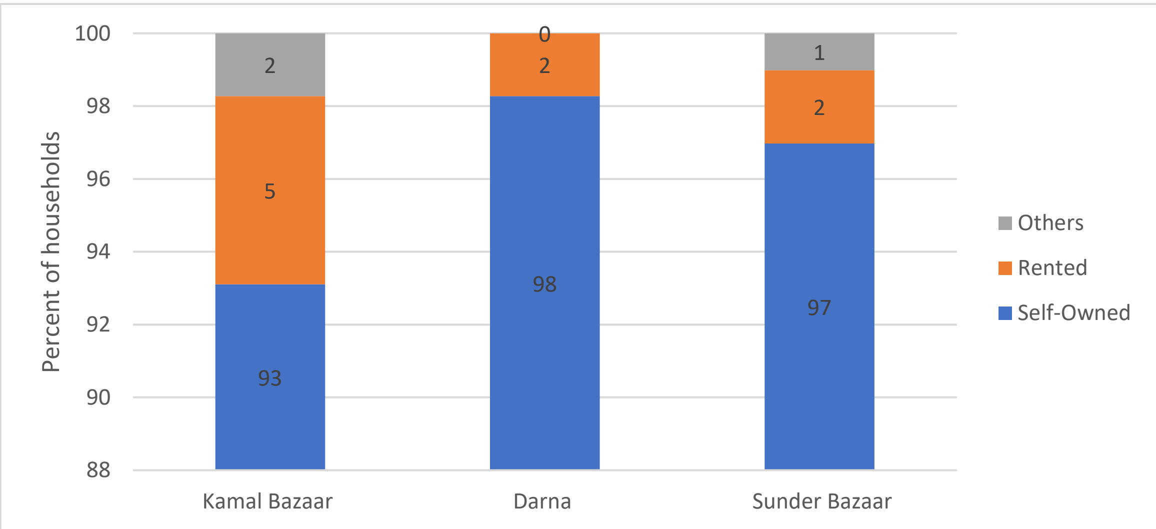
Housing is considered a part of physical infrastructure because houses are essential for producing the economic good of shelter (Goodwin 2003). For residents in the study sites, houses and buildings are not only physical spaces but also an integral part of their lifestyle, emotions and livelihood. One of the survey respondents in Darna said:

"Second to human relations, a house is the most important asset for us. Our close ones and we spend our entire life in the house together. We invest our earnings into it and we earn from it. We have emotional attachments with our houses.'

Mountains in Nepal are prone to flood, landslides and earthquakes (Dahal & Bhandary 2013; Jimee et al. 2019; Mishra et al. 2017). A well-built modern house can better protect lives and belongings at the time of disasters and can act as a financial security at the time of need (Bloch 2017). Therefore, owning a modern well-built house imparts a great sense of security and associated social prestige in Nepali society.

The survey results show that most of the households across study sites reside in their own houses [Figure 4.11]. There is no significant spatial variation in terms of house ownership between the study sites [Chi-square, P= 0.304]. The percentage of "Rented" is slightly higher in Kamal Bazaar than in the other study areas. This might be because the study area in Kamal Bazaar has a market with business operating in rented spaces.

Figure 4.11 Percent of house ownership



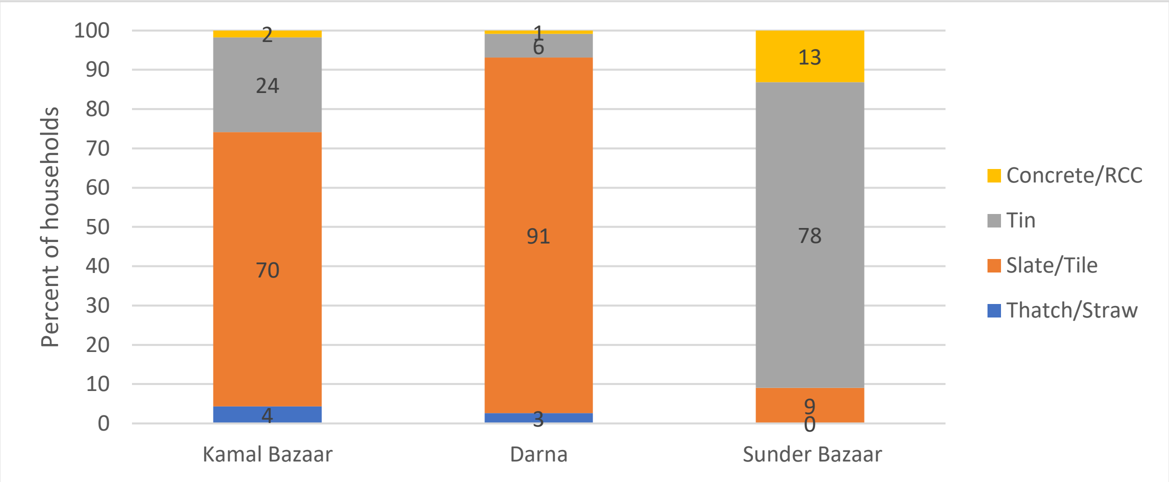
Source: Source: Field Survey, 2018

In order to assess the structural strength of houses, this study divided the houses into categories based on roof type. Generally, the classification of houses based on roof provides information about the structural strength and the ability of the house to withstand damaging forces such as fire, landslide and earthquake. On this regard, a local council staff in Darna said:

"Usually houses with thatched or straw roofs are the cheapest to build and structurally weak, whereas houses with concrete roofs are the most expensive and structurally sound. When we arrange the house type on an order on the basis of structural strength and cost from low to high, it's generally thatched or straw house then tiles or slate house then tin house and then finally concrete house."

The classification of houses on the basis of roof type is also one of the measures of house 'Types' in national census of Nepal (Central Bureau of Statistics 2014). While slate or tile was the most common roof type for houses in Darna and Kamal Bazaar, tin was the most common roof type in Sunder Bazaar [Figure 4.12] [Chi-square, P= 0.000]. This is probably because the cost of tin, steel and cement is higher in Darna and Kamal Bazaar due to poor transport infrastructure. In Sunder Bazaar, however the cost of tin, cement and steel are relatively cheaper due to regular and inexpensive transport services.

Figure 4.12 Percent of house ownership by roof types



Source: Field Survey, 2018

In addition to houses, this study enquired about toilets in the study sites. Every surveyed households reported that they have toilets in their households.

4.6.4 Electricity

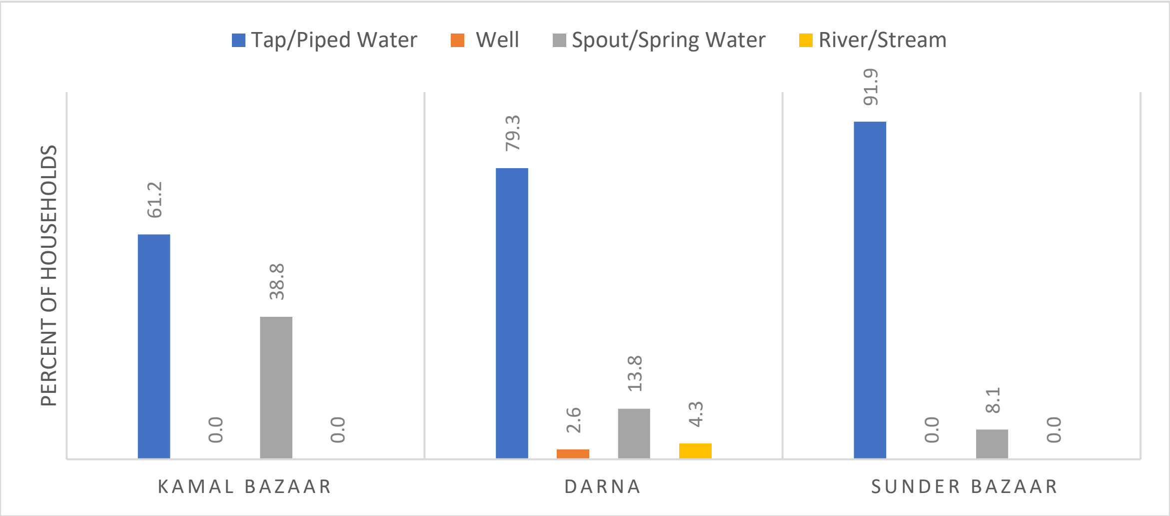
Electricity offers a wide range of livelihood opportunities (Arnaiz et al. 2018). All of the surveyed households in the study sites had access to electricity. However, the quality of electricity supply was not uniform. Households in Kamal Bazaar are not yet connected to the national electricity grid and receive a low ampere or low capacity electricity from either solar-wind micro grid or individual solar home systems for a limited number of hours in a day. According to survey respondents in Kamal Bazaar, the electricity supply solely based on the sun and wind is unreliable as it fluctuates with the variation of sunshine and wind flow in their surroundings. The low power and unreliable electricity has prevented households in Kamal Bazaar from using electrical appliances of their choice.

Like Kamal Bazaar, Darna is also not yet connected to the national electricity grid. The households in Darna however have access to more reliable electricity in comparison to the households in Kamal Bazar. Survey respondents in Darna mentioned that they have a stable electricity supply for 22 hours a day from a local micro-hydro station in their community. Unlike in Kamal Bazaar, electricity consumers in Darna can use electrical appliances of their choice. The households in Sunder Bazaar have connection to the national electricity grid since 1993, which allows them to use electrical appliances of their choice. The situation of electricity supply in individual study sites will be discussed in detail in chapter six.

4.6.5 Drinking water

Households in the study sites rely on community based piped water schemes, springs or spouts, wells and rivers or streams for their drinking water needs. The survey results show that the community based piped drinking water is the most common source of drinking water in the study sites [Figure 4.13]. However, the level of access to the sources of drinking water is not similar across study sites [Chi-square, P= 0.000].

Figure 4.13 Percentage of primary source of drinking water



Source: Field Survey, 2018

As seen on figure 4.13, the share of the residents with access to piped drinking water is lowest in Kamal Bazaar at 61.2% in comparison to Darna and Sunder Bazaar at 86.4% and 88.6% respectively. According to an expert in Kamal Bazaar, there are two major challenges in the expansion of piped drinking water projects in Kamal Bazaar. The expert said:

"First, there are very few water springs at the height of the settlement of Kamal Bazaar, which can be distributed through pipes using gravitational force. Second, the community does not have a reliable electricity supply to lift water from the sources located below the settlement."

At the time of this study, a solar PV based water-lifting project was present in Kamal Bazaar. The project has been designed to lift water from a source located below the settlement. However, at the time of this study, the system was not functioning due to a lack of repair.

4.7 Conclusion

This chapter provided a background on the study sites and discussed the livelihood systems in details. Five livelihood capitals namely natural capital, human capital, social capital, financial capital and physical capital were discussed. In order to assess natural capital, the status of land possession, access to forest and the quality of forests at the study sites were analysed. For human capital, the proportion of economically active population at individual study sites, the highest level of education in households and access to education and health services in the community were analysed. For social capital, ethnic or caste make up and the presence of community-based organisations in the study sites were analysed. For financial capital, the status of household's primary occupation, annual income and access to financial institutions were analysed. For physical capital, the status of local transport infrastructure, communication infrastructure, housing and toilets, electricity and drinking water infrastructures in the study sites were discussed. In addition to presenting information about different aspects of local livelihoods, a comparison between the study sites was made where possible. The next chapter will discuss the observed and perceived changes in climate and environment, and their impacts on local livelihoods in the study sites.

5 Climate change and associated impacts in the case study areas

5.1 Introduction

This chapter examines the local climatic trends through the analysis of physical climate data and local perceptions; and discusses the implications of environmental change on local livelihoods. First, the chapter provides a general overview of climate in the mountains and study sites. This is followed by the statistical analysis of trends in temperature and precipitation change. Next, the findings of the trend analysis are compared vis-à-vis primary data on local perceptions of climate change. Then the impacts of environmental change observed and experienced by local residents at the study sites are discussed. In doing so, the discussion draws from local knowledge, understanding and experiences of local residents, data from local councils, relevant literature from the region and the author's own observations to describe the most pressing impacts of environmental change in the mountain communities. Descriptive statistics and chi-square (X^2) tests were performed to summarize and compare local perceptions of change and impacts between study sites. At the end, a table provides the summary of the observed environmental changes and their associated impacts on livelihoods in the study areas.

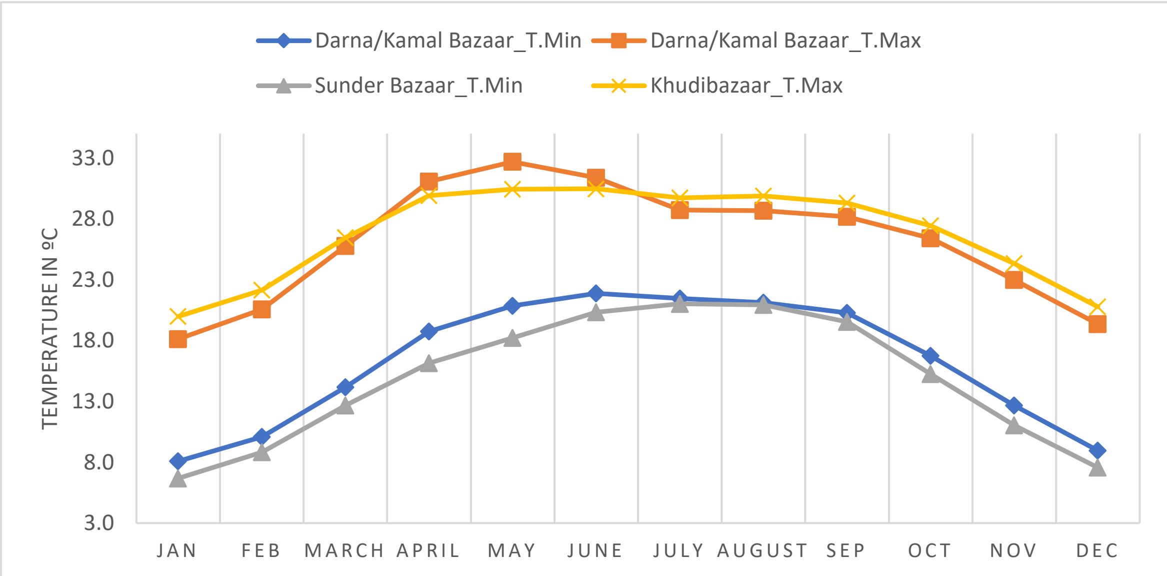
5.2 Physical climate characteristics of the mountains

Nepal's climate is influenced by the high Himalayas, South Asian monsoon circulation and westerly circulation (Shrestha et al. 2000; Shrestha et al. 1999). Local climatic conditions also vary with topography. In spite of a small land mass, Nepal has a diverse topography and as a result, Nepal experiences a wide range of climates from warm sub-tropical in the Terai to alpine type in the Himalayas (Lillesø et al. 2005). The mountain region that lies in the middle has a cool temperate climate with four distinct seasons namely, spring/pre-monsoon (March-May), summer/monsoon (June-September), autumn/ post-monsoon (October-November) and winter (December-February) (GON 2012; Nayava 1975). During the summer/monsoon, moisture laden air masses build up at the Bay of Bengal and then sweep to the Himalayas to deposit up to 80% of Nepal's total annual rainfall (Shrestha et al. 2000). Winter is relatively dry with occasional snow because of the westerly wind bringing in occasional cold fronts to the mountains (Karki et al. 2016).

The mountain region receives an average annual precipitation ranging from 275 mm to 2300 mm (WECS 2005), 70%-85% of which falls during summer (Shrestha & Aryal 2011). Winter precipitation is caused by the westerly weather system originating over the Mediterranean Sea. Although the winter precipitation is not as significant as the summer monsoon, it is vital for generating water flows for agriculture during winter, especially in the north west region of the country (Shrestha & Aryal 2011). The mountain region has a mean annual temperature ranging from 10ºC to 20ºC (WECS 2005).

All three of the case study sites for this research fall within the mountain region. Figure 5.1 below shows long-term average monthly maximum and minimum temperatures at the study sites. It can be observed on Figure 5.1 that average temperatures start to increase gradually from the first week of January to reach maximum in mid-June and then gradually decrease to reach the lowest in mid-December across study sites. The average monthly maximum and minimum temperatures at all study sites are almost equivalent, except that Darna and Kamal Bazaar have slightly higher temperatures than Sunder Bazaar in the months of April, May and June.

Figure 5.1 Long-term (1965-2017) average monthly maximum and minimum temperatures at study sites

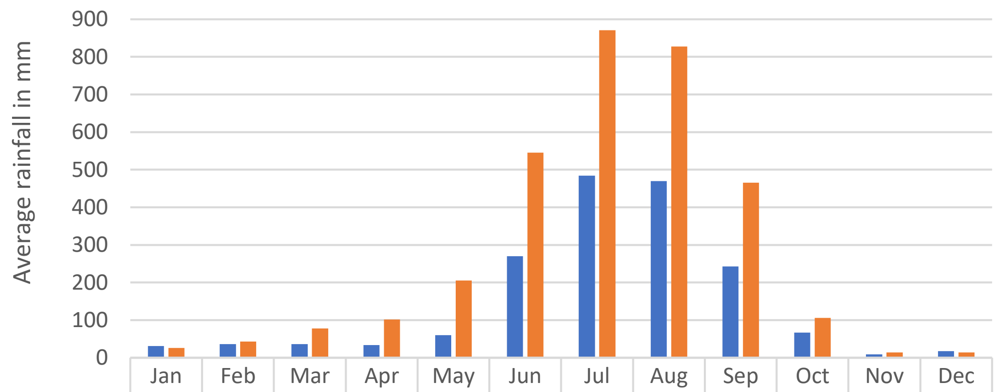


Source: Unpublished data from DHM records

Unlike the temperature data, precipitation data shows much variation in terms of average total monthly rainfall at study sites [Figure 5.2]. Sunder Bazaar received 3298 mm of annual rainfall while Darna and Kamal Bazaar received an annual average rainfall of 1759 mm. Sunder Bazaar in central Nepal receives most of that increased rainfall as compared to

Darna and Kamal Bazaar in the west during the months of June, July, August and September in the monsoon season. This variation is explained by the fact that the summer monsoon, which originates in the Bay of Bengal (Shrestha & Paudyal 1992) is the main cause of precipitation in Nepal (Shrestha 2000), and as it travels from east to west, it loses its influence (Nayava 1980; Shrestha & Aryal 2011). The distribution of average monthly rainfall in Figure 5.2 shows that for all the study sites, the highest precipitation occurs in the month of July and the lowest in November.

Figure 5.2 Long-term (1965-2017) average of monthly total rainfall at study sites



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Darna/Kamal Bazaar	31	37	36	34	60	270	484	470	243	66	9	18
Sunder Bazaar	26	43	78	102	206	545	871	828	466	106	14	14

Source: Unpublished data from DHM records

5.3 Climate change trends in the study areas

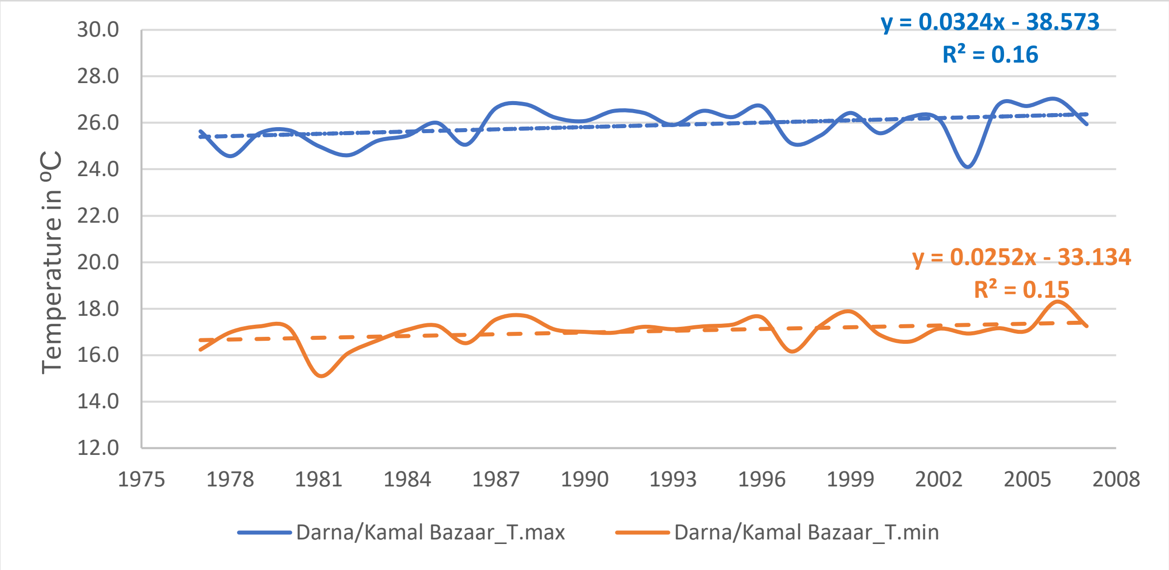
5.3.1 Change in temperature

Studies indicate an increasing trend in temperature in Nepali mountains (Government of Nepal 2016; Khatiwada et al. 2016; Krishnan et al. 2019; Nogués-Bravo et al. 2007; Salinger et al. 2014). The average daily maximum and minimum temperatures are on the rising trend at the study sites as well [Figure 5.3 and Figure 5.4]. The analysis of average daily maximum temperature (T.Max) data from 1977 to 2007[3] for Darna and Kamal Bazaar shows a significant rising trend at a rate of 0.0324ºC per year, P= 0.026 [Figure 5.3]. The analysis of minimum temperature (T.Min) data for the same period also shows a significant increasing trend at a rate of 0.025ºC per year, P= 0.029 [Figure 5.3]. For Sunder

[3] Weather records post 2007 at Pusma Camp Station were incomplete

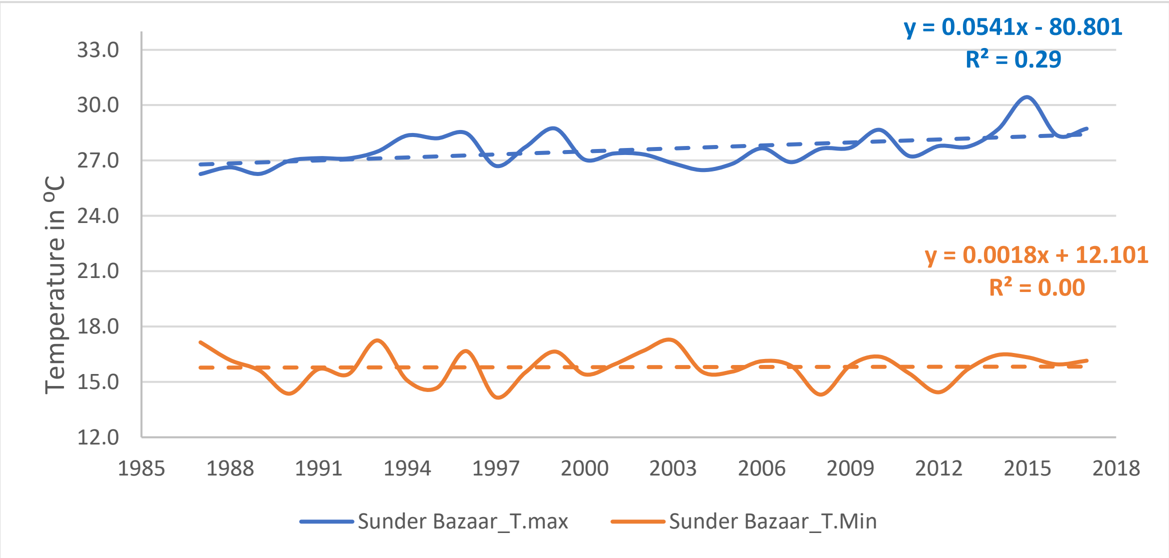
Bazaar, the analysis of average daily maximum temperature data from 1987 to 2017 shows a significant rising trend at a rate of 0.054°C per year, P= 0.002 [Figure 5.4], and the analysis of minimum temperature data shows a generally stable trend as shown in Figure 5.4.

Figure 5.3 Trends in annual averages of daily maximum and daily minimum temperatures in Darna and Kamal Bazaar



Source: Unpublished data from DHM records

Figure 5.4 Trends in annual averages of daily maximum and minimum temperatures in Sunder Bazaar



Source: Unpublished data obtained from DHM records

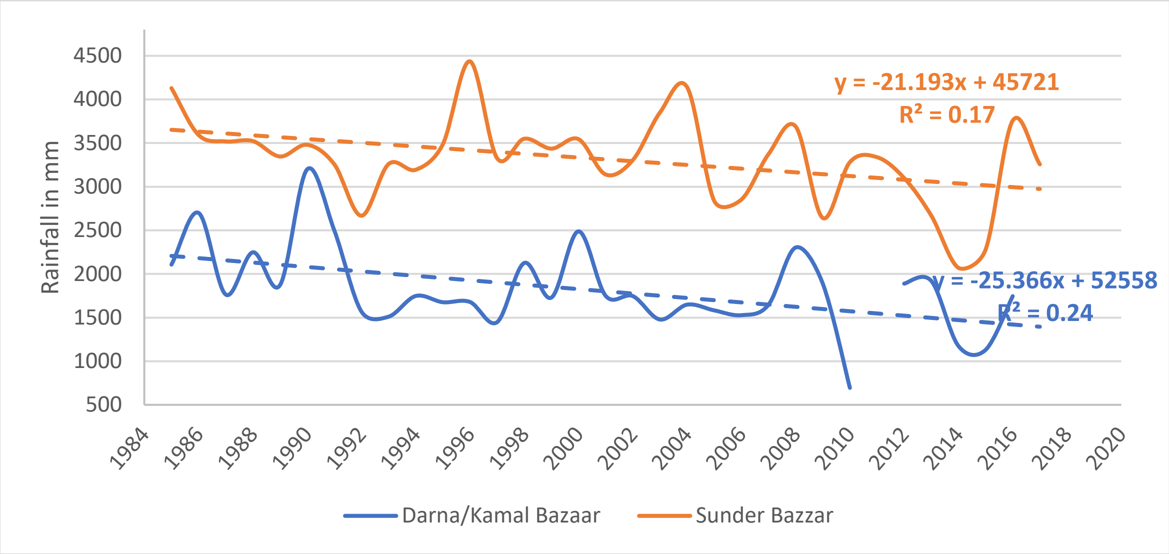
It can be observed from the analyses that the increasing trend in average maximum temperature in the study sites is higher than the increasing trend in average minimum temperatures.

While there may be some limitations in the quantitative analysis of meteorological data due to limited data and calculations, it should be noted that recent comprehensive studies on climate change in Nepal have indicated similar trends in Nepal. An analysis of weather records from 1979 to 2016 by Shrestha et al. (2019) found that mean annual temperature of Nepal has increased by 0.03°C/year with higher rate of increase after 2005, and 2016 being the hottest year. Similarly, Thakuri et al. (2019) observed an increase of 0.045°C/year in maximum near-surface air temperature and an increase of 0.009°C/year in minimum near-surface air temperature. A recent study by the Department of Hydrology and Meteorology found an increasing trend in average annual maximum temperatures at a rate of 0.056ºC per year and in average annual minimum temperatures at the rate of 0.002ºC per year in Nepal (DHM 2017). Gentle and Maraseni (2012) and Heyojoo et al. (2017) have also reported an increasing trend in temperatures in Nepal. Apart from increase in annual average temperatures, studies have reported increasing trends of hot days/nights and decreasing trends of cold days/nights. Krishnan et al. (2019) and Shrestha et al. (2019) found that the occurrences of extreme cold days and nights have decreased while the occurrences of extreme warm days and nights have increased significantly in recent years in Nepali mountains.

5.3.2 Change in precipitation

Precipitation records from the past do not show a uniform trend in Nepal (DHM 2017; Khatiwada et al. 2016; Nepal 2016). However, the analysis of annual total rainfall data for the last three decades (1985 to 2017) for Darna and Kamal Bazaar shows a significant decreasing trend in rainfall at a rate of 25.366 mm per year, P= 0.005 [Figure 5.5]. A similar analysis of the rainfall data for the same period for Sunder Bazaar also yielded a significant decreasing trend at a rate of 21.19 mm per year, P= 0.018 [Figure 5.5].

Figure 5.5 Trends in total annual precipitation (1985-2017) at study sites

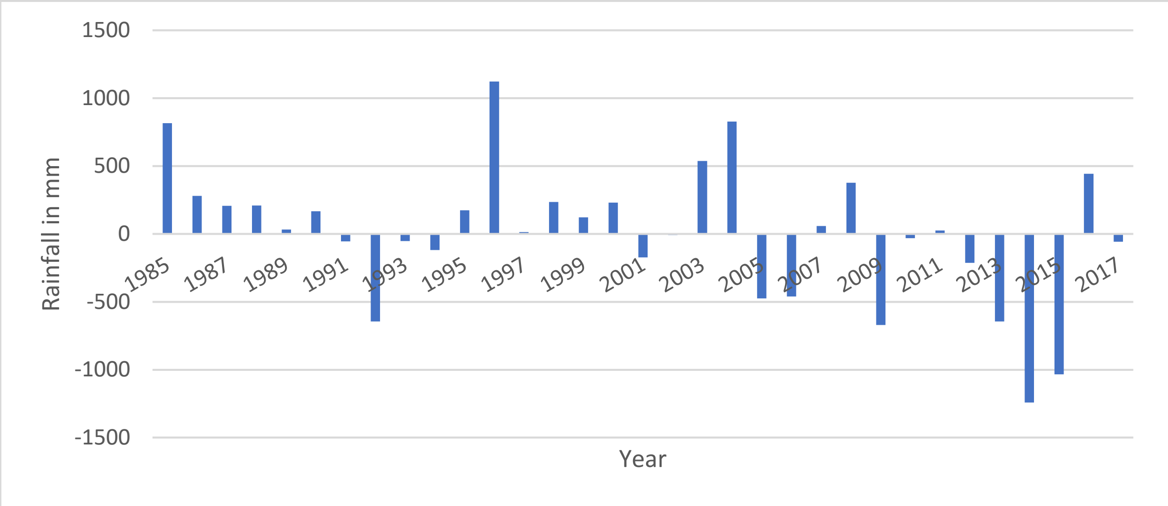


Source: Unpublished data obtained from DHM records

The trend analysis shows a greater decreasing trend in Kamal Bazaar and Darna, than in Sunder Bazaar [Figure 5.5]. This is concerning for communities in Kamal Bazaar and Darna as the western region already receives a smaller share of the summer monsoon than the central and eastern parts of the country (Shrestha 2000; Talchabhadel et al. 2018). The analysis of consecutive dry days indices by Karki et al. (2017) also suggests a widespread increase in dry periods over the whole country, adding burden to farmers. The declining trend in rainfall has been reported by other studies conducted in the region (Gentle & Maraseni 2012; Heyojoo et al. 2017; Panthi et al. 2015).

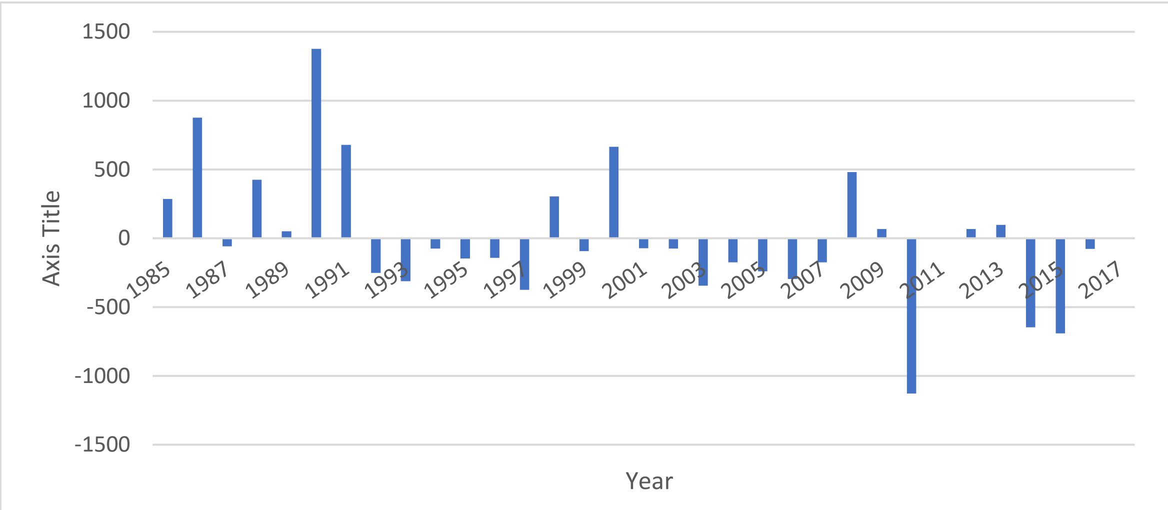
Apart from decreasing trends in rainfall, one important thing to observe on Figure 5.5 is the increasing inter-annual variability for the amount of annual rainfall in the study sites. Comparatively, Sunder Bazaar shows a higher variability. The annual rainfall anomaly charts below show yearly variations for the long-term (1985-2017) annual average rainfall.

Figure 5.6 Annual rainfall anomaly (1985-2017) around Sunder Bazaar



Source: Unpublished data obtained from DHM records

Figure 5.7 Annual rainfall anomaly (1985-2017) around Darna and Kamal Bazaar



Source: Unpublished data obtained from DHM records

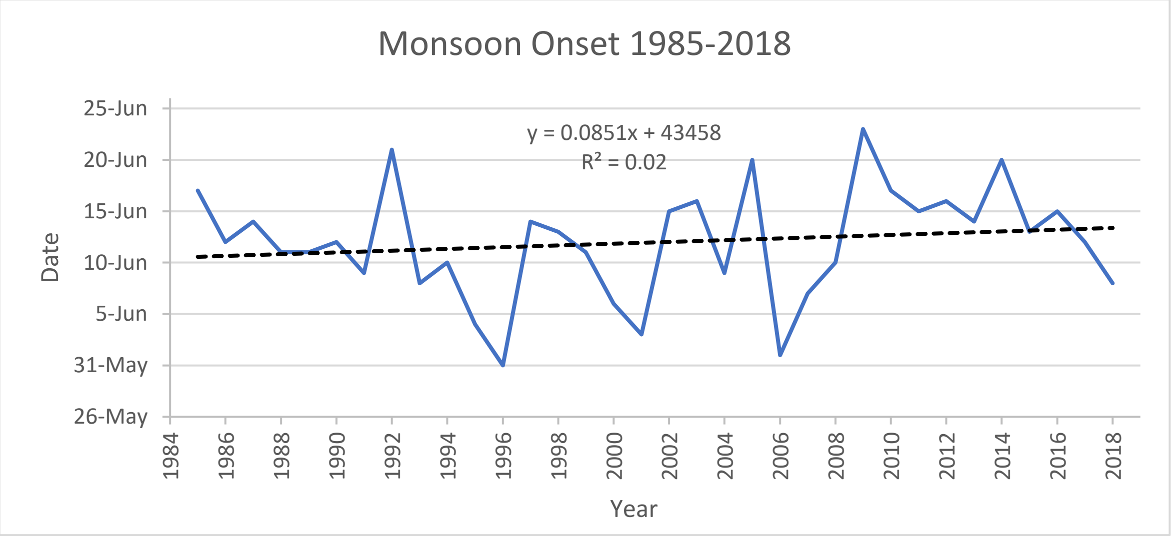
These findings of higher inter-annual variability are also consistent with the findings from other studies (Bhatta et al. 2015; Duncan et al. 2013; Pant 2003; Shrestha et al. 2000) conducted in the region.

5.3.3 Variations in onset and withdrawal of summer monsoon

The summer monsoon contributes 70%- 85% of total precipitation in Nepal (Shrestha & Aryal 2011; Shrestha et al. 2000). Therefore, the monsoon greatly influences the lives and livelihoods of most rain-fed agrarian communities in Nepal. The onset and withdrawal of monsoon is marked by changes in circulation and rainfall-distribution. The government of

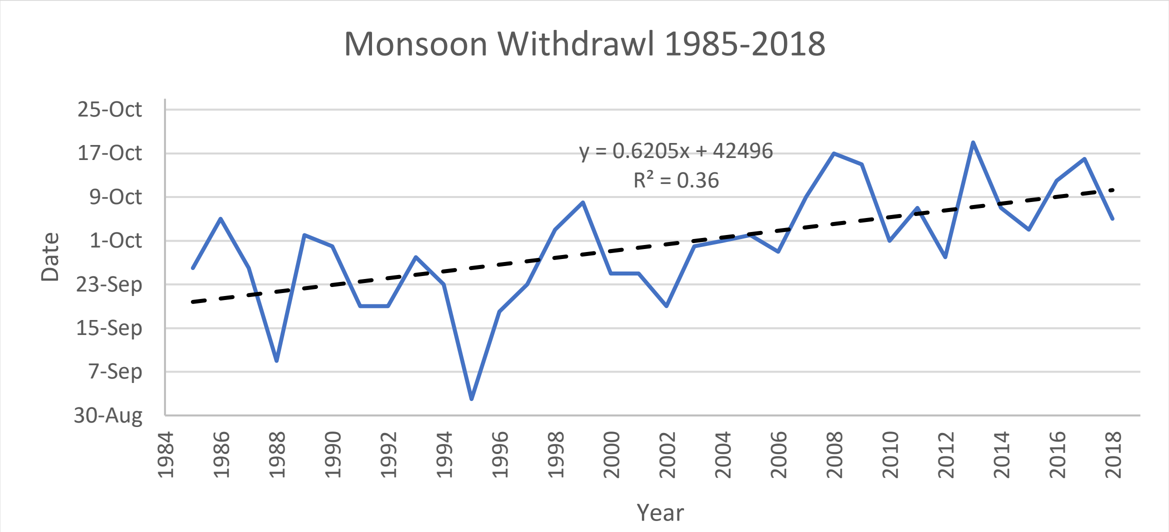
Nepal protocols consider the date of onset and withdrawal of monsoon as June 10 and September 23 respectively. However, the actual date of monsoon arrival is the day when total precipitation of 30 mm or more fall over three consecutive days with a minimum of 10 mm average daily rainfall in the month of June (DHM 2017). In order to detect a trend in the onset and withdrawal of monsoon, published data from 1985-2018 on DHM website were analysed. The analysis indicates high inter-annual variability with a trend towards delay. The onset as well as withdrawal are being postponed with withdrawal showing a higher degree of delay. Panthi et al. (2015) as well observed a later departure trend of monsoon from Nepal. In other cases, Bhatta et al. (2015), Gentle and Maraseni (2012) and Sujakhu et al. (2016) have also reported erratic monsoon trends in Nepali mountains.

Figure 5.8 Trend in monsoon arrival from 1985 to 2017 in Nepal



Source: Published data from DHM records

Figure 5.9 Trend in monsoon withdrawal from 1985 to 2017 in Nepal.



Source: Published data from DHM records

5.4 Local perception of climate and variability in the study areas

5.4.1 Integrating climate records and local perceptions

A mixed-methods approach that includes both quantitative as well as qualitative data provides a greater understanding of climate of the study area (Furberg et al. 2018). Beyond the quantitative approach, which characterises most climate change research, qualitative methods that focus on understanding local perceptions of climate can add findings and perspectives to fill the gap (Furberg et al. 2018).

In the context of this research with study sites located in the mountains, it is essential to understand that the variation in topography and altitude in mountains creates micro-climate system (Bhattarai & Mandal 2016; Chang et al. 2016) such that the climate dynamics of one area may not be consistent with another in the same region. In such case, quantitative data alone is insufficient and therefore including local perceptions of climate are vital to fill the gap. Another underlying reason to integrate local perceptions in this study is due to the fact that in developing countries, the availability of high quality long-term physical climate data is often limited and unreliable because of the lack of sufficient meteorological instruments and stations (Furberg et al. 2018). Nepal, being a lower-middle income country is no exception. A study conducted by Khatiwada et al. (2016) also highlights the lack of sufficient meteorological stations and data in the western mountain region of Nepal.

In such a context of limited data availability, there was a greater need to include local perceptions to supplement the physical climate data.

Further, integrating local perceptions and experiences of climate variability is helpful to develop a holistic understanding of the impacts of environmental change on the socio-ecological systems. Local experiences provide deep insights on how climate is embedded in local culture and lifestyle; and how climate variability impacts environment and the way of life (Hulme 2012). Additionally, local perceptions can validate findings and results derived from climate data analysis.

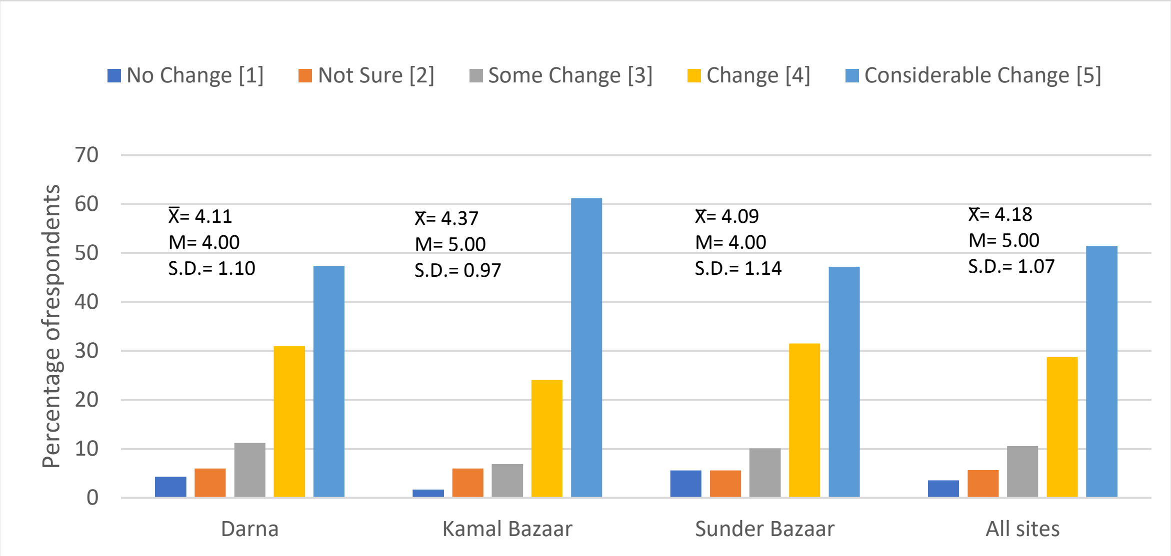
In this light, this research combines physical climate data obtained from secondary sources with primary data on local experiences and perceptions to understand and triangulate knowledge of the local climate system.

5.4.2 Local perceptions of changes in temperature

The majority of the survey respondents (91%) reported that they have observed changes in temperature over the past decades [Figure 5.10]. Of the total survey respondents, 51% have observed considerable change, 29% have observed change and 11% have observed some change in temperatures. The remaining 6% stated that they were not sure and 3% mentioned that they had not observed any changes. Based on the average score[4] for perception of change in temperature, it is observed that the residents of Kamal Bazaar reported the highest level of change in comparision to other study sites [Kamal Bazaar $\overline{X}$= 4.37, Darna $\overline{X}$= 4.11, Sunder Bazaar $\overline{X}$= 4.09] [Figure 5.10]. A chi-square test performed to examine the spatial differences in perciving the change in temperature indicates that there are no significant differences between the study sites [Chi-square, P= 0.305].

[4] Survey response on perception of change was quantified as 'No Change' = 1, 'Not Sure'= 2, 'Some Change' = 3, 'Change' = 4 and 'Considerable Change' = 5. Mean of the valid survey responses [$\overline{X}$] calculated for average score on perception. M= Median and S.D.= Standard Deviation.

Figure 5.10 Perceived change in temperature



Source: Field Survey, 2018

Among the survey respondents reporting a change in temperature, an overwhelming majority (94%) reported an increase in temperature or a warming trend and the reamining 6% reported a cooling trend. Local perceptions of changes in temperature by the majority of survey participants thus correspond, and in-fact suggest a greater degree of warming than indicated by the quantitative analysis of temperature trends [see section 5.3.1]. Survey and focus group participants shared several experiences of increasing temperatures in their communities. One of the survey respondents in Kamlabazaar said:

" It is definitely getting warmer. Earlier, I used to live at the base of this mountain, which used to be warmer than the top here. However, these days I find similar level of warmth even at the the top of the mountain. We use blankets less frequently than before."

Another survey respodent mentioned:

"When we were kids, we could see snow capped hill tops for one-two months after rain or snow in winter. These days, the snow on hill tops do not last for more than 10-15 days. This must be because of warming."

Similarly one focus group participant in Kamal Bazaar said:

"Our surroundings are warming. Earlier it used to be very foggy during monsoon and winter seasons in our village, however, these days we have less foggy days.This place used

to receive upto 1.5 feet of snow, but now we receive less snow and that too vanishes in a day or two."

A decerease in the amount and duration of snowfall was the most common indicator of warming for most of the survey respondents in Kamlabazaar. Respondents in Darna mentioned that although they do not receive snowfall in their village, their observation shows that the length and the amount of snow on nearby mountain tops have reduced in camparision to past. A survey respondent in Darna said:

"Earlier, nearby mountain tops used to be covered with snow from Dec/January until March/April, however these days we see snow for fewer days until Jan/Feb only."

Survey participants in Sunder Bazaar said that fans have now become a necessity in summer months, indicating an increase in temperatures over the past years. Focus group participants mentioned that the increasing number of local residents are adding fans to beat the summer heat. One of the focus group participants in Sunder Bazaar said:

"In the past, fans were not common in our village. However, these days, summer is hotter, also the number of mosquitoes have gone up. Therefore, fans are necessary to beat the heat and to avoid mosquitoes."

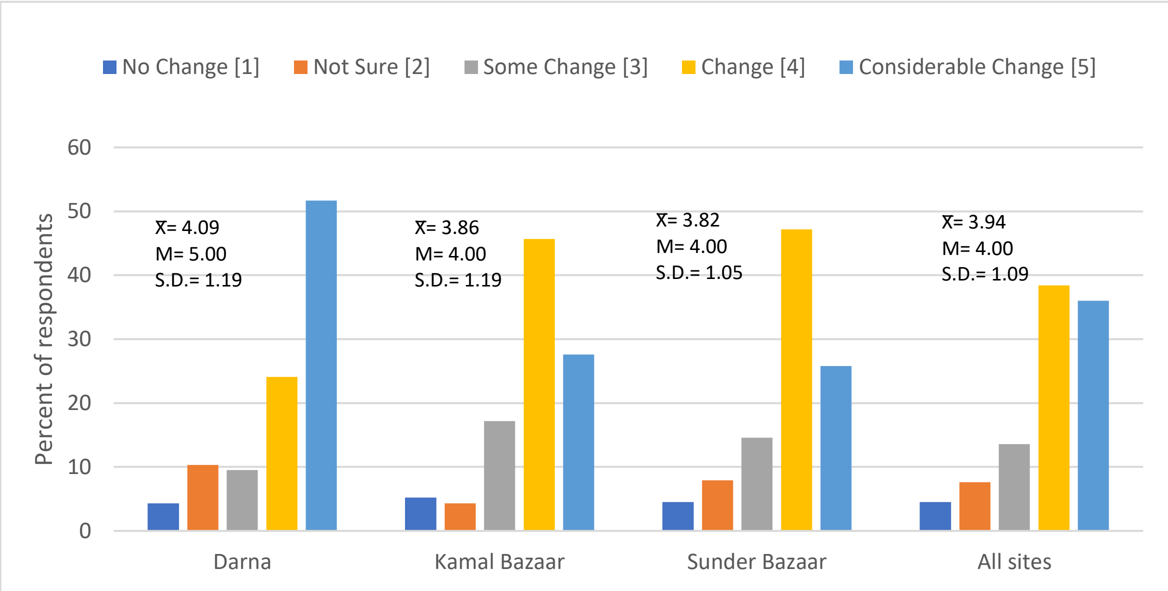
The warming trend has been echoed by other studies as well in the region. An appraisal exercise done for National Adaptation Program of Action (NAPA) to assess 'perceptions of climatic hazards and climatic changes' in the western mountains of Nepal also reported a warming trend, warmer days and less colder nights in the region (NAPA 2010). Khatiwada et al. (2016) found an increasing trend of mean annual average temperature at a rate of 0.03ºC per year at Surkhet station (DHM Index no. 406), which is close to Darna and Kamal Bazaar. Thus, local perception of change in temperature is consistent with findings from the quantitative analysis of weather records and other studies (DHM 2017; Kattel & Yao 2013; Khatiwada et al. 2016; Shrestha & Aryal 2011; Shrestha et al. 2019) from the region.

5.4.3 Local perceptions of changes in precipitation

The majority of the survey participants (88%) felt that the annual average rainfall is changing in their region [Figure 5.11]. Of all the surveyed participants, 36% have observed considerable change, 38% have observed change and 14% have observed some change in precipitation level. The remaining, 8% were not sure and 4% have not observed any change in precipitation. Among the participants reporting a change, 83% reported a decline and 17% reported an increase in the level of precipitation. Local perception of change in precipitation by the majority of survey respondents at the study sites thus corresponds to findings from the quantitative analysis of rainfall trends [see section 5.3.2].

Based on the average score calculated for survey responses, Darna residents reported the highest level of precipitation change [Kamal Bazaar $\bar{X}$= 3.86, Darna $\bar{X}$= 4.09, Sunder Bazaar $\bar{X}$= 3.82] [Figure 5.11]. The chi-square test indicates that the spatial difference in perceived change in precipitation level at the study sites is significant [Chi-square, P= 0.001].

Figure 5.11 Perceived change in rainfall



Source: Field Survey, 2018

The survey as well as focus group participants shared their experiences in support of their observation of declining precipitation. The most common example provided was the early drying up of springs in their communities. A woman focus group participant in Darna said:

"In our society, fetching water for household is usually a woman's responsibility. So, I know about the spring from where I regularly fetch water. When I was a kid, the spring used to have water throughout the year. However, these days, the spring sprouts during August-September and dries out by January. I am not sure what the reason is, but less rainfall could be one of the causes."

Some survey participants associated less rainfall with increase in drought-like situation. A survey participant in Darna said:

"We have less rainfall, that's why, I think we face more drought-like situations than in the past. "

With regard to dry spell, one of the experts in Darna mentioned that farmers are generally quick in noticing variations in rainfall pattern. He said, in recent years, he has heard more complaints about poor and inconsistent rainfall. One of the farmers in Kamal Bazaar said:

"Our parents and grandparents used to say that when the tip of a cow or a buffalo's horn and the leaves of a paddy crop look dry during the rainy season, then that is an indicator of a bad rainy season. Unfortunately, such rainy seasons are becoming more frequent these days."

An expert interviewed in Kamal Bazaar also suggested a decline in precipitation. He thinks that the reduced amount of precipitation in winter is leading to less snowfall in the region. He said:

"Earlier we used to see snow-capped mountain tops for months during winter, however, these days we see snow only for a few days. I think this is because of the warmer temperature and less rainfall or snowfall during winter."

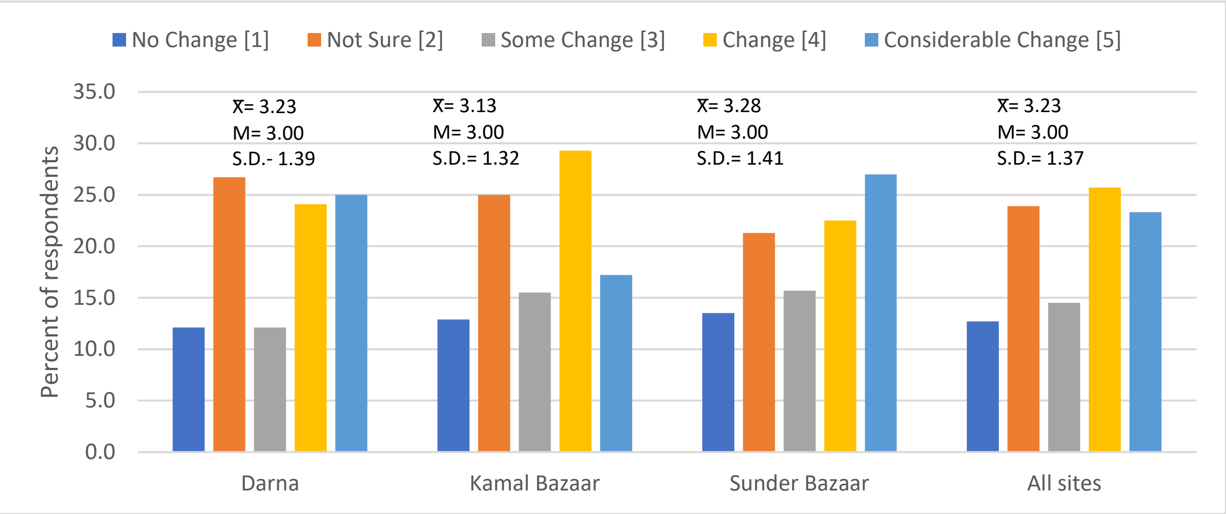
In Sunder Bazaar, focus group participants associated the reduced flow of springs and rivulets to declining rainfall. Overall, the common perception at the study sites suggest a decline in the amounts and durations of rainfall in comparison to the past. Other studies from the region have also reported declining rainfall trends (Heyojoo et al. 2017; NAPA 2010 Annex. 2; Panthi et al. 2015).

5.4.4 Local perceptions of variation in the onset and withdrawal of the monsoon in the study sites

The majority of the survey respondents (63%) reported that they have noticed changes in the onset and withdrawal of the monsoon over the past decades [Figure 5.12]. Of all the surveyed participants, 23% have observed considerable change, 26 % have observed change and 14% have observed some change in the arrival and withdrawal of monsoon system in Nepal. The remaining 24% were not sure and 13% have not observed any change. Among the respondents reporting a change, 86% reported a delay in monsoon onset and arrival. Local perceptions of the changes by majority of the survey participants thus corresponds to the findings form the quantitative analysis of monsoon arrival and withdrawal records [see section 5.3.3].

Based on the average score of survey responses, Sunder Bazaar residents reported the highest level of change [Kamal Bazaar $\bar{X}$= 3.13, Darna $\bar{X}$= 3.23, Sunder Bazaar $\bar{X}$= 3.28] [Figure 5.12]. There is no significant difference between the study sites in the perceptions of change in monsoon arrival and withdrawal [Chi-square, P= 0.633].

Figure 5.12 Perceived variation in onset and withdrawal of monsoon



Source: Field Survey, 2018

Research participants shared several examples of their observation of variability in monsoon arrival and withdrawal. A community leader, who has been participating in local climate change adaptation projects in Sunder Bazaar, informed that there was a one-month delay in summer rainfall last year. He mentioned:

"Crops need the right amount of continuous and consistent rains to give good yields. However, last year, the amount of rain, which should have fallen in the month of Shrawan (July-August), fell a month later. What is the use of such rains? Such untimely rains do more harm than good to our crops."

In Kamal Bazaar and Darna, locals shared similar views about the variation in rainfall timings. One of the farmers in Darna said:

"Earlier we used to receive good rain from the month of Jestha (May-June), however these days, even during the month of Asadh (June-July), there is no good rain. This delays our

maize cultivation. Asadh 15 is called "Ropai Day" (National Rice Day), however, these days we do not have enough water in our fields on Asadh 15 to kick-off our usual 'Ropai' day ceremony."

Focus group participants in Darna mentioned that although rainfall could not be expected always to be right on time, they wished it to be more consistent. In Kamal Bazaar, farming households with migrant family members mentioned that they have felt the changes in monsoon timing, because the monsoon arrival is directly linked to their seasonal migration to India. One of the survey respondents said:

"My husband takes 3 months of leave from his job in India prior to the start of monsoon to return home and to help in cultivation. However, these days the rainfall has become unpredictable and usually starts late. Therefore, my husband has also been pushing his leave to a further date."

The local perceptions of the monsoon at the study sites is similar to the results of an appraisal exercise done for NAPA to identify perceptions of climatic hazards and climatic change in western mountains of Nepal (NAPA 2010 Annex 2). Overall, the common perception at the study sites suggest a delay in the onset and withdrawal of monsoon in comparison to the past.

5.5 Observed environmental changes and their impacts in the study areas

The assessment of climate impacts involves identifying and evaluating positive and negative consequences of a changing climate on natural and human systems (Füssel & Klein 2006). The assessment of impacts is crucial to understand and designing effective adaptation strategies (Warren et al. 2018). The climate change impacts could be direct, such as in the form of deaths, injuries and property losses from extreme weather events like severe flooding or landslides, or could be indirect via changes to the socio-ecological systems. Examples of indirect or secondary impacts include higher temperatures, arid conditions or longer growing seasons, which if sustained over a long period, could lead to decreased agricultural production or increased insect pests and vector borne diseases (Haider et al. 2017; Trębicki et al. 2015; Van Munster et al. 2017). This section discusses the impacts of the observed changes in the environment in the study sites.

5.5.1 Increasing temperatures

Temperatures in the mountains of Nepal are rising faster than the global average (Government of Nepal 2016; Khatiwada et al. 2016; Krishnan et al. 2019; Nogués-Bravo et al. 2007; Salinger et al. 2014). The trend analysis of temperature records from the weather stations close to the study sites [see section 5.3.1] and local perceptions at the study sites [see section 5.4.2] indicate that temperatures are increasing. Research participants mentioned that the rise in temperature has many impacts.

Residents of Sunder Bazaar and Darna feel that the peak summer temperatures are increasing and uncomfortable summer nights are becoming more frequent in their region. Increasing daytime and night-time temperatures have forced locals in the study sites to seek coping measures such as avoiding farm work in the afternoon, drinking more fluids and installing fans in their homes. A survey respondent in Sunder Bazaar said:

"On very hot days, if possible we avoid outdoor works and travelling as we do not want to fall sick. If we need to travel on hot days, we use umbrellas and drink more fluids."

The increasing number of families are adding fans in their houses. One of the survey participants in Darna said:

"These days increasing number of people are bringing pedestal fans when they return from India or cities in Terai as fans are useful for cooling during hot summer days and nights."

Households, who do not have access to electric fans said that they sleep outside under the open sky to avoid hot temperatures inside their houses. One of the survey respondents in Darna said:

"During hot summer nights, we sleep either outside of our houses or inside with windows open. We know sleeping outside or with windows open is not safe, yet we do it to avoid heat."

Focus group participants in Darna and Sunder Bazaar were worried that the increasing temperatures could have negative impacts on their health. Survey respondents reported that infants, young children and old age people usually find it difficult to cope with extreme summer temperatures. A medical expert in Kamal Bazaar mentioned extreme heat or cold events could be detrimental to public health and especially to the wellbeing of vulnerable population. The expert said:

"Extreme heat or cold events leading to a high rise or drop in ambient temperatures can increase emergency cases and even cause the deaths of elderly people and those with impaired health conditions. We have already observed such cases in the country. Therefore, we should remain vigilant for the safety of everyone and especially of newborn, elderly and sick people."

Very high ambient temperatures have been associated with increases in hospital admissions (Pudpong & Hajat 2011) and mortality (Canoui-Poitrine et al. 2006; McMichael et al. 2008; Murage et al. 2017). Studies such as O'Neill and Ebi (2009) and Smith et al. (2016) also note that elderly, children, the ill and people with limited mobility are more vulnerable to temperature extremes because of climate variability. Research participants mentioned that special care of the vulnerable family members is taken by making them drink more water, arranging electric and hand held fans and allocating them a bedroom in the ground floor which is comparatively colder than the bedrooms on the higher floors of the house.

Unlike Sunder Bazaar and Darna, the residents of Kamal Bazaar did not complain of uncomfortable summer days and nights. According to one of the experts in Kamal Bazaar, this is probability due to year round colder climate because of its location at higher elevation. The study site in Kamal Bazaar is located at 1900 masl, whereas the study sites in Darna and Sunder Bazaar are located at 1215 masl and 700 masl respectively. Survey participants in Kamal Bazaar nevertheless reported that the intensity of cold during autumn and spring seasons is decreasing. As a result, households in Kamal Bazaar are using blankets and quilts for shorter periods in comparison to the past. A survey respondent in Kamal Bazaar said:

"When I was a kid, I remember using blankets until late spring, however, these days we give up blankets quite early in the mid spring."

Focus group participants in Kamal Bazaar think that the declining water availability in their region is linked to less snowfall, rapid melting of snow and increased rate of evaporation, which they believe are associated with increasing temperatures. One of the focus group participants said:

"Earlier, snow deposits on top of mountains used to last longer. Longer snow deposits meant long-term availability of water until the dry season. However, in recent years, snow does not last long. It must be due to rapid melting because of increased temperatures. Earlier melting of snow leaves our springs and rivers with less water flow during the dry season."

Increasing temperatures have been linked to early melting of snow and thus reduced water availability in other parts of Nepal as well (Bhatta et al. 2015).

The impact of warming is not only limited to humans. A cattle farmer in Sunder Bazaar and a poultry farmer in Darna mentioned that the hotter temperature causes inconvenience and sometimes death of their livestock. The poultry farmer in Darna informed that she lost 15% of her broiler chicks to hotter temperatures. She said:

"Chicks during their initial days are very sensitive to cold and hot temperatures. I have a small farm and just a pedestal fan to cool the temperatures during hot summer days. However, last year the fan broke and without a fan to cool indoor temperatures under a tin shade, 15% of the chicks died."

A cattle farmer in Sunder Bazaar mentioned that his European breed, which he chose over others for greater milk production is not accustomed to hotter temperatures, and therefore finds difficult to cope during hotter days. The farmer said that he avoids taking cows out of the shed and provides additional baths and water to drink on hotter days. Hussain et al. (2016) have linked several livestock diseases to warming temperatures in the HKH region. In addition to livestock, farmers mentioned that consecutive hot days in summer affect their crops. The farmers said that if not well irrigated, crops could die or give very low yield due to loss of moisture in soil. As mentioned by research participants, Tsering et al. (2010) have also reported higher rates of evapotranspiration and loss in crops due to hotter temperature in eastern parts of Nepal.

Similarly, survey respondents reported greater spoilage of agriculture produce and especially of vegetables due to hotter temperatures. An expert in Kathmandu mentioned that the increasing temperatures would likely accelerate vegetable and fruit spoilage leading to a greater food waste and economic losses in the future. Rawat (2015) also notes that higher temperatures increase the chances of food spoilage.

In addition to the problems discussed above, research participants in every study site reported a considerable increase in the number of mosquitoes. Research participants think that the increase in mosquito numbers is linked to warming in their region. Focus group participants in Darna mentioned that mosquitoes, which were earlier limited to Terai in southern Nepal are now abundant in their region because of the increasing temperatures. One of the focus group participants in Darna said:

"We maintain better hygeine and cleanliness. In spite of that, the number of mosquitos has increased, which means the weather is warming and favouring their growth."

Rossati (2017) notes that a warmer climate presents a more favorable condition for survival and completion of mosquito life cycles. In spite of the majority of respondents linking increase in mosquito numbers to warming, some of the respondents however, attributed the newly introduced transport services in their village to improting mosquitoes from the towns of Terai. They said:

"Buses and jeeps are carrying mosquitoes along with people and goods."

In order to deal with mosquitoes, the residents of Darna, Kamal Bazaar and Sunder Bazaar have added mosquito nets in their bedrooms. Some of the households with better financial resources in Kamal Bazaar have installed higher capacity solar photovoltaics to add pedestal fans to their bedrooms. In Darna and Sunder Bazaar, households have started adding pedestal and ceiling fans to cope with increasing temperatures and mosquitoes.

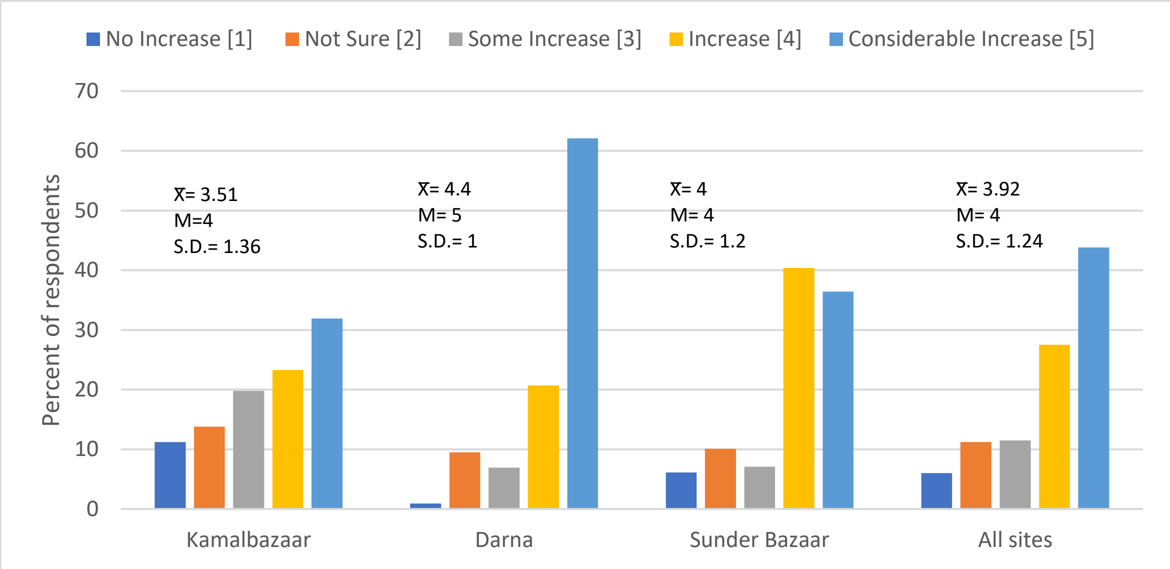
Overall, research participants associated increasing temperatures with several negative impacts on local liefestyle, health, water resources, livestock, crop productivity and increase in number of mosquitoes. Other research have discussed similar impacts of rising temperatures on different aspects of livelihoods such as crop productivity (Jalloh et al. 2013; Kangalawe et al. 2017), health (Tonnang et al. 2010) and water availability (Nnaji 2012).

5.5.2 Increases in invasive species

Biological invasion is a leading cause of decline in native biodiversity (Kohli et al. 2004) and loss of ecosystem services (Pejchar & Mooney 2009). Survey respondents reported rapid growth of invasive species in their region. Of all the surveyed participants, 44% have observed considerable increase, 28% have observed increase, and 12% have observed some increase in invasive species in their surroundings [Figure 5.13]. The remaining, 11%

were not sure, and 6% have not observed any increase in invasive species. Based on the average score of survey responses, residents of Darna reported the highest level of increase in invasive species [Kamal Bazaar $\bar{X}$= 3.51, Darna $\bar{X}$= 4.4, Sunder Bazaar $\bar{X}$= 4] [Figure 5.13] [Chi-square, P= 0.000].

Figure 5.13 Local perception of increase in invasive species



Source: Field Survey, 2018

Invasive plant species at the study sites are in the form of shrubs and weeds. Invasive shrub species are generally called *"Banmara"* and weed is called *"Jhaar"* in local vernacular. Crofton Weed (*Ageratina adenophora)* and Umbelanterna (*Lantana camara*), both commonly called *Banmara* were the most reported invasive plant species at the study sites.

Figure 5.14 Umbelanterna (*Lantana camara*) invasion in the local forest in Darna

Source: Field Survey, 2018

Figure 5.15 Crofton Weed (*Ageratina adenophora*) invasion in roadside in Kamal Bazaar

Source: Field Survey, 2018

Survey respondents in Darna mentioned that they have noticed a massive expansion in invasive species in the last 10 years. A survey respondent in Darna said that *Banmara* is gradually taking over all the spaces and is increasingly becoming a problem for them. Another survey respondent in Kamal Bazaar mentioned that they initially noticed

Banmaras only in open spaces inside forest, however, lately the *Banmaras* have spread to roadsides, playgrounds and house compounds. In addition to common invasive species such as *Ageratina adenophora* and *Lantana camara*, the residents of Sunder Bazaar complained about the rapid growth of '*Maaobaadi Jhaar'* and '*Lajjawati Jhaar'* (*Mimosa pudica*) in their surroundings.

Figure 5.16 Weed taking over free spaces in a house compound in Sunder Bazaar

Source: Field Survey, 2018

According to survey respondents, their major concern about invasive species is the loss of forage for their cattle as invasive species limit the growth of other plant species. One of the survey participants in Darna said:

"It is becoming tough to raise goats and cows now. We cannot collect green tree branch from community forest, which limits us to grass and plants in our field and roadside. However, Banmara is covering all the grass and limiting the growth of other plant species. Unfortunately, our cattle do not feed on Banmaras."

Bhatta et al. (2015) also found reduced regeneration capacity of other plant species because of invasive species *Lantana camara* in Nepali mountains. A woman in Sunder Bazaar mentioned about challenges in collecting forage due to the expansion of *'Lajjawati Jhaar'* in her fields. She said:

"Rapid expansion of 'Lajjawati Jhaar' in our fields is becoming a new challenge for us. Small thorns in 'Lajjawati Jhaar' prick us when we try to collect forage from our fields for our cattle. Last month I had to visit a clinic for medicines after the wound from the prick got worse."

Farmers also reported losses due to unwanted weed growth in their fields. One of the farmers in Sunder Bazaar said:

"More weed in farm means additional labour and less yield. In either of the case, we lose income."

Focus group participants in Kamal Bazaar mentioned that the massive growth of invasive species on roadsides make walking along the narrow trails difficult. Forest users in Darna said that the quantity of edible plants, medicinal plants, fruits, berries, and aromatic plants in their local forests have reduced due to the expansion of invasive species. One of the community forest user group members in Darna said:

"Few years ago, we were planning to grow medicinal herbs like 'Lemongrass' and 'Citronella' in our community forest to increase our income. We had seen similar efforts giving good results in other places. However, the rapid growth of 'Banmara' in our forest has forced us to abandon our plans. Moreover, 'Banmara' has also reduced the number of mushrooms, bamboo shoots, "Jibre Saag" and "Niuro" (edible herbs collected as vegetables) in our forest."

Similar to the experiences shared by local residents, Bisht et al. (2016) have highlighted increased labour input in agro-ecosystem, loss of crop productivity, loss of forage, loss of non-timber forest products, and slowing of forest regeneration as primary impacts of rapid expansion of invasive plant species in the region.

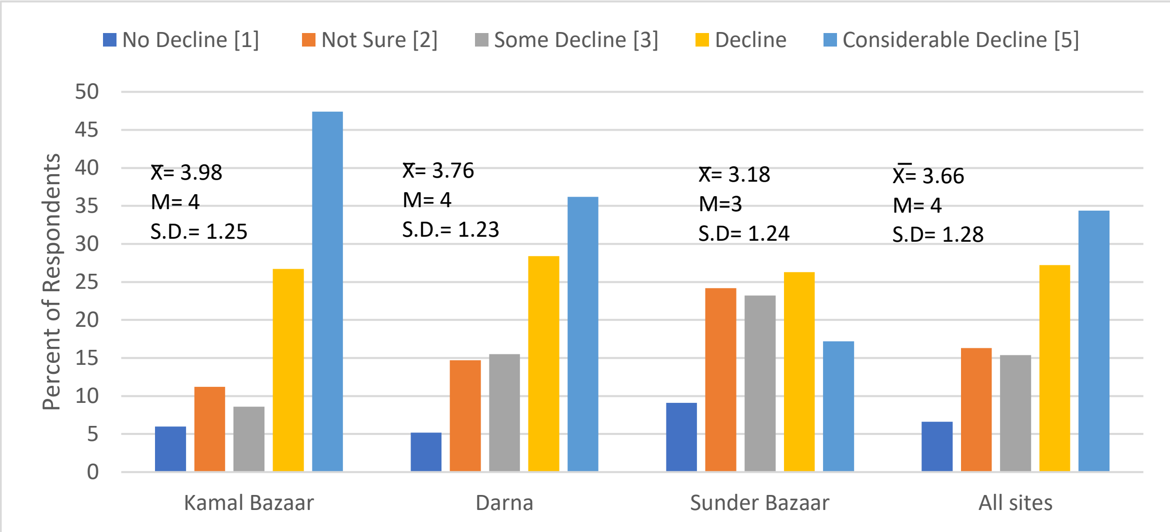
While most of the research participants generally discussed the disadvantages, experts in Sunder Bazaar and Darna mentioned few advantages of the invasive species. An expert in Sunder Bazaar mentioned about the potential use of invasive plant species as a pesticide in fields. He said that the dried leaves and branches of *'Banmaara'* (*Ageratina adenophora)* and *Lantana camara* could be used as pesticide to limit weed growth. The expert in Darna said that the leaves and branches of *'Banmaara'* could be crushed to make Bio-Briquettes and used as kitchen fuel.

When asked the reason behind the massive proliferation of invasive species, many respondents did not proffer an explanation. Some of the survey respondents in Darna and Kamal Bazaar are of opinion that the introduction of transport in their villages might have brought invasive species from outside. While the reason for rapid expansion of the invasive species at the study sites could be many, changes in climate may have affected the dynamics and favoured the growth of certain species. Lamsal et al. (2018a) argue that climate change is affecting the dynamics of invasive alien species in the Himalayan region.

5.5.3 Declining rainfall and water availability

Water is a resource vital for survival as well as economic growth. Growing local population densities combined with a changing climate are exacerbating the pressure on limited water sources not only in the mountains of Nepal but in many places around the globe (Gosling & Arnell 2016). Survey respondents in the study areas reported decreases in rainfall [see section 5.3.2 and 5.4.3] and declining water availability. Of all the surveyed participants, 34% have observed considerable decline, 27% have observed decline and 16% have observed some decline in water availability in their communities. The remaining 16% were not sure and 7% have not observed any decline [Figure 5.17]. Based on the average score of survey responses, the residents of Kamal Bazaar reported the highest level of decline in water availability [Kamal Bazaar $\bar{X}$= 3.98, Darna $\bar{X}$= 3.76, Sunder Bazaar $\bar{X}$= 3.18] [Figure 5.17][Chi-square, P= 0.000].

Figure 5.17 Local perception of declining water availability in the study sites



Source: Field Survey, 2018

The decline in water availability in Kamal Bazaar was reported mostly in the form of early drying up of springs, which are the main sources of water for the household usage. Kamal Bazaar is a village on top of a hill where there are very few springs. Most of the springs are below the settlement area. As the nearby springs have dried up, locals need to travel farther for water. An expert said the shortage of drinking water is one of the major problems in his community. He said:

"*During the wet season, there is enough water. However, as the dry season kicks in, the water shortage becomes terrible. When the nearby springs dry up, we need to walk up to 2 kilometres to other sources to collect water. Sometimes, the water from river is not as clean as water from our springs.*"

The situation during the dry season becomes so bad that businesses such as restaurants and hotels, which need more water, pay up to NRs.100 per 100 litres to water porters to fetch water from distant sources. When water is needed at a large scale for events like weddings and construction, trucks or tractors are used to fetch water in big drums from the nearby rivers. The cost of hiring a truck or a tractor can reach up to NRs. 5000 per trip. The cost of water is exorbitant for the poor community of Kamal Bazaar, where the standard of living and per capita income is already among the lowest in the country. Local business owners were upset with the situation. One of the restaurant owners said:

"We have a serious water shortage here. We are among the poorest in the country and yet we pay for water like we pay for petrol. I am ready to personally contribute free labour and some funds to solve this problem. If the water problem is not addressed soon, I will not be able to continue my business."

Figure 5.18 A woman collects water in a gallon in Kamal Bazaar

Source: Field Survey, 2018

Figure 5.19 Drums for water collection at a poultry farm in Darna

Source: Field Survey, 2018

Like Kamal Bazaar, research participants in Darna also mentioned the early drying up of springs as the most common indicator of declining water availability in their community. Focus group participants in Darna said:

"During the months of Chaitra and Baisakh (March-April), springs dry up and we have serious water scarcity here. Population is increasing, however, the water resources like springs and small ponds are drying up. Sometimes locals even fight amongst themselves for water."

In Sunder Bazaar, the situation was slightly better in comparison to other study sites [see Figure 5.17]. That better situation is probably due to the superior drinking water and irrigation infrastructure in place in Sunder Bazaar in comparison to the other study sites.

In parallel with the findings of this research, a decline in water availability has been reported in other mountain communities in Nepal. Poudel and Duex (2017) observed a decline in the flow of and drying up of springs in Nuwakot district in central Nepal. Bhatta et al. (2015) observed drying up of natural springs and decline in water availability by up to 25% in Dolakha district in central Nepal. McDowell et al. (2013) identified reduced water availability for household uses and tourism business in Khumbu region in eastern Nepal. While the shortage of water for household usage is a major problem for everyone, it is specially challenging for women and girls, because in rural Nepali communities household chores including the collection of water are generally considered women's responsibility (Nellemann et al. 2011). One of the women in Kamal Bazaar highlighted the additional burden due to shortage of water. She said:

"Drying up of springs means added burden particularly to women. As more time and effort need to be spent in collecting water, we get less time to socialise or participate in other productive activities. Less water also means compromised hygiene and sanitation."

In addition to the shortage of water for household usage, survey respondents discussed the impacts of less water availability on their livelihoods. One of the survey participants in Kamal Bazaar said:

"For most of us, farming is the only means of livelihood. In our region, farming is very much dependent on rain. If we do not have good rain, we will not be able to produce food and income for our families."

Farmers mentioned that longer dry spells and lack of moisture harden the soil, which makes tilling land difficult, time consuming and expensive. A farmer in Darna said:

"When there is good rain, the soil becomes soft as it absorbs enough moisture. This makes ploughing, tilling and weeding easy. However, during dry spells, the soil becomes hard and tough to work on, which requires more labour. More labour means additional cost for us."

In order to cope with declining rainfall and less water availability, farmers in Darna and Kamal Bazaar are shifting to crops that require less water such as millet and maize instead of paddy. In a different study in eastern Nepal, Bhatta et al. (2015) also found farmers avoiding traditional crops like paddy and looking for alternatives because of insufficient water in their fields.

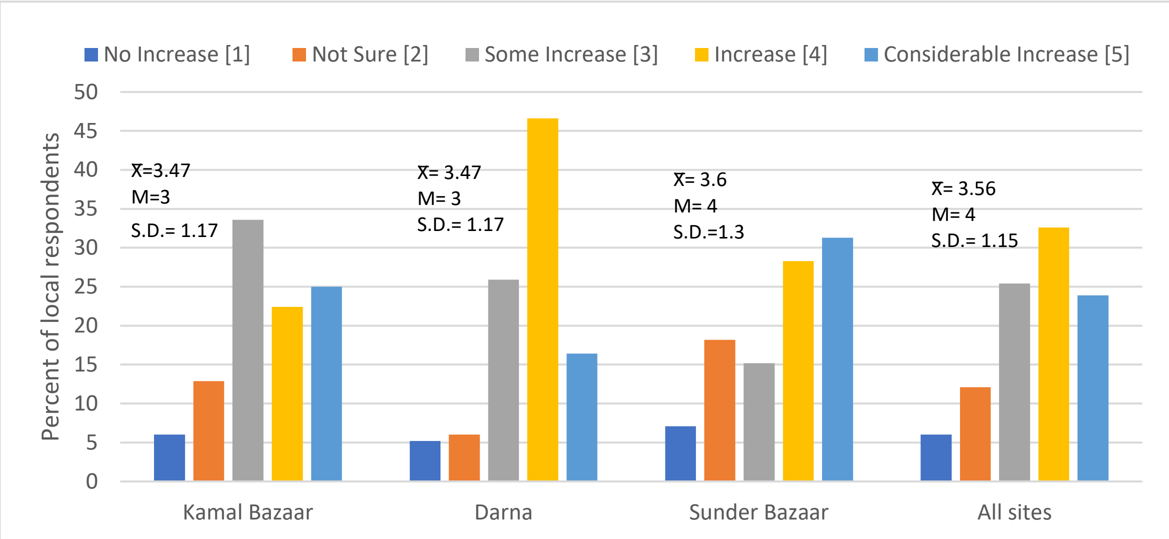
Apart from altering traditional agriculture practices, survey respondents in Kamal Bazaar and Darna mentioned that they travel to cities and to India looking for jobs when agriculture alone is not enough to feed their families. Alfthan et al. (2018) note that lower agricultural production encourages outmigration of males to cities and overseas. Research participants mentioned that the outflow of working age population has led to severe shortage of skilled personnel like carpenters and masons in their villages.

Thus, it is observed that the decline in water availability has multiple impacts on livelihoods. Alfthan et al. (2018) argue that water availability in the HKH region including Nepal will decline because of the reduced water level in rivers due to retreating glaciers. Reduced water availability in the mountains has the potential to affect communities reliant on them by affecting irrigation, hydropower, agriculture, drinking water and recreation (Carey et al. 2017). Bhatta et al. (2015) and Rasul (2010) argue that any reductions in water availability for agriculture has devastating effects on the livelihoods and food security in the mountain regions of Nepal. Therefore, Facon (2000) suggests countries like Nepal need to invest massively in water development and national irrigation system by 2025 in order to avoid water becoming an overriding constraint to socio-economic development and food security.

5.5.4 Increases in insect pests and diseases

Insect pests cause significant damage to human health, agriculture and economies (Deutsch et al. 2018; Dhaliwal et al. 2010; Dhaliwal et al. 2015; Oliveira et al. 2014). Survey respondents reported the increase in the number of insect pests on their crops, the increase in the number of mosquitoes and increases in livestock diseases. Of all the surveyed participants, 24% have observed the considerable increase, 33% have observed increase, and 25% have some increase in the number of insect pests and diseases in their surroundings. Of the remaining, 12% were not sure, and 6% have not observed any increase in insect pests and diseases [Figure 5.20]. Based on the average score of survey responses, residents of Sunder Bazaar reported the highest level of increase in insect pests and diseases [Kamal Bazaar $\bar{X}$= 3.47, Darna $\bar{X}$= 3.47, Sunder Bazaar $\bar{X}$= 3.6] [Figure 5.20] [Chi-square, P= 0.000].

Figure 5.20 Perception of increase in insect pests and diseases in plants, animals and surroundings



Source: Field Survey, 2018

Research participants reported an increase in pest infestation in their crops, livestock and surroundings. Farmers across study sites stated that pests such as stem borer and false smut have increased in their paddy fields. According to International Rice Research Institute (IRRI), the stem borer destroys paddy crop at any stage from seedling to maturity and false smut causes chalkiness of grains that leads to reduction in grain weight (IRRI 2020). Farmers were worried about increasing pest infestation. A farmer in Darna said:

“*Rice and wheat are our main crops. We put in a lot of effort and money for greater yields. We depend on them for the year-long supply of our staple diet and income. Any damage to these crops due to a pest infestation results in our heavy losses and is a threat to our livelihoods.*”

As farming is the main source of livelihood for majority population in the study areas [see section 4.5.1], any loss to the yield of their crops can push the already poor set of population to vicious circle of chronic poverty (Koirala 2018).

Figure 5.21 False smut (*Ustilaginoidea virens*) balls on paddy crop in Darna

Image: Field Survey, 2018

Focus group participants in Sunder Bazaar stated that the production of citrus fruits such as oranges has declined due to a new disease on plants, which they had not previously encountered. Survey participants in Kamal Bazaar reported increase in the cases of "*Maalu"* and *"Dadhelo"* - early and late blight diseases in potato and tomato plants. Similarly, survey participants in Sunder Bazaar also complained about increase in insect pest in their vegetable crops. One of the of the survey participants stated that he has noticed an increasing number of insect species such as *"Dhamiro"* (termites) and *"Rato Kamilo"*(red ants) in his vegetable crops. Another survey respondent in Sunder Bazaar reported increased numbers of gastropods such as *"Shankhe Kira"*- snail and *"Chiple Kira"*- slug in his kitchen garden. Focus group participants in Sunder Bazaar mentioned that the increasing crop damage and yield loss in their kitchen garden is one of the main reasons for them to abandon vegetable farming. The focus group participants said:

"Red ants damage our potato crops. Termites damage stem and roots of the other crops. Termites also damage the wooden support for climbing vegetable plants. Snails and slugs

eat leaves of crops like cauliflower. The loss of yield because of these pests simply discourages us to plant any vegetable crops."

Focus group participants in Sunder Bazaar mentioned that of all the crops grown, vegetable crops are usually more affected by pests because there is less use of pesticide in vegetable crops in comparison to others. Most of the households grow vegetables for self-consumption. Therefore, they do not prefer to use harmful chemicals. Even with the use of chemicals, farmers in Darna and Sunder Bazaar think that insect pests have now become more resistant. One of the farmers in Darna said:

"I do not wish to use more pesticide, however, I am increasing pesticide use every year. I think the insect pests have become more resistant, which is why the regular pesticide has lost its efficacy."

Matzrafi (2019) notes that climate change is expected to exacerbate pest damage through reduced pesticide efficacy in the future. Farmers expressed concern that the need to use greater amount of pesticides adds financial burden and could lead to a loss of income. Focus group participants in Sunder Bazaar stated that pesticides make up as much as a quarter of their monetary investment in farming.

Figure 5.22 Pest infestation in a vegetable field in Sunder Bazaar

Source: Field survey, 2018

In addition to crops, farmers in the study sites reported new and increased cases of diseases in livestock. The most common disease in livestock reported was "*Khoret",* also called Foot-and-Mouth disease. Focus group participants in Kamal Bazaar and Darna stated that the cases of Foot-and-Mouth disease have increased in recent years in their communities.

Farmers do not have an idea of what is causing the new and increased insect pest and disease problems in their crops and livestock. However, they think the adoption of new hybrid crops and livestock as one of the reasons. In spite of the views that the imported hybrid varieties are more prone to pests as compared to local varieties, farmers across study sites generally prefer to use hybrid crop and livestock varieties because they are easily available and promise greater yields. One of the farmers in Kamal Bazaar compared the use of hybrid varieties to gambling. He said:

"I think the local variety can better withstand insect pests. Yet, I choose hybrid seeds in the hopes of a greater yield. Sometimes we get good results. However, sometimes we lose our crops because hybrid varieties are more susceptible to insect pests. Therefore, it is similar to gambling. If you are lucky you win, if not, you lose."

In addition to increased pests and diseases, survey participants reported an increase in the numbers of insects such as ants, cockroaches and mosquitoes in their surroundings. A survey respondent in Sunder Bazaar said:

"We find lots of cockroaches these days. Cockroaches contaminate our food and even bite us when we are asleep."

Almost every single survey respondent reported an increase in the number of mosquitoes. Research participants were worried about the increasing number of mosquitoes and the disease associated with them. A survey participant in Darna said:

"In the past, mosquito related diseases like Malaria and Dengue were mostly limited to the warmer regions of the Terai. As far as I can remember, during my childhood, our communities with colder climates in the mountains had no mosquitoes and no such diseases. However, with increasing number of mosquitoes, I fear such deadly diseases will be common in our mountain communities."

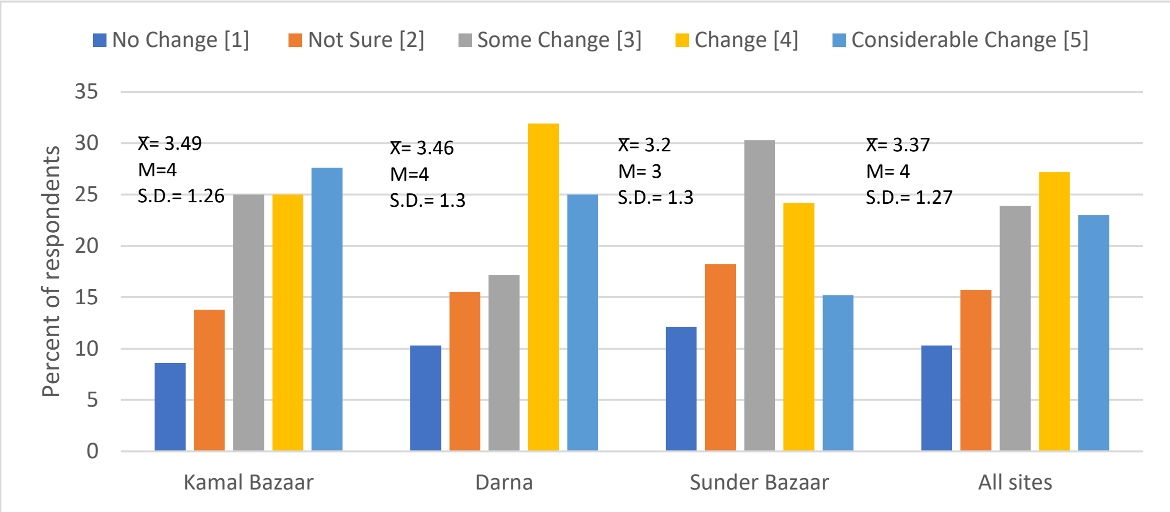
Many people from Kamal Bazaar and Darna travel for work to Indian states such as Delhi, Uttar Pradesh, Haryana and Punjab, which are very prone to mosquito borne diseases like Malaria, Dengue and Chikungunya (Mutheneni et al. 2017). Local residents were worried that the cases of such life threatening illness will go up as increasing mosquito numbers will multiply such illness imported by visitors to Indian cities. Rossati (2017) argues that a warming climate provides a favourable environment for vectors and pathogens to thrive, thus predicting increased numbers of vector and vector borne diseases in future. Recent reports from various parts of Nepal including temperate mountain regions suggest an unprecedented surge in the reported cases of Dengue and other mosquito related illness (Nepali Times 2019; The Washington Post 2019). In order to deal with the growing mosquito numbers, residents of the study areas have started installing nets and fans in their bedrooms. Research participants reported that the installation of nets and fans has added financial burden to them.

Overall, research participants reported an increase in the number of insect pests and their multiple impacts on health and wellbeing, agricultural productivity and household expenses. Although the increase of insects pests and diseases discussed above may not be directly attributable to climate change in each case, higher temperatures and precipitation changes have been found to strongly influence insect growth, development, reproduction and survival (Sharma 2014). Climate change has been reported to affect insect populations by shifting their distribution to higher elevations and reduce winter mortality (Karuppaiah & Sujayanad 2012). Patterson et al. (1999) and War et al. (2016) argue that the changing climate could alter pest problems by making pest population and presence unstable, leading to outbreaks and great losses in some areas, while a decline in others. The 2019-2020 locust outbreak in East Africa, Arabian Peninsula and South Asia including Nepal is one such example (Stone 2020).

5.5.5 Changes in flowering, fruiting and relocation of species

Ecosystems in the mountains are already experiencing significant changes (Bhattacharjee et al. 2017). Survey participants reported changes in flowering and fruiting, and a shift in the distribution of plant and animal species in their region. Of all the surveyed participants, 23% have observed considerable changes, 27% have observed changes and 24% have observed some change in flowering, fruiting and relocation of species. The remaining 16% were not sure and 10% have not observed any changes [Figure 5.23]. Based on the average score of survey respondents, residents of Kamal Bazaar reported the highest level of changes in flowering, fruiting and relocation of species [Kamal Bazaar $\bar{X}$= 3.49, Darna $\bar{X}$= 3.46, Sunder Bazaar $\bar{X}$= 3.2] [Figure 5.23] [Chi-square, P= 0.226].

Figure 5.23 Local perception of change in flowering, fruiting and relocation of species



Source: Field Survey, 2018

Survey respondents in Darna reported the upward shift of *Saal* tress (*Shorea robusta)* and changes in fruiting pattern of some plants species in their region. One survey respondent said:

"We now have Saal trees growing in higher places where only pine trees used to grow earlier."

Another survey respondent in Darna said:

"We have started noticing banana and mango trees producing fruits in our region. I do not remember any bananas or mango trees producing fruits earlier."

Survey respondents in Kamal Bazaar also mentioned the upward shift of *Saal* trees and changes in the fruiting of mango plants in their villages. Survey respondents said that the availability of *Saal* trees and mango fruits at higher altitudes was a positive change for them. A survey respondent stated:

"In our communities, Saal tree has the highest timber value for furniture and construction. The leaves of Saal trees are used to make disposable plates called 'Tapari', which has wide-ranging uses in local culture. It is a good thing that Saal is now growing at higher altitudes in our community. Additionally, the availability of mangoes locally is also a good news."

The observation of the upward movement of tree species shared by local residents are consistent with the findings from other studies conducted in the region. For example, Aryal et al. (2014) and Gaire et al. (2014) have also reported the shift of tree line to higher elevation in central Nepal. In Sunder Bazaar, however a decline in the fruiting of orange trees was reported. A farmer in Sunder Bazaar said:

"Earlier, we used to produce high volume of tasty oranges. We used to export a lot of them to cities. However, these days we do not get the same yield because of the declining number of fruits on the trees."

In addition to the changes in plant species, the research participants shared some changes observed in animal species as well. The changes reported in animal species were about numbers rather than relocation. While the numbers of animal species such as monkey, wild boar, deer and birds were reported to have increased in the forests of Kamal Bazaar, Darna and Sunder Bazaar, species such as leopards and bears were reported to have either decreased or disappeared in Darna and Kamal Bazaar. Farmers across study sites mentioned about the increased incidences of human-wildlife conflicts. Focus group participants in Darna said:

"Whatever grows in our farms, monkeys and wild boars destroy it. We tried fencing our vegetable farms, however, that is not effective. Monkeys jump over the fence and wild boars dig under the fence. We do not feel like growing maize and vegetables anymore"

When asked, what has led to an increase in such problems in recent years, the focus group participants highlighted the lack of bigger predators in their forest. They said:

"Earlier we used to have predators like leopards, bears and jackals in our local forest. However, major predator such as leopards and bears have now either disappeared or declined in numbers, which has resulted in the increase of monkeys and wild boars."

The changes in the numbers of wildlife at the study sites could have been due to various reasons and therefore, once again it cannot be directly and only be attributed to climate change. For example, land use change, especially the loss of forest has also been found to accelerate species redistribution (Guo et al. 2018). Similarly, the relocation and the changes in the fruition of some plant species at study sites also cannot be directly and only attributed to climate change. However, we should take into account that the changing climate is impacting biological systems at multiple scales, from genetic to ecosystems

(Hoffmann et al. 2019; Singh et al. 2011). Studies have suggested that a changing climate affects biodiversity by changing the phenology and species distribution, pollution, and habitat destruction because of land use change and extreme weather events like flood, fire and landslides (Lamsal et al. 2018a; Pecl et al. 2017; Root et al. 2003; Thuiller 2007; Tsering et al. 2010). Thus, we can expect climate change to exacerbate vertical upward migration of some species and the extinction of the others (Alfthan et al. 2018; Chen et al. 2011), especially as species that have adapted to one climatic zone over thousands of years are no longer able to survive in that particular zone with new conditions (Xu & Grumbine 2014).

5.5.6 Increasing variability in monsoon onset and withdrawal

The South Asian monsoon is one of the main factors influencing Nepal's climate (Shrestha et al. 2000). The monsoon has such an importance in Nepali lifestyle and culture that the start of the full swing of monsoon is marked and celebrated as "*Ropai"* or national paddy day on Ashad 15th of the Nepali calendar. Similarly, "*Indra Jatra*" festival is celebrated by the Newar community in Kathmandu valley around the month of September to mark the end of monsoon and to thank lord *"Indra"*- the god of rains. However, the changing monsoon pattern [see section 5.3.3 and 5.4.4] is affecting regular agriculture practices and livelihoods of many households in the study areas.

Farmers reported increasing uncertainty in the arrival and withdrawal of the monsoon as a serious challenge to their traditional farming practice. One of the survey respondents in Sunder Bazaar expressed his frustrations over erratic monsoon as below:

"The monsoon is unpredictable these days. For example, the monsoon was delayed by a month last year, which postponed our harvest by 1.5 months. Such uncertainties cause financial losses and disrupt our way of life."

According to an expert in Darna, uncertain monsoon has negative impacts on paddy, the most valuable crop at all three-study sites. The expert said:

"The delay in monsoon in June affects paddy germination and plantation; lesser rain during mid monsoon in July- August increases farm weeds and reduces seed sizes; and heavy rainfall during the late monsoon in September damages the final harvest."

Shrestha et al. (2015) predict a negative yield in agricultural production and food production throughout the HKH region because of uncertainties in the onset and duration of monsoon among other factors. Karki and Gurung (2012) and Poudel and Duex (2017) have identified several impacts of variation in temperature, rainfall and dry periods to the agro-ecological system in the region. Several livestock diseases have also been linked to the changed rainfall patterns (Hussain et al. 2016).

The delaying trend and high-inter annual variability in the onset and withdrawal of monsoon creates challenges and confusion among farmers. This was mostly evident in Darna and Kamal Bazaar where agriculture is mostly rain fed and the majority of adults are seasonal migrants to India. Seasonal migrants return to their homes during the main cropping season for cultivation. These workers usually get a limited annual leave of around one to two months. However, the delayed monsoon forces them to either extend their leave or return to India without fully cultivating their farms. In either case, they lose a considerable portion of their income. One of the seasonal migrants in Kamal Bazaar stated:

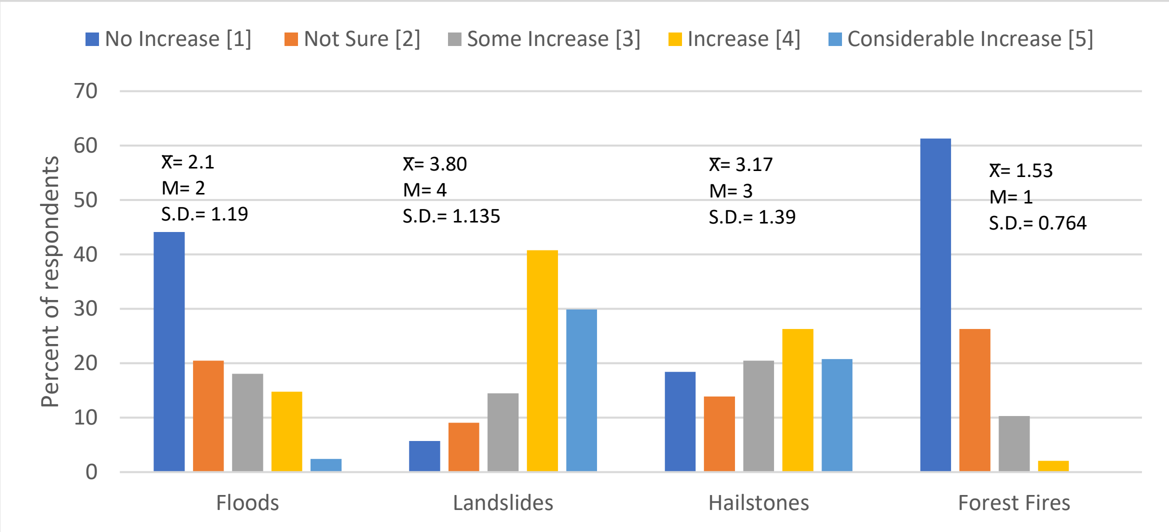
"The onset of monsoon has become very erratic these days. This has serious implications for seasonal migrants like us. We have to apply for leave well in advance, as other migrant workers also want to join their family for cultivation during the rainy season. We get a very limited amount of leave with little scope for extension. When we come to our village, we expect the monsoon to be on time, so that we can quickly wrap up our cultivation and return to our jobs. However, when there is a delay or insufficient rainfall, we are helpless. We do not have irrigation facility here, therefore, we have to wait and rely on nature. If we are lucky with rains, we can resume our jobs on time; else, we leave our lands barren."

In Nepal, increasingly a sizeable amount of farmland is being abandoned (Chapagain & Gentle 2015; Tamang et al. 2014) due to the lack of workers (Bhandari 2018). Abandoned farmland combined with likely reductions in agricultural yield due to reduced water availability will further worsen an already serious food security situations in the region (Pant 2012; Poudel & Duex 2017).

5.5.7 Changes in the frequency of natural hazard events

Nepal has a combination of rugged topography, active tectonics and a high seasonal and intensive precipitation, which makes it's fragile environment very vulnerable to hazards and associated disasters (Chalise & Khanal 2002). Climate change is expected to increase the frequency and intensity of extreme weather events leading to the higher occurrences of flash floods, landslides and debris-flow in Nepal (Shrestha et al. 2015). Survey respondents reported changes in the occurrence of natural hazards in their region [Figure 5.24].

Figure 5.24 Local perception of the increase in natural hazards



Source: Field Survey, 2018

Survey respondents in all the study sites reported an increase in the cases of landslides. Of all the surveyed respondents, 30% have observed considerable increase, 41% have observed increase and 14% have observed some increase in the cases of landslides. The remaining 9% were not sure and 6% have not observed any increase [Figure 5.24]. Research participants in Kamal Bazaar mentioned that the cases of landslides have become quite common in their village during the rainy season. One of the focus group participants said:

"As soon as the monsoon starts, we see a number of landslides around steep slopes and roadsides. Earlier, there used to be less landslides."

Research participants in Darna also shared similar opinion. Focus group participants mentioned that the scale of landslides are however different from the past. They said:

"Earlier we used to have few but massive landslides. These days, there are frequent but smaller landslides all along the roads.

Like Kamal Bazaar and Darna, the residents of Sunder Bazaar also reported an increase in the number of landslides. One of the survey respondents in Sunder Bazaar said:

"It is now common to see landslides on a regular basis near roadsides. Deforested areas and areas close to construction sites also have frequent landslides."

A common observation across study sites was the reporting of landslides near roadsides. When inquired further about it, an expert in disaster risk management in Kathmandu stated that the haphazard opening of road tracks around mountains has led to the increased cases of landslides near roadsides. He expressed dissatisfaction about the way the new roads were being built. He said:

"*Our villages have remained isolated for ages. Therefore, everyone wants road connectivity as early as possible. In this rush and excitement, the tracks for roads are being built without any detailed study. A dozer operator who is barely trained for 3 months is laying tracks on these mountains, which is ridiculous and scary at the same time. Moreover, there is no infrastructure around roads on slopes to support them. Therefore, the area around newly built tracks on mountains are fragile and prone to landslides when there is a heavy rain."*

Focus group participants in Sunder Bazaar also agreed that the haphazard building of tracks on mountains is increasing the frequency of landslides. However, they also blamed the earthquake in 2015 for increased cases of landslides in their region. One of the focus group participants said:

'*The powerful shake by the earthquake in 2015 has made the soil on mountains loose. I think that is the reason why we have observed increased cases of landslides during and after the earthquake.* "

A local expert in Darna also pointed to the role of extreme rainfall events in exacerbating the occurrence of landslides, while acknowledging the role of haphazard road construction. The expert said:

"Whenever, we have heavy rainfall, we find more cases of landslides than in the past, because these days the landscape is fragile. During the case of heavy rainfall in 2013, we saw numerous landslides in our region."

Another expert in Sunder Bazaar also stated that with likely increase in extreme rainfall events, he is expecting more cases of landslides in future. Climate change is expected to increase the frequency and intensity of extreme weather events in Nepal (Shrestha et al. 2015).

Specific examples of losses were linked with landslides at the study sites. An expert working in the field of disaster risk reduction in Sunder Bazaar mentioned that a massive landslide in the area swept away an entire school and some houses few years ago. Focus group participants in Sunder Bazaar mentioned that landslides in the past have killed people and livestock, and destroyed farms, houses, and physical infrastructure. A survey respondent in Darna said that he lost a cow shed, two goats and two oxen to a landslide four years ago. Focus group participants in Kamal Bazaar mentioned that it was common to lose some agricultural land to small-scale landslides every year. Douglas (2009) notes that heavy rainfall induced floods and landslides can have substantial impacts on food production and security in the western region of Nepal. Alfthan et al. (2018) found that 40% of households reported decrease in agricultural yield, due to floods, landslides, droughts, frost, hail, pests and diseases in the HKH mountains.

Figure 5.25 Landslide in a paddy field in Kamal Bazaar

Source: Field Survey, 2018

Additionally, research participants reported landslides damages to physical infrastructures such as schools, drinking water projects and roads. An expert in Darna mentioned that the damage to infrastructure is putting pressure on development budget. The expert said:

"We have very little budget for infrastructure development. When landslides damage the existing infrastructure, we cannot focus on new one as we lose budget on reconstruction. Moreover, constructing new infrastructure also becomes costly as more money has to be spent to make it landslide safe."

Figure 5.26 Roadside infrastructure to prevent landslides in Darna

Source: Field Survey, 2018

Apart from landslides, survey respondents reported some increase in the cases of hailstones in their region. Of all the surveyed respondents, 21% have observed considerable increase, 26% have observed increase, and 21% have observed some increase in the cases of occurrence of hailstones. The remaining 14% were not sure and 18% have not observed any increase [Figure 5.24]. Survey respondents across study sites reported that hailstones are common in the months of March, April and May in their region. Research participants in Kamal Bazaar mentioned that hailstones damage roofs and cause loss of crop and livestock. Focus group participants in Sunder Bazaar reported that hailstones generally affect their wheat and vegetable crops. One of the focus group participants said:

"Hailstones hit us hard during the harvest season. We lose our harvest to hailstones."

A survey respondent in Kamal Bazaar reported that she lost her greenhouse and tomato crops to hailstones last year. Another survey respondent in Darna said that a hailstorm event damaged the roof of her house and cowshed and killed a cow.

The incidences of hailstones are quiet common in the study areas (Lohani 2007). Reports citing crop damages worth millions of rupees due to hailstones make frequent rounds in TV and print media every year (Baral 2019; Deuba 2016; Rimal 2018; THT 2017). Paudel et al. (2014) have also documented several thunder and hailstorm related losses in Nepal.

In the case of floods, the majority of the survey respondents reported that they have not observed any increase. Of all the surveyed respondents, only 2% have observed considerable increase, 15% have observed increase, and 18% have observed some increase in flooding. The majority of the survey respondents, 44% reported that they have not observed any increase and another 21% were not sure about the increase [Figure 5.24]. Research participants think afforestation, successful community forests and the construction of embankments in recent years have checked the increase in the cases of floods in their communities. A survey respondent in Sunder Bazaar said:

"Earlier we used to see a lot of flooding around Paudi river. However, after the construction of embankments and culverts, the instances of floods have reduced.

Similarly, a survey respondent in Darna said:

"The increase in forest cover along the river banks has mitigated the flooding events in our community."

In spite of the fall in flooding events, the cases of floods have however, not completely disappeared in the study areas. According to the research participants, incidences of small scale flooding around streams and rivers are still common. An expert in Darna mentioned that extreme rainfall events could still lead to a potential flooding. When asked about the flood in recent memory, survey respondents generally mentioned about the extreme rainfall event in 2013, which had led to a massive flooding in the far-west Nepal and Uttarakhand, India.

Survey respondents and experts mentioned loss of human lives and livestock, destruction of private and public properties and loss of farm productivity as the impacts of flooding in the region.

Figure 5.27 Flood deposited debris on a paddy field in Sunder Bazaar

Source: Field Survey, 2018

In the case of forest fires also, the majority of the survey respondents have not observed any increase. Of all the surveyed respondents, 61% have not observed any increase and another 21% were not sure about the increase of forest fires [Figure 5.24]. Focus group participants in Sunder Bazaar mentioned that the effective forest management through community forestry programs and greater awareness in population about the importance of forest have helped in reducing the incidences of forest fires in their community. A focus group participant in Sunder Bazaar said:

"Earlier, most of the forest fires were lit by villagers, sometimes by accident and sometimes deliberately to grow new vegetation for cattle. However, this practice has now stopped after the launch of community forestry program in our village."

The focus group participants in Darna and Sunder Bazaar also attributed the fall in forest fire incidents to effective community forest programs.

Overall, based on the survey perception results, the study found that the cases of floods and forest fires have not increased whereas the incidences of landslides and hailstones have increased in recent years. The increase in the cases of landslides and hailstones have resulted in higher deaths and injury of humans and livestock, loss of agricultural yield and damage and loss of private and public properties. While the increase in landslides and hailstones events in study sites cannot be directly attributed to climate change alone, it is understood that climate change acts a risk multiplier to increase the frequency and intensity of such extreme weather events in Nepal in future (Shrestha et al. 2015).

5.6 Conclusion

This chapter analysed the changes in temperatures and precipitation and its impacts on local livelihoods at the study sites. The statistical analysis of climate data indicates a warming and a declining precipitation trend. Both the trends are consistent with local perceptions and recent studies from the region. The analysis of the monsoon arrival and withdrawal data from the published government sources indicates a high inter-annual variability with a trend towards delay.

The chapter further discussed the impacts of the observed environmental changes. Increasing temperatures, increases in invasive species, declining rainfall and water availability, increases in insect pests, changes in flowering, fruiting and relocation of species, increasing variability in monsoon, and changes in frequency of natural hazard events were identified as the major environmental changes and associated impacts in the study areas. Research participants discussed a broad range of impacts of the observed environmental changes on their lifestyle, production systems and livelihoods. Table 5.1 provides a summary of the most pressing impacts shared by research participants in the study areas. The impacts have been arranged in a descending order with the impacts of increasing temperatures on top and the impacts of changes in the frequency of natural hazard events at bottom. The overall perception of impact score ($\bar{X}$) reflects the level of impact felt by survey respondents in the study sites. The next chapter discusses about DRETs present in the study sites.

Table 5.1 Summary of the observed environmental changes and their associated impacts in the study areas

Observed Environmental Changes	Average of perception score by survey participants on 1-5 scale [5]					Impacts
	Kamal Bazaar	Darna	Sunder Bazaar	Overall	(P)	
Increasing temperatures	$\bar{X}$= 4.37	$\bar{X}$= 4.11	$\bar{X}$= 4.09	$\bar{X}$= 4.20	0.305	-Hot summer days and uncomfortable nights -Early melting of snow leading to water scarcity -Increase in number of mosquitoes -Decline in farm productivity
Increases in invasive species	$\bar{X}$= 3.6	$\bar{X}$= 4.4	$\bar{X}$= 4.0	$\bar{X}$= 4.0	0.000	-Coverage of pastures, fields, trails and forests by invasive species -Decrease in supply of grazing land and forage for cattle -Difficulty in walking through narrow trails on mountain slopes -Increased labour input in farms and for fodder collection -Loss of non-timber products from forest -Use of invasive species as pesticide and kitchen fuel
Decline in rainfall and water availability	$\bar{X}$= 3.98	$\bar{X}$= 3.76	$\bar{X}$= 3.18	$\bar{X}$= 3.66	0.000	-Water shortages for household and agricultural use -Additional time to fetch water from distant sources -Decline in farm productivity
Increases in insect pests and diseases	$\bar{X}$= 3.4	$\bar{X}$= 3.4	$\bar{X}$= 3.6	$\bar{X}$= 3.5	0.000	-Insects like cockroaches and ants damage food and bite humans -Increased cases of vector borne diseases -Added expenses on pesticides, insecticides and medicines -Decline in farm (crops as well as livestock) productivity
Changes in flowering, fruiting and relocation of species	$\bar{X}$= 3.49	$\bar{X}$= 3.46	$\bar{X}$= 3.22	$\bar{X}$= 3.37	0.226	-Increase in the numbers of Saal trees and amount of banana and mango fruits -Decline in orange production -Loss of crops to wild animals
Increasing variability in monsoon	$\bar{X}$= 3.13	$\bar{X}$= 3.23	$\bar{X}$= 3.28	$\bar{X}$= 3.23	0.633	-Creates uncertainty and confusion among farmers -Affects traditional crop calendar -Affects travel routine and income of seasonal migrant labourers -Affects harvest and sometimes loss of agricultural yield
Changes in the frequency of natural hazard events	$\bar{X}$= 2.76	$\bar{X}$= 2.53	$\bar{X}$= 3.05	$\bar{X}$= 2.77	0.000	-Human injuries and death -Loss of agricultural yield (crops and livestock) -Loss of private and public properties

[5] Perception score on scale 1-5, where 1= No Change, 2= Not Sure, 3= Some Change/Increase, 4= Change/Increase 5= Considerable Change/Increase. ($\bar{X}$) = Mean, (P) = Chi-square

6 Decentralised Renewable Energy Technologies (DRETs) in the case study areas

6.1 Introduction

This chapter introduces and provides detail of DRETs present in the study sites. The size or the capacity of DRETs, the cost and the source of funding to acquire the DRETs, the uses of DRETs, associated operational expenses, and the level of satisfaction with DRETs are discussed in detail for individual technologies present for the study sites.

6.2 DRETs in Kamal Bazaar

Kamal Bazaar is a remote off-grid community in Achham district in Sudur Paschim province. The community is not yet connected to the national electricity grid and the availability of other modern energy sources such as coal, diesel, liquefied petroleum gas (LPG) and petrol is limited and expensive due to poor transport infrastructure. The community relies on solar PV and solar-wind micro grid for access to electricity.

6.2.1 Solar Photovoltaics (PV)

Solar PV generates electrical power by converting solar radiation into direct current electricity, which is then stored in batteries for later use. At household level, a solar PV system is generally called a Solar Home System (SHS). A SHS is a unit consisting of solar PV panels and batteries that provide power to individual households. The survey findings indicate that the capacity of SHS installed in Kamal Bazaar ranged from 20 watts (W) to 100W, with the smaller 20W units being the most common. Among the households surveyed, 71% had a 1-20W system, 15% had a 21-40W system, 9% had a 41-80W system and 5% had a system that generated greater than 80W in energy.

According to survey respondents, a 20W system allows simultaneous use of three 5W Light Emitting Diode (LED) bulbs and charging of a mobile phone. A local vendor in Kamal Bazaar said that a 20W system costs NRs.7000 and comes with a solar panel and a 20-Ampere battery. The SHS above 20W have additional solar panels and higher capacity battery. Wiring and installation can additionally cost up to NRs. 500. A SHS has a 25 year warranty on solar panels and a 2 year warranty on battery.

Figure 6.1 Solar PV panels on rooftops in Kama Bazaar, Achham

Source: Field Survey, 2018

Among the surveyed households, 83% mentioned that they invested their own funds and the remaining 17% mentioned that they used the mix of their own and borrowed funds to install SHS in their households. Although the SHS sold in Kamal Bazaar is government-subsidised, 92 % of the surveyed respondents mentioned that they were not aware of any subsidy. When asked about this with one of the SHS vendors in Kamal Bazaar, the vendor said:

"This is because of the process where vendors and dealers are responsible for the claim of subsidies rather than the beneficiaries. The local vendor sells the system at a subsidised price to a customer. The vendor then reports the proof of sale and installation by sending the sales receipts and pictures to AEPC. Once the documents are verified, the subsidy amount is released to the vendor. During this process, the costumer does not have to go through the hassle of claiming the subsidy. Therefore, the costumer might not be aware of a subsidy component."

According to Nepal government's 'Renewable Energy Subsidy Policy, 2073', Kamal Bazaar in Achham district falls under category 'A', which is eligible for a subsidy of NRs. 5000 on 10-20W SHS and NRs.10,000 on SHS greater than 50W per system per household (Ministry of Population and Environment 2016b). Without a government subsidy, the 20W SHS would cost NRs.12000 instead of NRs.7000 in Kamal Bazaar.

There is virtually no cost for operating SHS. Survey respondents said that the only costs associated with the operation of SHS are the replacement of LED bulbs when they get damaged, and the change of distilled water in batteries once every 2 years. According to a local solar vendor, one 5 W LED bulb costs around NRs.150 and a litre of distilled water costs NRs.40 in Kamal Bazaar. Among the surveyed users, 16% are very satisfied, 47% are satisfied, 12% are neither satisfied nor dissatisfied, 19% are dissatisfied and the remaining 6% are very dissatisfied with their SHS. According to survey respondents, the major satisfaction about SHS was about the ability to use electricity for lighting and mobile phone charging at no operational cost. The major dissatisfaction with their SHS was about the uncertainty of power availability during foggy and cloudy days; and the inability to use electrical appliances, which requires high power to operate such as TV, fridge and pressing iron.

In addition to individual households, public facilities also rely on solar PV systems for electricity in Kamal Bazaar. Local council offices, the police station, a bank, schools and the primary health centre rely on roof top solar PV systems for electricity. Telecommunication provider Nepal Telecom and Smart Cell run their internet and mobile phone services on solar PV systems. Kamal Bazaar has a drinking water scheme, which uses electricity produced from Solar PV system to pump water from a distant source to a tank on top of a village.

Figure 6.2 Solar PV panels on rooftop at a school in Kamal Bazaar

Source: Field Survey, 2018

Figure 6.3 Solar PV based drinking water lifting project in Kamal Bazaar

Source: Field Survey, 2018

Figure 6.4 Telecom and internet infrastructure operating on solar PV system in Kamal Bazaar

Source: Field Survey, 2018

6.2.2 Solar-Wind micro grid

The solar-wind micro grid in Kamal Bazaar is locally centralised infrastructure consisting of solar PV, wind turbines, batteries and an inverter system that provides electricity to multiple households, business, offices, police station and health centre through a micro grid. As stated earlier, solar PV generates electrical power from solar radiation. Wind turbines produce electricity by converting kinetic energy of wind into electrical energy. According to an expert in Kamal Bazaar, the idea of a wind power based micro grid first occurred to the residents of windy village when they saw wind-based power generation during their trips to India. After few years of consultation with Alternative Energy Promotion Centre (AEPC), a solar-wind micro grid system with a peak-installed capacity of 31 kilowatts (KW) was completed in 2017. AEPC is the nodal government agency to promote decentralised renewable energy systems in Nepal. The solar-wind micro grid power plant is located on a hilltop in Kamal Bazaar to maximise wind interception [Figure 6.5].

Figure 6.5 Solar-wind micro grid system in Kamal Bazaar, Achham

Source: Field Survey, 2018

The Kamal Bazaar Solar-Wind Energy Project Management Committee, formed after the consultation with local residents, political leaders and AEPC, oversees the management and operation of the micro grid. The committee has appointed a salaried technician to operate and to provide security for the electrical equipment of the grid. The technician mentioned that the grid has two 10KW horizontal axis wind turbine units complemented by 11.180KW (43x260W) of solar PV panels. According to the technician, a battery system (2Vx1000Ahx120 numbers) and an inverter (2x25KVA stacking Inverter/3 Phase) stores the power generated during the day and distributes in the evening from 5 pm to 9 pm, when it is most needed in the village. The micro grid has one switching station and 1537 metres of cable network to distribute electricity. An engineer at AEPC who is engaged with the micro grid project mentioned that the electricity output or the power available for distribution on any day depends on the amount and duration of solar radiation and wind flow in Kamal Bazaar on that day.

According to one of the members of Kamal Bazaar Solar-Wind Energy Project Management Committee, the micro grid project was built at a cost of NRs.15, 400,000. The AEPC provided 80% of the project cost as a subsidy grant. The remaining 20% was provided by Kamal Bazaar village council. Additionally, local residents provided free labour for the project. At the household level, each household paid a sum of NRs.5000 for a connection and the installation of a 'Meter Box' on their premises. The executive member informed that at the time of this study, the micro grid was connected to 147 households, 15 local businesses, 3 government offices, 1 police station and 1 primary health care centre in Kamal Bazaar. According to the micro grid technician, individual households receive 100W and businesses can receive up to 1500W of power.

Survey respondents said that they primarily use electricity for light bulbs, to listen to radio and to charge their mobile phones. Businesses use electricity to operate light bulbs, television, computers and printers. A hotel operator in Kamal Bazaar said that he uses electricity from the micro grid to run a fridge and to operate a TV in dining hall. At the time of the research, the micro grid was only partially functional. Focus group participants in Kamal Bazaar mentioned that the system was not functioning in full capacity after the system was struck by lightning within three months of operation.

The operational expense for using the micro grid is a fixed amount for every household. According to survey respondents, households connected to the micro grid pay a fixed sum of NRs.100 per month for 100W supply of power. One survey respondent said that the tariff system does not consider the power consumed, and instead charges a fixed rate for the connection. Businesses pay NRs.1500 per month for 1500 W power supply. Among the surveyed users of solar-wind micro grid in Kamal Bazaar, none are very satisfied, 31% are satisfied, 20% are neither satisfied nor dissatisfied, 34% are dissatisfied and the remaining

15% are very dissatisfied. The satisfied users of the grid said that they were happy with the micro grid because they were getting higher capacity electric power in comparison to commonly available 20 W or 40 W SHS. Major dissatisfactions about micro grid were due to the partial operation of the grid and due to unreliable availability of power on rainy and cloudy days.

6.3 DRETs in Darna

Like Kamal Bazaar, Darna is a remote off-grid community in Achham district in Sudur Paschim province. The community is not yet connected to the national electricity grid and the availability of other modern energy sources such as coal, diesel, petrol and LPG is also limited and expensive due to poor transport infrastructure. The village relies on a local micro-hydro power plant for the supply of electricity. In addition to micro-hydro, households in Darna have access to improved cooking stoves (ICS), another popular DRET in Nepali villages.

6.3.1 Micro-hydro

The micro-hydro in Darna is a micro-scale hydroelectricity generation scheme located along the bank of ‘Kailash Khola’ river. The micro-hydro produces electricity by converting the kinetic energy of running water into electrical energy. According to a technician at Darna micro-hydro project, the production part of the project has four major components; a water intake upstream, a canal, a penstock and a power house downstream in the bank of the river. The water intake diverts water from ‘Kailash Khola’ river into the canal. The canal is 1740 m long and carries water to a forebay tank that connects to the penstock. The penstock is 55 m in length with a gross head of 32 m. The power house has a single unit “Cross flow (T-15)” turbine with a generator attached to it. When the water running through the penstock hits the turbine, the generator produces electricity. The project has a designed peak output capacity of 83KW. Electricity produced in the powerhouse is then distributed through a micro grid, which has five transformers, 567 pillars and 88.8-kilo meter of wire network. Apart from supplying electricity to Darna, the project exports 25KW electricity to a nearby Kala Gaun village.

Figure 6.6 Micro-hydro powerhouse in Darna, Achham

Source: Field Survey, 2018

According to an expert in Darna, the project operates on a cooperative model. The micro-hydro project is officially called “Darna Micro-Hydro Co-operative Limited”. The cooperative has an executive committee, which appoints a manager to look after finance and administrative functions and two technicians to operate the micro-hydro power plant.

According to the manager, Darna micro-hydro project was built in August 2013 at a cost of NRs.35,589,559. The project received a subsidiary grant of NRs.17,890,525 i.e. 50% of the total project cost from AEPC and a grant of NRs.7,000,000 i.e. 39% of the total project cost from national Poverty Alleviation Fund (PAF). The remainder of the cost was borne by local residents and the village council. The village council provided NRs.7,216,980 and local residents provided free labour worth NRs.3,482,054 in lieu of a financial contribution to the project.

At the beginning of the micro-hydro project, a locally elected users’ committee oversaw the operations of the project. Consumers paid a fixed sum of NRs.100 per month per costumer for the supply of electricity. There was no metering to measure the amount of power consumed and costumers could draw as much electricity as they wanted. However, after this revenue collection model proved unsustainable, the users’ committee with guidance from AEPC decided to transform the project to a co-operative model in April 2016. AEPC facilitated the transformation process. Immediately after the transformation, the revenue collection method was revised and metering was introduced. Each costumer paid NRs.1500 to install a ‘Meter Box’ at their premises. The power tariff was also revised with added mandatory service fees. As per the new rates, a household pays a minimum monthly service fee of NRs.60 and an additional charge for usage at a rate of NRs.7 per kilo Watt-hour (kWh). Business customer pays a minimum monthly service fee of NRs.500 and an additional charge for usage at a rate of NRs.10 per kWh.

At the time of this study, the project was supplying electricity to 1062 households, 12 schools, 5 government and non-government offices, 6 computer and photocopy service centres, 5 flour mills and 4 poultry farms in Darna. Households use electricity primarily for lighting, charging mobile phones and listening to radio. Apart from that, a few households also use electricity to operate fans, fridges, TVs, iron and rice cookers. Offices and service centres use electricity for lighting and to run computers, printers and photocopiers.

The survey found that the monthly operational expenses for using electricity from the micro-hydro project ranged from NRs.70 to NRs.3500 per costumer. The project manager said that the majority of the household costumers consume much less, around 2 to 3 kWh power and therefore pay around NRs.80-90 per month. The median monthly operating expense of the surveyed household is NRs.90. The survey found that on average 63% consumers pay between NRs.60 to NRs.100 per month, 21% consumers pay between NRs.101 to NRs.150 per month, 9% consumers pay between NRs.151 to NRs.300, 3% consumers pay between NRs.301to NRs.600, and the remaining 4% consumers pay above NRs.600 per month. The highest average monthly expenditure reported was NRs.3500 by a business, which operated a rice and flourmill in the village. Of the total surveyed households, 94% used their own fund to get a connection to the micro-hydro project. Remaining 6% said they used self and borrowed funds.

Every household in Darna is connected to the micro-hydro and therefore has access to electricity. Electricity is available for 22 hours in a day. The power plant is shut down for 2 hours daily for routine inspection and maintenance. Electricity from the micro-hydro is available year-round. Among the surveyed respondents, 56% are very satisfied, 31% are satisfied, 10% are neither satisfied nor dissatisfied, and 3% are dissatisfied with the micro-hydro project in their village. All satisfied consumers wish to continue with the project even after their village connects to the national electricity grid in the future.

6.3.2 Improved cooking stoves (ICS)

In addition to micro-hydro, households in Darna have access to ICS, another common technology promoted in rural Nepal. AEPC on its website defines ICS as, "...one of the most simple, inexpensive and widely used technology designed to improve combustion efficiency of biomass and reduce exposure to indoor air pollution" (AEPC 2018). At the time of this study, 82% of households in Darna had ICS in their homes. Households in Darna started building ICS since early 2016. A local co-operative called "Krishi Sahakari Sanstha" with support from government and non-government agencies was leading "One house, One ICS" campaign to increase the numbers of ICS in the village. According to a co-operative staff, clay, sugar, salt, rice husk and metal rods are the main raw material to build ICS. Building a single unit of ICS costs around NRs.1900, which is covered entirely by the co-operative for households in Darna.

An expert at AEPC in Kathmandu said that ICS technology is very simple and can be built by local masons after few hours of training. Apart from occasional cleaning, ICS does not require any major maintenance. Stoves are rarely damaged and can be repaired locally. According to the survey respondents in Darna, there is no operational cost associated with

Figure 6.7 Improved cooking stove in one of the houses in Darna, Achham

Source: Field Study, 2018

ICS. In-fact, ICS helps in reducing household expenses by reducing demand for fire wood usage.

Despite being a simple and cost saving technology, many ICS users reported that they were not satisfied with the technology. Of all the surveyed respondents, none were very satisfied, 51% were satisfied, 13% were neither satisfied nor dissatisfied, 23% were dissatisfied and the remaining 12% were very dissatisfied with the ICS technology. The main reason as identified by the survey respondents for dissatisfaction was the inability of users to use it like a traditional cooking stove. A traditional oven or a stove in Darna is open, which lets users roast food items inside it, and the open structure allows heat to escape, which helps in keeping kitchen space warm during winters. However, an ICS is enclosed to prevent heat loss and smoke escaping from it, which prevents the user to use it in ways similar to traditional stoves. Generally, older survey respondents, who are used to traditional stoves, expressed greater dissatisfaction for the technology.

6.4 DRETs in Sunder Bazaar

Sunder Bazaar has access to electricity through the national electricity grid and can easily accesses petroleum products because of good connectivity to other parts of the country. Households in Sunder Bazaar widely use biogas technology to meet their fuel needs in their kitchens.

6.4.1 Biogas

AEPC identifies biogas technology as an eco-friendly, renewable and economical means of heating and cooking fuel (AEPC 2019). Biogas is a mix of methane and other gases produced by anaerobic decomposition or fermentation of organic waste by methanogenic bacteria (Weiland 2010). Cow and buffalo dung are commonly used as organic waste in rural areas. The gas produced is composed of 50-70% Methane, 30-40% Carbon Dioxide, 1% Hydrogen sulphide and nominal quantity of some other gases with energy content of 6-6.5 kWh/m^3 (AEPC 2019). The ignition temperature of the gas is 650^0C-750^0C. The gas can be used for cooking or to generate electricity. In addition to gas production, a biogas plant also releases semi-solid sludge, generally called slurry. The slurry can be used as organic fertiliser in farms.

Figure 6.8 A newly constructed biogas plant in Sunder Bazaar

Source: Field Survey, 2018

According to a biogas expert in Sunder Bazaar, biogas plants were first constructed in 1992 in Sunder Bazaar. Initially the technology was limited to a few wealthy households. However, rising household income combined with subsidy and successful campaign encouraged local residents to replace traditional fuelwood based cooking stoves with the biogas technology. Although no official record was available, the local expert estimated that around 75% households in the study area had biogas plants by mid-2018. The last census record of 2011 shows that around 38% households in the study site had biogas plants (Central Bureau of Statistics 2014).

Generally, 4 m^3 and 6 m^3 were the most common size of household biogas plants in Sunder Bazaar. Of the surveyed households, 61% had 4 m^3, 31% had 6 $m^{3,}$ 7% had 8 m^3 and the remaining 1% had 10 m^3 biogas plants. According to a local biogas vendor, building a biogas plant needs a sizeable capital investment and a minimum 3 m by 5 m area of land. Apart from the cost of land, at the time of this study, a 4 m^3 plant cost around NRs. 60,000 and a 6 m^3 plant cost around NRs. 90,000 to build.

According to a biogas expert in Sunder Bazaar, a subsidy amount of NRs.25, 000 for 4 m^3 and NRs.30,000 for 6 m^3 and above was available for households in the study area at the time of the research. Households belonging to Dalit caste could receive additional 10% of the subsidy amount. Explaining the subsidy process, the expert said:

“The local vendor charges the net amount after deducting subsidy to the beneficiary. The vendor claims the subsidy amount from AEPC by sending a proof of completion of the project. Local biogas vendors send sales receipt and pictures of newly constructed and operational biogas plants as proof of the project completion. Apart from government subsidy, few NGOs also provide grant of up to NRs.10, 000 to the needy households. However, the grant from NGOs is not always guaranteed.”

Of all the surveyed respondents, 87% said that they had received a subsidy for their biogas plant and the remaining 13% said they did not receive any subsidy. Unlike in Kamal Bazaar, the majority of the subsidy beneficiaries in Sunder Bazaar were aware of the subsidy grants. This is probably because building a biogas plant involves considerable consultation, where a biogas dealer provides detailed breakdowns of all the costs and subsidy from the government.

According to the survey respondents, there is no operating cost associated with biogas, as the major raw material for a biogas plant are cattle and human waste. A local biogas expert in Sunder Bazaar said that the waste from a buffalo and four family members is enough to operate a 4 m^3 biogas plant. He said:

“One buffalo and family size of four is enough to operate a 4 m3 biogas plant. In a six cubic meter plant, 36 kilogram of cattle dung from two buffalos and human waste from toilet can generate enough methane gas to cook food on a single stove for two and half hours. Moreover, you can use other organic waste from kitchen and forest if you have less supply of cattle or human waste.”

The expert said that the use of biogas helps to achieve greater saving for households. The expert added that biogas plants are durable and rarely need any cost for repair. The builder provides a 3-year warranty on equipment and physical structure of the plant. According to survey respondents, the most common repair in biogas plant is the replacement of the valve, which costs approximately NRs.500.

In terms of satisfaction among the surveyed respondents, 18% are very satisfied, 45% are satisfied, 20% are neither satisfied nor dissatisfied and the remaining 17% are dissatisfied with biogas technology. Among the dissatisfied respondents, increasing difficulty in managing dung was identified as the main reason for dissatisfaction. The availability of dung is decreasing as families are giving up cattle rearing in Sunder Bazaar. One of the survey respondents said:

"I wish to continue using my biogas in future. However, I am getting older and my children do not want to raise any cattle. Without cattle, we do not have dung to continue using biogas."

Apart from decreasing availability of dung, the inability to use chemicals in cleaning biogas-connected toilet was another reason for dissatisfaction among biogas users. When inquired about the issue with a biogas expert in Sunder Bazaar. The expert said:

"Earlier people constructed toilets outside of their houses. However, these days people want a toilet inside their house for convenience. When you have toilets next to your kitchen or bedroom, you want to keep it clean and without bad odours. For that, people clean their toilets by using strong chemicals like Harpic and Acid. Use of such chemicals in a biogas-connected toilet disrupts the decomposition process. Therefore, using chemical is not recommended. This is discouraging households in adding biogas to their newly constructed houses."

The expert added that growing incomes and easy availability of bottled LGP in local markets is other factor reducing interest in biogas.

6.5 Conclusion

This chapter introduced and provided details about solar PV and solar-wind micro grid in Kamal Bazaar, micro-hydro and ICS in Darna and biogas in Sunder Bazaar. Solar PV and solar-wind micro grid provide electricity, which is generally used for lighting, to listen to radio and to charge mobile phones. Households and offices with higher capacity solar PV and solar-wind micro grid connection use electricity additionally to operate fans, fridges, TVs and computers. Micro-hydro provides electricity to connected households in Darna. Like Kamal Bazaar, households in Darna use electricity for lighting, to listen to radio, to charge mobile phones and to operate fans, fridges, TVs and computers. Households in Darna receive stable and higher ampere electricity in comparison to Kamal Bazaar. Biogas and ICS technologies are used in kitchen for cooking meals. Biogas provides cooking fuel (Methane) through the decomposition of organic waste. ICS helps in limiting indoor pollution and reducing fire wood demand through efficient combustion of biomass. The chapter discussed in details about the size or capacity, costs, subsidy, uses, operational expenses, and the level of satisfaction for individual DRETs. Among the studied DRETs, the popularity of micro-hydro was found to be highest, whereas the popularity of ICS was found to be lowest. The next chapter discusses the climate adaptation benefits of DRETs in the study sites.

7 Climate change adaptation benefits of decentralised renewable energy technologies (DRETs) in the case study areas

7.1 Introduction

The earlier chapters revealed that households in the study sites are experiencing increasing climate variability and environmental change. Increasing temperatures, declining rainfall and water availability, increasing variability in the monsoon, changes in the frequency of natural hazard events, increases in invasive species and insect pests, changes in flowering and fruiting and relocation of species are some of the major environmental changes identified by respondents. These changes have a broad range of impacts on local lifestyles, production systems and livelihoods [see Chapter 5]. Most survey respondents feel that they are not effectively equipped to deal with the changes and associated impacts. Survey respondents noted that a few coping measures are being practiced with locally available resources and knowledge. However, such limited actions alone are not enough. Households need more resources to deal with climate risk and their impacts in their communities.

In this context, this chapter discusses how DRETs can help households to deal with climate risk and their associated impacts. The chapter discusses the examples of the observed climate adaptation benefits of solar PV and solar-wind micro grid in Kamal Bazaar, micro-hydro and ICS in Darna, and biogas in Sunder Bazaar.

7.2 Direct and indirect climate adaptation benefits of DRETs

There are a range of actions and approaches to deal with the challenge of climate change. For example, Eakin et al. (2009) note direct actions against specific climate change risks as one and actions aimed at addressing underlying social factors of vulnerability as another. As discussed earlier [section 2.5], for the purpose of this research, DRETs' direct engagement in managing climate risk are called direct climate adaptation benefits of DRETs. Generally, such benefits contribute to climate adaptation by addressing biophysical vulnerabilities. Similarly, in the context of this study, the direct climate adaptation benefits refer to DRETs' contribution in directly addressing the observed environmental changes and their associated impacts in the study sites. On the other hand, DRETs' contribution in reducing socio-economic vulnerability by improving broader socio-economic factors such as income, literacy and access to natural resources are called indirect climate adaptation benefits. Generally, such benefits contribute to climate adaptation by strengthening adaptive capacity of the households [see section 2.5]. For the purpose of this research, the indirect climate adaptation benefits or DRETs' role in reducing socio-economic vulnerability are assessed by analysing the impacts of DRETs on five livelihood capitals based on the sustainable livelihood approach (Carney, 1998; DFID, 1999; Ellis, 2000). The first section of this chapter discusses the direct climate adaptation benefits and the latter section discusses the indirect climate adaptation benefits of DRETs.

7.3 Direct climate adaptation benefits of DRETs

7.3.1 DRETs' role in dealing with increasing temperatures

The statistical analysis of climate data indicates a warming trend [see section 5.3.1]. The warming trend is consistent with the perception of survey respondents [see section 5.4.2]. Research participants stated several impacts of increasing temperatures on their livelihoods [see section 5.5.1].

According to research participants, DRETs help them in directly dealing with increasing temperatures and associated impacts. DRETs that provide electricity can directly assist households to cope with warming by powering electrical appliances for cooling and refrigeration. Households in Kamal Bazaar and Darna that receive electricity from solar-wind micro grid and micro-hydro use electric fans to cool indoor air temperature and refrigerators to chill water and store food items. Survey respondents in Darna mentioned that fans provide great relief from hotter temperatures. One of the survey respondents said:

"During summer, the upper floor of my house with corrugated zinc roof becomes very hot. It is almost impossible to stay indoors. However, the pedestal fan that I got last year provides a great relief."

According to an expert in Darna, the use of pedestal fans to cool indoors during summer is increasing in his village. Focus group participants in Darna mentioned that the availability of power for electric fans has been more useful for pregnant and nursing mothers, infants, children, elderly, and sick people as these groups of people have low tolerance to hotter temperatures. One of the focus group participants said:

“I have a small baby girl who is very sensitive to hotter temperature and mosquitoes. Earlier, when my eldest child was born and when we had no micro-hydro project in the village, I used to rely on hand-operated fan. The hand-held fan was not effective enough in cooling and scaring mosquitoes. My hands would be exhausted. Sometimes, I would unknowingly hit the baby with the fan. Neither me, nor my child could sleep well. However, with the arrival of electric fans, everything has changed. The electric fan is powerful and safe.”

Figure 7.1 An electric fan powered by the micro-hydro in Darna

Source: Field Survey, 2018

Electric fans additionally contribute to household safety. According to focus group participants in Darna, sleeping outside during hot summer nights was common before the availability of electricity in the village. While sleeping outside, the locals were vulnerable to insects and wild animals. One of the focus group participants in Darna shared her story:

“Earlier, during uncomfortable summer nights, we either slept outside under the open sky or opened our windows for the flow of cold air from outside. Both of them were risky, because we could be attacked by wild animals or be bitten by insects. With electric fans, local residents can now avoid sleeping outside.”

In addition to electric fans, households operate refrigerators with electricity from solar-wind micro grid and micro-hydro. Fridge owners reported that chilled drinks from fridges provide them relief on hot summer days. A survey respondent who works as a porter in

Kamal Bazaar mentioned that chilled beverages available in the market help him avoid being lethargic. Restaurant owners in Kamal Bazaar and Darna mentioned that apart from drinks, they also store perishable food in fridges. Higher temperatures increase the chances of food spoilage (Rawat 2015). Survey respondents in Darna and Kamal Bazaar mentioned that fridges help in reducing food spoilage and food poisoning. One of the restaurant owners in Kamal Bazaar said:

"Earlier, we could not prepare a large amount of food items in fear that they would go to waste. We opened our restaurant with limited amount of food, and once the food items sold out, we used to shut down our shop. However, with the fridge, we do not have to worry about any leftover food going to waste. Therefore, now we prepare big amounts and are open until late. The availability of fridge has reduced our wastage and increased our earnings."

Another restaurant owner in Kamal Bazaar reported that complaints about food poisoning have decreased after he started using the fridge in his shop. A meat shop owner in Darna mentioned that electricity and a fridge are very important to maintain the freshness of meat products, and therefore very crucial for his business.

Figure 7.2 Refrigerator operating on a solar-wind micro grid power at a hotel in Kamal Bazaar

Source: Field Survey, 2018

In addition to household and commercial uses, another important use of the fridge was observed in hospitals and pharmacies. The Primary Health Centre (PHC) in Kamal Bazaar uses refrigerators to store vaccines and other important medicines. A pharmacy in Darna uses a fridge to store medicines like insulin, which is required frequently by patients with diabetes. A pharmacy operator in Darna said:

“High ambient room temperatures can spoil vaccines and medicines like insulin. Therefore, a fridge is important to increase the shelf life and effectiveness of medicines when it is warm outside.”

Figure 7.3 Vaccine storing refrigerator at Primary Health Centre, Kamal Bazaar

Source: Field Survey, 2018

The use of fridges in medical facilities have made vaccines and essential medicines locally available. The availability of crucial medicines in villages has saved time, effort and money for households in Kamal Bazaar and Darna. One of the survey respondents in Darna, who is also diabetic said:

“Earlier I had to travel all the way to Mangalsen to buy my medicine. It was expensive and tiring. The ability to buy the medicine here in the village has been lifesaving to an old person like me.”

An expert in Kamal Bazaar said that without refrigerators, the local population would need to spend a whole day travelling even for basic vaccines and medicines.

Overall, DRETs such as solar-wind micro grid and micro-hydro were found to be very useful in directly dealing with the problem of increasing temperatures in the study sites. Electricity from such DRETs help households to cope with hotter temperatures by enabling the use of electric fans and refrigerators. In spite of such advantages, survey respondents in Kamal Bazaar noted few limitations of their DRETs. The survey respondents with just 100W power supply to their households mentioned that the electricity from solar PV and solar-wind micro grid is not sufficient and reliable to allow the use of electrical appliances of their choices for the desired duration. Survey respondents with businesses in Kamal Bazaar, which receive high capacity electricity from solar-wind micro grid stated that they are using heavy electrical appliances such as refrigerators at a risk as the supply of electricity is not stable. The micro-hydro users in Darna, however, did not report such issues in their power supply.

7.3.2 DRETs' role in dealing with declines in rainfall, uncertain monsoon and reduced water availability

Water is a resource vital for survival as well as economic growth. Research participants reported that they have noticed increasing variability in monsoon arrival and withdrawal, and decline in rainfall and water availability [see section 5.4.3 and 5.4.4]. Such changes in monsoon and water availability have multiple impacts on local livelihoods [see section 5.5.3 and 5.5.7]. According to research participants, DRETs are useful in coping with water shortages and uncertain monsoon.

In Kamal Bazaar, where the drinking water shortage is consistently becoming worse, a solar PV based drinking water project pumps water from a distant spring to the community. The project uses electricity from solar PV to lift water to a tank located above the town of Kamal Bazaar. Water collected in the tank is then distributed through pipes and taps as required. Focus group participants in Kamal Bazaar mentioned that the solar PV based project has been solving the most serious problem created by water shortages in their community. One of the focus group participants said:

"Before the solar water project, we had to constantly worry about arranging water for household use. We used to spend a long time collecting it. Hotels and restaurants even paid for water. Shortages of water had compromised our lifestyle, sanitation and hygiene.

However, with the solar water project, we can save time, use that time on other productive activities and even improve our hygiene and sanitation."

Figure 7.4 Solar PV based water pumping station in Kamal Bazaar

Source: Field Survey, 2018

Local experts in Kamal Bazaar think that there could have been no better solution than solar PV to solve their water shortage problem. One local expert said:

"Since Kamal Bazaar is not connected to the national grid, the only other source of electricity to pump water from the distant spring would have been either a diesel generator or solar PVs. Kamal Bazaar is a remote place with limited transport services. Ensuring a constant supply of diesel is uncertain and costly. Therefore, solar PV is a better choice and we recommend it to other off-grid communities as well."

Impressed with the solar PV based drinking water project, the local village council is thinking of building a solar PV based irrigation project in the community. The case of solar PV based drinking water project in Kamal Bazaar shows that a pump driven by electricity from solar PVs is one of the most effective tools to transport water from sources identified at farther distances in water scarce areas. Unfortunately, during the study period, the project was not in operation due to the damage to underground pipes during nearby road construction. An expert in Kamal Bazaar informed that the repair process would begin before the start of dry season, when water shortages worsen in the community.

While the solar PV project is addressing drinking water shortages in Kamal Bazar, the micro-hydro project is helping to mitigate the impact of uncertain monsoon and reduced water availability in Darna. The canal built for micro-hydro to transport water from river to powerhouse facilitates irrigation during dry season. The manager of the micro-hydro project mentioned that as the demand for electricity dips, excess water in the canal is diverted to fields for irrigation. For that reason, most of the diversion to fields occur during the night when there is very little demand for electricity. The manager informed:

"The project was constructed with the added benefit of irrigation in mind. Therefore, irrigation infrastructure such as secondary canals to transport water from power house to fields were built along with the project."

Figure 7.5 Micro-hydro facilitated irrigation infrastructure in Darna

Source: Field Survey, 2018

The manager stated that the project provides water for irrigation throughout the year and benefits 102 households. The irrigation facility has helped farmers cope with uncertain monsoon and reduced rainfall. A farmer benefitting from the micro-hydro facilitated irrigation project said:

"Agriculture in our region is mostly rain fed. Any delay or decline in rainfall amount has serious impacts on our crops. Earlier we were helpless. Now, thankfully, irrigation from micro-hydro saves us during difficult times. I wish we could extend irrigation facility to every fields in this village"

Another farmer in Darna mentioned that the irrigation facility has enabled him to cultivate previously under-utilised lands. He said:

"Earlier, I used to plant rice only in half of my plots as the other half did not have access to enough water. However, with the availability of water through the irrigation scheme, I have now extended my rice plantation to underutilised lands."

Farmers benefiting from the project reported that the consistent availability of water has enabled them to plant crops throughout the year, which has improved land productivity and their annual income. The visible impacts of the irrigation project in building resilience to uncertainty in rainfall have encouraged community members to extend irrigation facility to other parts of the village. The micro-hydro project is planning to use excess electricity in extending irrigation. At the time of the research, the overall demand for electricity in Darna was less than the peak production capacity of the project. The power consumption during the night is almost none. The manager informed that the excess power produced during the day and night could be used to lift water from a nearby river to irrigate fields. A local expert in Darna mentioned that such irrigation projects would be effective to cope with an increasingly uncertain monsoon and possible droughts in the future. The local expert said:

"Using micro-hydro for pump irrigation will be a win-win situation for everybody. The micro-hydro earns more revenue and farmers can produce more with less worry about droughts and uncertain rainfall."

Apart from solar PV and micro-hydro, ICS and biogas may also contribute to address the declining water availability problem. One of the focus group participants in Darna said:

"I believe trees play an important role in conserving water resources, because it slows down evaporation and prevents erosion around water sources."

Focus group participants in Sunder Bazaar provided examples of the Hindu culture, where protecting vegetation and maintaining cleanliness around water bodies are considered a standard practice to preserve water sources. Ellison et al. (2017) argue that trees contribute to rainfall by recharging atmospheric moisture and improve ground water recharge through enhanced soil infiltration. Other studies have also highlighted positive impacts of trees and forests in water storage and regeneration (Bremer et al. 2019; Creed et al. 2016; Ellison et al. 2017).

Overall, DRETs such as solar PV and micro-hydro have helped households in directly addressing the problem of uncertain monsoon, declining rainfall and reduced water availability in Kamal Bazaar and Darna. While the direct role of ICS and biogas in addressing the water scarcity problem is not clear, survey respondents think that these DRETs contribute in mitigating the problem by preserving water sources and preventing early drying up of water sources.

7.3.3 DRETs role in dealing with disasters and crises

The combination of active tectonics, rugged topography, high seasonal rainfall variation, and periods of intensive precipitation makes Nepal very vulnerable to hazards and disasters (Chalise & Khanal 2002). In addition, the changing climate is expected to increase the frequency and intensity of extreme weather events, leading to increased frequency and intensity of such events as flash floods, landslides and debris-flows (Shrestha et al. 2015). Research participants reported an increase in the cases of landslides and hailstones in the study areas. According to research participants, DRETs such as solar PV, solar-wind micro grid, micro-hydro and biogas help users to prevent and prepare for disasters and manage responses at the time of crisis.

A solar PV based weather monitoring system set up in Kamal Bazaar collects and exchanges weather information with Department of Hydrology and Meteorology to inform communities about forecasts of damaging weather situations. The timely information allows households to prepare and minimise their losses to disasters. Focus group participants in Kamal Bazaar mentioned that they feel secure after the installation of the weather monitoring system in their village. One of the focus group participants said:

"In the past, sometimes disaster struck us at night, while all of us were fast asleep. However, with the weather monitoring system, we feel secure as we get information about possible disaster beforehand."

Figure 7.6 Solar PV based weather monitoring system in Kamal Bazaar

Source: Field Survey, 2018

An effective weather monitoring and early warning system needs good communication infrastructure to share weather warnings in a timely manner. Radio, TV, internet and especially mobile phones are important for information sharing. In Kamal Bazaar and Darna, the communication infrastructure operates on electric power drawn from DRETs such as solar PV, solar-wind micro grid and micro-hydro. Two telecom companies (namely Nepal Telecom and Smart Cell) and an internet service provider company (called 'World Link') provide telephone and internet services based on the electricity supplied by Solar PVs in Kamal Bazaar. In Darna, the telecom infrastructure operates on electricity supplied by micro-hydro. Similarly, individuals and households in Darna and Kamal Bazaar operate phones, radios and TVs with electricity supplied by solar PVs, solar-wind micro grid and micro-hydro.

Figure 7.7 Solar PV based telecom infrastructure in Kamal Bazaar

Source: Field Survey, 2018

In addition to weather warnings, radio, TV and internet help to share information about disaster prevention and response during the crisis. Survey respondents in Darna and Kamal Bazaar mentioned that their awareness about disaster had improved after they had greater access to radio, television and mobile phones. For example, a survey respondent in Darna said:

"We learnt about earthquake proof housing infrastructure through TV and radio. We also learnt about the importance of clean drinking water at the time of crisis through TV and radio."

While radio and TV are popular among older generations, internet on mobile phones is popular with younger people. A survey respondent in Darna said that her children get information quicker than she does through social media like Facebook. Mobile phones are also important for individual-to-individual communication. One of the focus group participants in Kamal Bazaar said that he uses mobile phones to inform his relatives about any potential hazards and to inquire about their wellbeing during a crisis. Improved communication because of solar PV, solar-wind micro grid and micro-hydro has helped communities in preparing and responding well to the crisis. One of the local experts in Kamal Bazaar mentioned:

"Although I do not have a fixed number to say how many lives and properties have been saved by the improvement in communication infrastructure, I can certainly say that it has played a very important role in minimising our losses. Our disaster management plan has therefore given special attention towards effective use of communication systems like mobile and FM radio."

Another advantage of DRET in disaster management has been through river management. The infrastructure built for the micro-hydro project in Darna has contributed in preventing floods and riverbank erosion. The manager of the micro-hydro said:

"The canal constructed for micro-hydro can be used to divert water flow whenever there is high volume of water in the river. This helps in preventing floods downstream. The embankments constructed for the micro-hydro project help in checking river bank erosion."

Apart from disaster prevention, research participants mentioned about advantages of solar PV, micro-hydro and biogas during the time of crisis. Survey respondents in Kamal Bazaar and Darna mentioned that unlike in the past, electricity is very useful for lighting and cooking during a disaster event. One of the survey respondents in Kamal Bazaar said:

"In the past, it used to be difficult without light. Sources of traditional lighting such as 'Jharro' and kerosene lamps used to die out in the rain and strong wind. Electric lights however, do not have such problems. With electric lighting from solar PV, we can better protect ourselves at the time of disaster."

Similarly, survey respondents in Darna said that they worry less about lighting and cooking fuel during the time of crisis because of the availability of electricity from the local micro-hydro. A survey respondent mentioned that she relied on a rice cooker and heater when her entire stock of fuelwood was washed away by a landslide. Focus group participants in Darna said that having access to electricity gives them confidence that they would not die of hunger even if their fuelwood stock is lost to flood or landslide. A focus group participant said:

"It is difficult and sometimes impossible to burn wet firewood during rainy season and flooding. Therefore, having electricity and rice cooker provides us a sense of security that we can cook when we do not have firewood."

A similar opinion about biogas was shared in Sunder Bazaar. Survey respondents said that the availability of a biogas in a household ensures a steady supply of kitchen fuel during the time of crisis. The major sources of kitchen fuel in Sunder Bazaar are biogas, firewood, kerosene, and LPG cylinders. Apart from biogas, households do not have control over the supply of other sources of kitchen fuel. Community Forest User Groups regulate the supply of firewood from forest and the supply of LPG and kerosene is vulnerable to road blockades and economic forces. The complete autonomy over the use of biogas makes biogas a preferred choice during the times of crisis. Survey respondents provided examples of the 2015 Gorkha earthquake and the fuel crisis that followed, as examples of advantages of biogas during the time crisis. A survey respondent in Sunder Bazaar said:

"During the earthquake and fuel crisis, there was a shortage of food and fuel. Especially households relying on kerosene and LPG cylinders had a difficult time because they were not easily available in the market. Households with biogas did not have to worry about cooking fuel."

An expert in Sunder Bazaar said that people realised the advantage of biogas over other kitchen fuels during the crisis. He said:

"Apart from other advantages, biogas proved very useful during natural as well as political crisis. Biogas vendors are now highlighting this fact as their selling point to costumers."

According to an expert in Sunder Bazaar, full ownership and control over the technology is one of the factors that has encouraged households to adopt the biogas technology. Research participants in Darna shared similar opinions about the suitability of micro-hydro during the crisis. They mentioned that they were least affected during national electricity shortages because of the full control over their micro-hydro project. An expert in Darna said:

"When the national electricity grid connected costumers were facing up to 16 hours of load shedding a day, we enjoyed a stable and regular supply of electricity in our community. This was possible because of our full ownership and control over operation of our micro-hydro project."

Focus group participants in Darna think that they will lose control of their micro-hydro, if it is connected to national electricity grid, and therefore want to continue with the decentralised management of their micro-hydro. One of the focus group participants in Darna said:

"We doubt the intention and ability of the central electricity authority to help us during the time of crisis. The central grid always prioritises city residents. We want to connect to the national grid, however, if that means, we are not going to get power when we need it, then we will reject the connection. We will agree to connect with the grid if we can continue to operate our micro-hydro project in a decentralised manner."

In general, research participants think that DRETs are more suited for crises because DRETs by nature are decentralised and allow greater control to their users.

Overall, the cases and examples discussed above show several direct contributions of DRETs in preventing and preparing for disasters and in managing responses at the time of crisis.

7.3.4 DRETs' role in dealing with human health issues

Growing evidence suggest that the changes in broad-scale climatic systems are already affecting human health, including levels of morbidity and mortality from extreme heat, cold, droughts, forest fires, changes in air quality and the ecology of infectious diseases (Kinney 2018; McIver et al. 2015; Murage et al. 2017; Patz et al. 2005; Watts et al. 2015; Wu et al. 2016). Similarly, research participants discussed several impacts of increasing temperatures, disasters and increase in numbers of insect pests on human health and wellbeing [see chapter 5]. According to research participants, all the studied DRETs provide health benefits in one form or another.

As stated earlier in this chapter, the electricity producing DRETs such as solar-wind micro grid and micro-hydro help households deal with increasing temperatures by providing cooling and refrigeration services. A detail discussion about how electricity facilitates cooling and refrigeration to deal with uncomfortable temperatures and in preventing food poisoning is available in section 7.3.1 of this chapter. Additionally, electricity is also useful in dealing with increasing insect pest problem in households. Survey respondents in Darna and Kamal Bazaar mentioned that better illumination from electric lamps in their houses help them to avoid insects in their surroundings. Survey respondents reported that the biggest advantage of electric lighting was felt in their kitchen. According to survey respondents in Kamal Bazaar, when preparing and consuming food in the dark, they used to frequently find insects, larvae and other unwanted materials in their food, which immediately eroded their appetite and was a health risk. However, with electric lamps this issue has been mostly addressed. One of the survey respondents in Kamal Bazaar said:

"It is quite common to find tiny insects and larvae like 'Ghoon' [Wheat Weevil (Sitophilus granaries)] in our stored food grains. Without enough light indoors, it used to be very difficult to remove them from our food. Consuming them would give us a bad taste, vomiting, loss of appetite and stomach ache. Better illumination from electric bulbs help us find them easily and get rid of them from our food."

A survey respondent in Darna mentioned:

"Kerosene lamps and 'Jharro' do not provide enough illumination. Under these lights, we do not know if there are any unwanted materials like insects, stones, hair strands or dirt in our food. With brighter electric bulbs, we can identify and remove them."

Brighter illumination from electric lamps also help individuals to protect themselves from the bite of mosquitoes and venomous creatures. One of the focus group participants in Darna said:

"In darkness, we cannot see if there is any scorpion or a snake inside our house. Brighter electric lights, which work well in rain as well as strong wind, are therefore very useful to be safe from such poisonous creatures."

In addition to lighting, survey respondents in Darna reported that they use electricity to operate mosquito repellent liquid vaporiser and fans to repel mosquitoes at night. Electric lighting also helps in improving the respiratory system and the health of eyes in people. Focus group participants in Kamal Bazaar reported that the use of electrical lights reduces eyestrain and respiration related problems. One of the focus group participants said:

"Earlier, we used to rely on traditional' Jharro' and kerosene lamps for light in our homes. 'Jharro' and kerosene lamps both emit black smoke that causes eye irritation, headache and respiratory problems. Our nose used to fill with black soot. Working or reading under low light conditions was stressful. Electric lamps, however, are much better as they do not emit smoke and are very bright."

The impact of smoke on health and the contribution of DRETs in addressing the smoke problem is discussed in detail later in section 7.5.2.2 of this chapter.

Another major advantage of electricity is its use within the health facilities. The availability of electricity at the Primary Health Centre (PHC) in Kamal Bazaar and a health post in Darna has led to important medical services being available locally. Residents of Kamal Bazaar and Darna mentioned that the availability of electricity in their communities also brought medical services to their doorsteps, which otherwise would be miles away and often too far in times of emergency. According to medical staff in Kamal Bazaar and Darna, electricity from DRETs such as solar PV, solar-wind micro grid and micro-hydro facilitate the use of various medical and lab equipment, vaccine storage, tele-medicine, and the 24-hour operation of emergency and birthing services.

The PHC gets electricity from rooftop solar PV panels and solar-wind micro-grid in Kamal Bazaar. Electricity from these sources has enabled the centre to run emergency services 24 hours a day, perform minor surgeries, carry out lab tests, store vaccines and use ultrasonography device. According to a medical staff at Kamal Bazaar PHC, the PHC is the biggest medical facility within the region of two municipalities and two village councils, which caters for around 95,000 people. Focus group participants in Kamal Bazaar mentioned that the supply of electricity from DRETs to their PHC has been very valuable to their community, as that has saved many lives, time and money particularly during the times of stress. Focus group participants in Kamal Bazaar said:

"Earlier, we had to travel all the way to Mangalsen (district headquarters) for basic lab tests and to perform video-x-rays (Ultrasonography). In addition, if it were an emergency during the dark hours, we had to either wait or walk to Managalsen. Due to the burden of travelling and associated expenses, in many cases, we chose not to seek medical assistance. That worsened our health and caused early deaths. Now, with lab tests and video-x-ray services here, the situation has improved. However, we would still want a greater level of service as we already have electricity in the centre."

In addition to these services, the centre uses electricity to operate sterilisation devices, heating and cooling devices, and computers and printers to record patient details. The medical staff at the PHC said that apart from providing crucial services, the availability of electricity has been helpful in increasing efficiency and improving the service delivery. He said:

"Electricity has improved our vaccine storage capacity. Sufficient lighting helps us to perform medical check-ups and surgeries better even during dark hours. Quick lab reports

help initiate treatment procedures early, which can sometime be very crucial to save the life of patients."

Figure 7.8 Electric laboratory equipment at the Primary Health Centre in Kamal Bazaar

Source: Field Survey, 2018

Apart from PHC, an NGO operating in Kamal Bazaar uses solar PVs to provide tele-medicine service. One of the NGO staff said that their community health care workers travel to remote wards to visit patients who cannot walk to PHC. The health workers collect information from such patients using a mobile-based app called "Commcare". The information stored on the app is then transferred to their hub at PHC through internet for remote analysis. After analysing the information, the hub sends recommended courses of action to community health workers on their mobile phones. This process of tele-medicine requires laptops, mobile phones, internet connection and other electrical devices, which all charge and operate on electricity drawn from solar PVs in their hub at Kamal Bazaar. The NGO staff mentioned that they routinely provide mobile ultrasonography to pregnant women. The mobile ultrasonography devices are charged on solar PVs at their base station in Kamal Bazaar.

Figure 7.9 Portable ultrasonography device at an NGO in Kamal Bazaar

Source: Field Survey, 2018

Focus group participants in Kamal Bazaar think that DRETs such as solar PV and solar-wind micro grid have contributed considerably to improving their medical services and their ability to deal with medical problems. They think that other off-grid sources of electricity would not have been a better choice for their PHC. One of the focus group participants said:

"Given the absence of grid electricity and the inability to construct a micro-hydro, electricity from solar and wind looks like a good option for this community. The PHC can use diesel generators, however, the lack of proper transport services make the supply of diesel uncertain. Moreover, diesel would add to the cost of operation and pollute the air around PHC."

Like Kamal Bazaar, electricity from the micro-hydro project has improved medical facilities and services in Darna. According to a medical staff at Darna Health Post, the availability of electricity has enabled the health post to expand the range of medicines and vaccination services, improve safety and operate the birthing centre 24 hours a day. The medical staff reported that in the past they relied on hand-held torchlights for activities during the night-time. Therefore, birthing and other health services were not available after daytime. The availability of electricity has now allowed them to extend their service. Similarly, before electricity was available, sterilisation of equipment at the birthing centre used to be done with hot water by burning firewood. Such a process was prone to contamination and was inefficient. Now, sterilisation is done with an electrical equipment and such sterilisation processes have improved the safety for patients.

Figure 7.10 An electric sterilisation device (left) and a fridge (right) at Darna Health Post

Source: Field Survey, 2018

The Darna medical staff added that electricity has made it possible to store essential medicines and vaccines in fridge for a longer duration. Earlier, vaccines were transported in ice packs from district headquarters for immediate distribution in the village. The transportation of vaccines used to take around two hours. Lack of vaccine storage led to wastage and sometimes ineffective vaccination of children. The health post has now increased the vaccination services from 3 days to 5 days a week. In addition, one local pharmacy in Darna also now uses electricity to store medicines and operate a Nebuliser for the treatment of asthma, Chronic Obstructive Pulmonary Disease and other respiratory diseases.

Thus, the installation of DRETs such as solar PV, solar-wind micro grid and micro-hydro has extended the scope of medical services for households in Kamal Bazaar and Darna. In addition to medical services, households mentioned that their awareness about public health has improved with the greater use of radios, television and internet because of the availability of electricity through DRETs, which will be discussed later in section 7.5.5.3 as part of DRETs' impacts on physical capital.

7.3.5 DRETs role in dealing with issues in agriculture

Research participants discussed negative impacts of the observed environmental changes such as increasing temperatures, declining rainfall, increasing variability in monsoon, changes in flowering and fruiting, increases in insect pest and increases in invasive species on agriculture in the study sites [see chapter 5]. Other research have also outlined the impacts of temperature increase (Högy et al. 2013; Liu et al. 2016; Zhao et al. 2017), precipitation change (Zaveri et al. 2016), increase in insect pests (Deutsch et al. 2018; Dhaliwal et al. 2015), and increase in invasive species (Bisht et al. 2016) on agriculture. According to research participants, DRETs such as micro-hydro, solar PV and biogas are helpful in addressing the impacts of environmental changes on agriculture.

One of the important direct measures to address the problems of decline in water availability and uncertain monsoon is through the provision of irrigation. The role of micro-hydro in enhancing irrigation facilities in Darna has been already discussed in section 7.3.2. Additionally, the micro-hydro project is planning to operate a cold house to prevent rapid spoilage of agricultural produce due to hotter temperatures. The manager at the micro-hydro project stated that the cold house will run on excess power from the micro-hydro project and will enable farmers to store their agricultural produce in colder temperatures for longer times. He mentioned that such a facility would reduce wastage during hot summer and benefit both farmers and costumers financially. However, at the time of this research, the cold storage project was still at planning phase.

In Kamal Bazaar, solar PV has facilitated the operation of a laboratory dedicated to agriculture science for a vocational education and training (VET) program. The VET program runs a one and half course called Junior Agriculture Technician with an aim to produce skilled local workforce in agriculture. The teaching staff of the program stated that the laboratory is an essential part of the curriculum and the provision of electricity through solar PVs has facilitated the operation of laboratory and library for the program. Students of the VET program mentioned that their training focuses on maximising yield by better understanding crops, soil type, insect pests and invasive species prevalent in their region. The teaching staff mentioned that the VET program and the local laboratory have been playing an important role in addressing the problems in agricultural sector in the region.

Figure 7.11 Solar PV panels on top of a school conducting 'Junior Agriculture Technician' course in Kamal Bazaar

Source: Field Survey, 2018

Another impact of DRET in the agriculture sector is the production of organic manure by biogas plants. While research participants reported a decline in crop productivity due to environmental changes such as hotter temperatures, uncertain monsoon and increased insect pests, farmers in Sunder Bazaar mentioned that the manure from biogas plants has helped them to boost their agricultural productivity. In addition to producing combustible gas for household use, biogas produces organic manure as a by-product called bio-slurry. The bio-slurry contains essential plant nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K), which can be used as a readymade organic fertiliser for crops (AEPC 2019; Wang 2014). Focus group participants in Sunder Bazaar mentioned that they have observed an increase of 30-40% in crop productivity after using the bio-slurry. One of the focus group participants said:

"Earlier, I did not use any fertiliser on my vegetable crop. When I started using bio-slurry, I observed an increase of around 30-40% increase in productivity."

Apart from enhancing agricultural productivity, bio-slurry is good for soil's health and environment. Focus group participants in Sunder Bazaar mentioned that biogas manure is their first choice of fertiliser in their fields. One of the focus group participants said:

"Manure from biogas improves crop productivity, saves money on the purchase of expensive chemical fertiliser and above all it is good for soil and environment."

While a majority of the research participants in Sunder Bazaar agreed that bio-slurry improves crop productivity, three survey respondents did not fully agree with that point. Those who disagreed think that the bio-slurry does not have any crop productivity enhancing qualities because it loses its potency in the form of gas during the fermentation process. One of the disagreeing survey respondents said:

"I think the slurry from biogas is not effective as other fertilisers because it loses its power during fermentation. The power of the cattle dung escapes as combustible gas".

Shrestha (2014) also recorded similar remarks during her study in Gorkha, Nepal. When this issue was raised with a local biogas expert in Sunder Bazaar, the expert however dismissed the logic and said:

"It is a scientifically proven fact that bio-slurry contains essential plant nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K), which enhances crop productivity."

Groot and Bogdanski (2013) note that bio-slurry as a by-product of biogas has the potential to improve soil fertility, soil structure and enhance crop productivity. The impact of bio-slurry in improving soil quality will be discussed further in section 7.5.1.2 of this chapter.

Thus, the examples discussed above show that DRETs such as micro-hydro, solar PV and biogas have been very useful in addressing the impacts of environmental changes on agriculture.

7.4 Overall direct climate adaptation benefits of DRETs

Table 7.1 summarises the direct benefits of DRETs in dealing with the observed environmental changes and associated impacts in the study sites.

Table 7.1 Overall direct climate adaptation benefits of DRETs

Increasing Temperatures		
DRETs	**Usage/contribution**	**Level of satisfaction of the DRET uses**
Solar PV	Low capacity electric fans for cooling	*
Solar-Wind Micro Grid	Fans and fridges for cooling, refrigeration of vaccines and medicines	**
Micro-Hydro	Fans and fridges for cooling, refrigeration of vaccines and medicines	***
ICS	None Reported	º
Biogas	None Reported	º
Decline in rainfall, uncertain monsoon and reduced water availability		
Solar PV	Electric pump to address drinking water shortage in Kamal Bazaar	**
Solar-Wind Micro Grid	None reported	º
Micro-Hydro	Canal built to transport water to power house facilitates irrigation	***
ICS	Research participants think forest protection by ICS prevents drying up of water resources	*
Biogas	Research participants think forest protection by biogas prevents drying up of water resources	*
Disasters and crises		
Solar PV	Weather monitoring and early warning system contributes to minimising disaster losses Electric lighting performs better than traditional 'Jharro' or kerosene lamps during emergencies Communication infrastructure supported by solar PV is vital to disaster management	***
Solar-Wind Micro Grid	Electric lighting performs better than traditional 'Jharro' or kerosene lamps during emergencies Communication infrastructure operating on solar-wind is vital to disaster management	**
Micro-Hydro	Electricity provides a reliable substitute to traditional lighting and firewood during a crisis Communication infrastructure operating on micro-hydro is vital to disaster management Physical infrastructure built for micro-hydro helps in minimising flooding and river bank erosion	***
Biogas	Biogas is less vulnerable and therefore offers a more reliable and consistent supply of kitchen fuel in comparison to other sources during a crisis	*

ICS	None Reported	º
Human Health		
Solar PV	Electric lighting helps to avoid insects and harmful animals Electricity facilitates the operation of medical and laboratory equipment and extension of medical services at health facilities Supports the operation of tele-medicine	***
Solar-Wind Micro Grid	Electric lighting helps to avoid insects and harmful animals Electricity facilitates the operation of medical and laboratory equipment and extension of medical services at health facilities Electricity facilitates operation of fans and mosquito repelling machines	***
Micro-Hydro	Electric lighting helps to avoid insects and harmful animals Electricity facilitates operation of fans and mosquito repelling machines Electricity facilitates the operation of medical and laboratory equipment and extension of medical services at health facilities	***
ICS	None Reported	º
Biogas	None Reported	º
Agriculture		
Solar PV	Facilitates operation of a laboratory and VET school	*
Solar-Wind Micro Grid	None Reported	º
Micro-Hydro	Canal built to transport water to power house facilitates irrigation Plans for pumped irrigation using excess electricity from micro-hydro Plans for cold storage using excess electricity from micro-hydro	**
ICS	None Reported	º
Biogas	Bio-slurry from biogas enhances agricultural productivity	**

Source: Field Survey, 2018

The level of user satisfaction for different DRET uses is based on the aggregate score where,: º = Not Applicable, * = 'Low' if aggregate score >= 3 and =< 3.5, **= 'Moderate' if aggregate score > 3.5 and =< 4.25, and ***= 'High' if aggregate score >4.25 and =< 5. The level of satisfaction was measured in the following scale: 'Very Satisfied'-5, 'Satisfied'-4, 'Neither Satisfied nor Dissatisfied'-3, 'Dissatisfied'-2, 'Very Dissatisfied'-1.

7.5 Indirect climate adaptation benefits of DRETs

As stated earlier, DRETs' indirect climate adaptation benefits are analysed by assessing the impacts of DRETs on five livelihood capitals namely human capital, social capital, physical capital, natural capital and financial capital based on sustainable livelihood approach (Carney, 1998; DFID, 1999).

7.5.1 Impact on natural capital

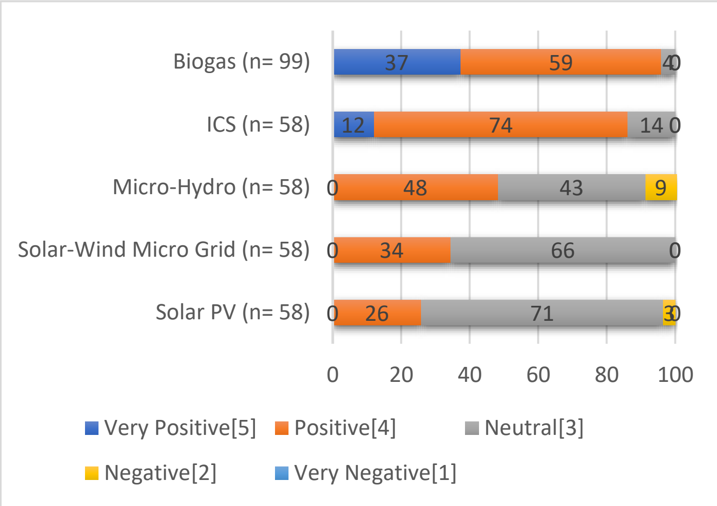
Natural capital constitutes the wide range of tangible and intangible goods and services provided by nature on which users depend for their livelihoods (Pandey et al. 2017). Improving the stock of natural capital contributes to climate adaptation (Bailey et al. 2019; Kuang et al. 2019; Martin & Watson 2016) by reducing people's vulnerability to climate change in a range of ways; including by minimising the losses of ecosystem goods and services, insuring against future disasters, and by safeguarding the agricultural gene-bank for future use (Kumar 2019; Martin & Watson 2016). In order to assess DRETs' impact on natural capital, this study evaluated the impact of DRETs on forest, land and water.

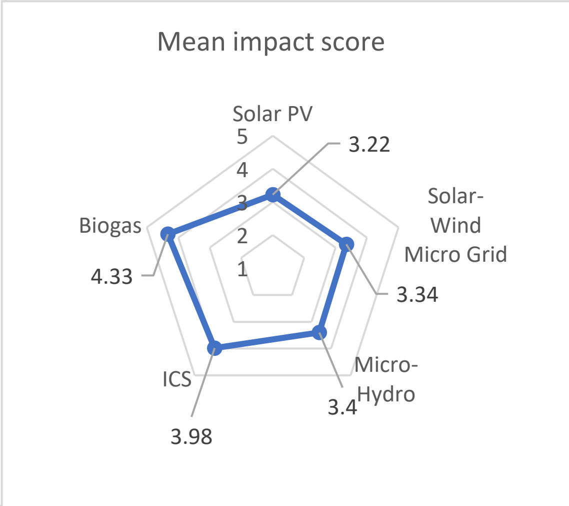
7.5.1.1 Forest

The forest is an important natural resource that provides timber, kitchen fuel, cattle forage, edibles and medicinal plants for livelihood. Survey participants associated all the studied DRETs positively with the improvement in forest management. Of all the surveyed respondents, biogas users reported the highest net positive impacts[6] ($\bar{X}$=4.33, S.D. = 0.553) followed by ICS ($\bar{X}$=3.98, S.D. = 0.513), micro-hydro ($\bar{X}$=3.4, S.D. = 0.647), solar-wind micro grid ($\bar{X}$=3.34, S.D. = 0.479) and solar PV ($\bar{X}$=3.22, S.D. = 0.497) [Chi-square, P= 0.000] [Figure 7.12].

[6] $\bar{X}$= Mean impact score of survey responses on scale 1-5 [1= Very Negative, 2= Negative, 3= Neutral, 4= Positive, 5= Very Positive], S.D.= Standard Deviation

Figure 7.12 Perceived impact of DRETs on forest management





Source: Field Survey, 2018

Biogas users positively mentioned that biogas has contributed to the forest conservation by reducing demand for firewood. Biogas users in Sunder Bazaar mentioned that they are using either none or much less forest firewood after the installation of biogas in their households. One of the focus group participants in Sunder Bazaar said:

"Before we had biogas, we used to visit forest once a week to collect firewood. Now, that we have biogas, we do not need firewood as the gas from biogas plant is enough to cook our meals."

An NGO staff member in Sunder Bazaar mentioned that he has observed a decline in tree felling and good regeneration of forest, after the majority of households built biogas in his community. He said:

"In our childhood, there was a dense forest in our area. Collecting dried logs and pruning branches off big trees used to meet our community's need for firewood. However, as population grew, the forest and trees became scarce. Then, people started felling young trees and collecting whatever they could get. This was destroying our forest. With biogas, however, the need for firewood has reduced. The cases of tree felling has reduces, and this is helping forest to regrow and expand."

A recent study conducted in Nepal suggests that households switching from firewood to biogas can expect to collect 50% less firewood in Terai and 30% less in mountains (Meeks et al. 2019). The same study indicates that across regions, biogas reduces the amount of firewood collected by around 800-950 kilogram per year. Other research conducted in

Nepal and elsewhere have also highlighted the positive impacts of biogas on forest management and associated biodiversity conservation (Chand et al. 2012; Dai et al. 2015; Katuwal & Bohara 2009; Meeks et al. 2019; Mottaleb 2019; Sapkota et al. 2014; Shane & Gheewala 2017).

Second to biogas, ICS users reported the most positive impacts of their DRETs on forest management [Figure 7.12]. Unlike biogas, ICS does not replace firewood with other type of fuel. ICS reduces the demand for firewood by improving combustion efficiency of biomass (AEPC 2019). One of the ICS users in Darna said that she found ICS to be much more efficient than traditional stoves. She said:

"I noticed that with ICS we need about 50% less firewood than in a conventional cooking stove. My neighbours also have similar experience with the use of ICS. Now, I do not need to collect firewood as often as in the past."

Focus group participants in Darna associated the reduced demand for firewood with forest conservation. Similar positive impacts of ICS on forest has been highlighted by Aggarwal and Chandel (2004), Barnes et al. (1993) and Dresen et al. (2014), and together these findings suggest a widespread benefit of ICS for forest management. The positive contribution of ICS in forest improvement has motivated CFUG members to promote ICS among its members. One of the CFUG members in Darna said:

"We believe that ICS offers many advantages. Reduced pressure on forest resources because of lower demand for firewood is one of them. Therefore, we have teamed up with a local cooperative to scale up ICS uptake in Darna."

In addition to biogas and ICS, the users of micro-hydro, solar-wind micro grid and solar PV also associated their respective DRETs positively with the improvement in forest management, although at a lower scale [Figure 7.12]. The micro-hydro users who reported positive impacts mentioned the displacement of *'Jharro'* by electric lighting as the primary reason for improvement in forest cover. *Jharro* is a resin rich wooden stick obtained from pine tree whose flame provides smoky and barely adequate indoor lighting (Bhusal et al. 2007). According to the survey respondents in Darna, *Jharro* is collected by making a cut on the stem of a pine tree. The cut forces the tree to produce resin around it. The resin-rich layer of wood is then chipped away after a week to burn and generate light. Continuous *Jharro* production from the same tree eventually kills the tree. Displacement of *Jharro* by electric lighting has thus led to the protection of pine trees in local forest.

In a few cases, micro-hydro has contributed in reducing firewood use. Three survey respondents stated that they have started using electric heating instead of firewood. An expert in Darna said that people and especially families with newborn babies prefer electric to firewood heating because electric heating is smoke free. Again, the reduction in firewood use also contributes to forest protection. Although the majority of the micro-hydro users reported positive impacts [Figure 7.12], five users however felt that micro-hydro does more harm than good to forest. They think that the impacts of micro-hydro construction and the need of wooden poles for distribution lines have actually destroyed more forest tress than have saved them. Like micro-hydro, the users of solar-wind micro grid and solar PV who reported positive impacts mentioned the displacement of *'Jharro'* by electric lighting as the primary reason for improvement in forest cover.

The improvement in forest management has contributed to an increase in the numbers of plants and animal species in local forests. Focus group participants in Sunder Bazaar mentioned that they have noticed the reappearance of some plant species including some with medicinal values. Similarly, focus group participants in Darna mentioned that the number of wild animals has increased with the increase in forest density and cover. An expert in Sunder Bazaar stated that the improvement in forest management is beneficial for their community as they have access to greater resources in forest. The expert said:

"Increase in forest density and reappearance of some plant species with medicinal value is a good news for our community. We have more forest resources at our disposal. We can also sell them to make an income."

Focus group participants in Darna think that the improvement in forest is directly linked to their improvement in livelihood. One of the focus group participants said:

"Forest is an integral part of our livelihood. We depend on forest to build our houses, to feed our cattle and to collect firewood for our households. Access to greater amount of forest resources means an easier life for us."

Focus group participants in all the study sites think that the availability of forest resources at times of crisis is a great advantage for the community. An expert in Kamal Bazaar highlighted the benefits of having immediate access to forest resources such as timber and tree leaves to build emergency shelters when houses are damaged by disasters such as floods, landslides and earthquakes. Focus group participants in Sunder Bazaar provided examples of their own experience during the Gorkha 2015 earthquake. One of the focus group participants shared:

"*The earthquake damaged many houses. Many were homeless. Those who had their houses intact also could not live in their houses because of frequent after-shocks. We used forest resources such as timber, bamboo and leaves to construct temporary shelters. We collected firewood from forest to collectively cook outside. However, those living in cities like Kathmandu had no such access to forest resources and therefore had to live outside under the open sky and eat dried and junk foods."*

Another focus group participant in Sunder Bazaar mentioned that having a good forest has benefitted his community even after the earthquake. He said:

"Communities without forest, such as those in cities are paying exorbitant price for timbers to rebuild their houses. However, we are getting timber at much cheaper rates from our local forest. We also get building materials such as sand, gravel and stones at reasonable rates because they are locally available in our here."

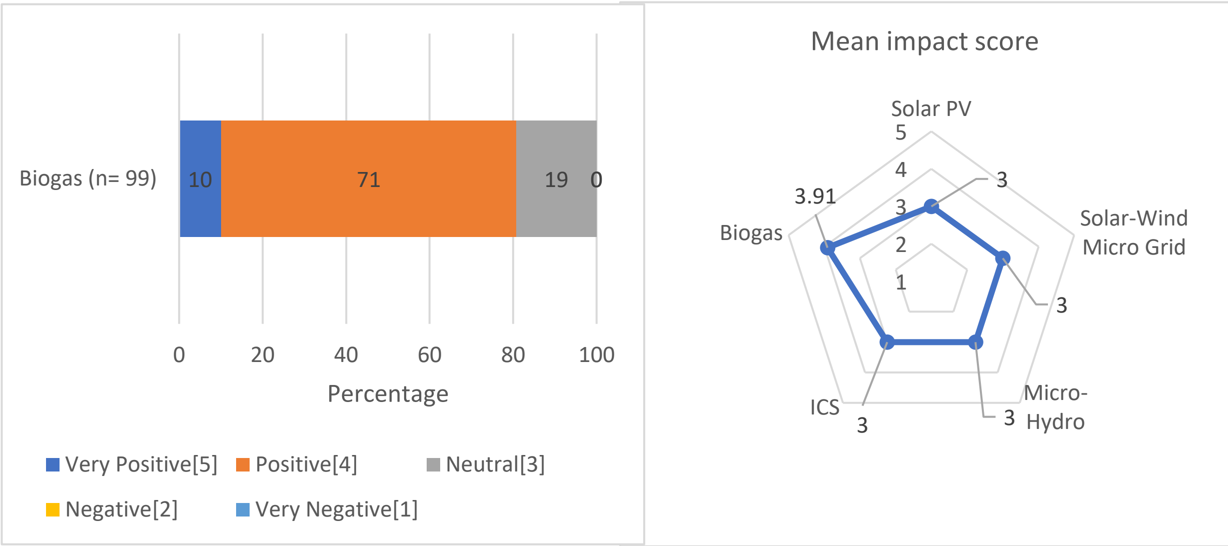
Like research participants, Mishra et al. (2017) argue that natural capital and particularly forest is crucial for immediate and long-term recovery of disaster-hit communities.

Thus, all the studied DRETs were found to have positive impacts in forest management with biogas users reporting the highest and solar PV users reporting the least positive impacts.

7.5.1.2 Land

Land is the most important natural resource in rural Nepali communities as it is the main source of production, income and employment (Bhandari 2004; Deere & Doss 2006). The changing climate will likely increase land degradation and loss in soil nutrients (Eldridge & Beecham 2018). Among the users of DRETs, only biogas users reported positive impacts on land and soil quality ($\bar{X}$=3.91, S.D. = 0.536). As more than 90% of the users of solar PV, solar-wind micro grid, micro-hydro and ICS reported neither positive nor negative impacts, their impacts on land and soil quality have been considered neutral [Figure 7.13].

Figure 7.13 Perceived impact of DRETs on land and soil quality



Source: Field Survey, 2018

Biogas users mentioned that 'bio-slurry' a by-product of biogas enhances soil health and soil productivity. Bio-slurry is a semi-liquid residue left after a series of anaerobic digestion processes inside the biogas plant (AEPC 2019). A biogas expert in Sunder Bazaar mentioned that the slurry contains nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K), which enhances soil quality and crop productivity. According to the expert, bio-slurry offers following benefits:

- Bio-slurry adds humus to soil, which enhances soil's capacity to retain water
- Bio-slurry is a pathogen-free manure as potential microorganisms causing disease on plants are killed during the fermentation process
- Weed growth is lesser with bio-slurry than with other fertilisers

Gurung (1997) claims that bio-slurry improves physical and biological qualities of soil by improving soil structure, improving water holding capacity, cation exchange capacity, reducing erosion and provisioning of nutrients. Focus group participants in Sunder Bazaar preferred bio-slurry to synthetic fertilisers because they think the long-term use of synthetic fertilisers degrades the soil quality. One of the focus group participants said:

"I think continuous and excessive use of synthetic fertilisers alone can make our soil unhealthy. Therefore, I prefer a mix and if possible a higher share of bio-slurry or organic manure."

Figure 7.14 Bio-Slurry discharge being collected in a pit in Sunder Bazaar

Source: Field Survey, 2018

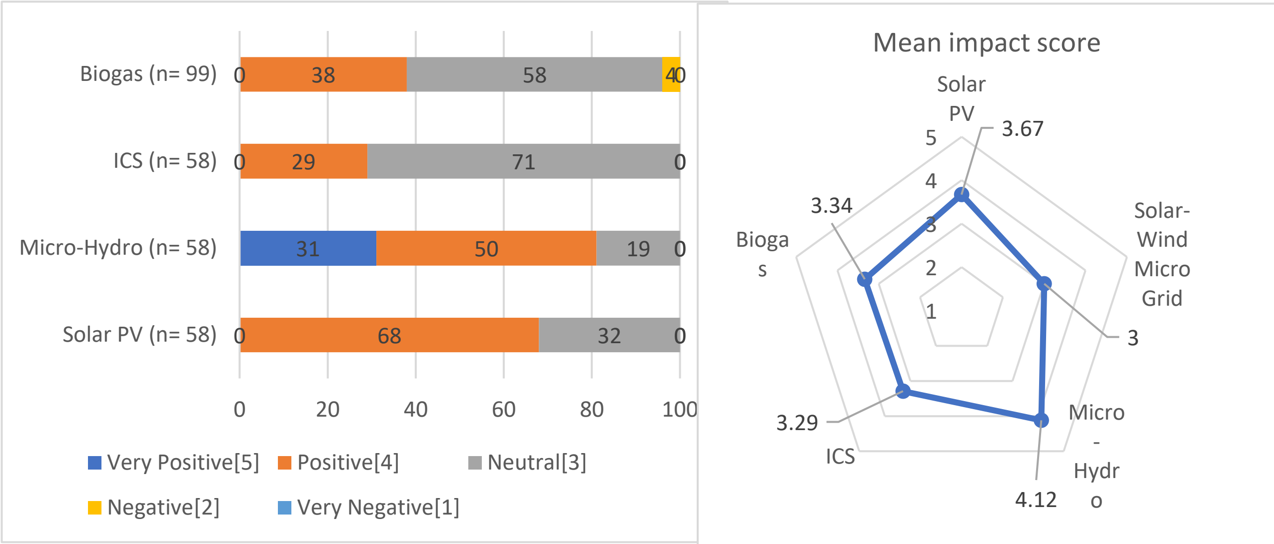
Lal (2009) argues that intensive and unreasonable use of chemical fertilizer on agricultural land causes massive loss of soil's organic carbon, leading to increased production cost and higher CO_2 emissions. Zheng et al. (2017) recommend a combined application of bio-slurry with chemical fertiliser for an effective and eco-friendly way to improve soil quality.

Thus, among the studied DRETs, only biogas was reported to have positive impacts in improving land and soil quality.

7.5.1.3 Water

Water is critical for the viability of ecosystems and healthy flow of ecosystem services. Among the studied DRETs, the users of micro-hydro reported the highest net positive impacts ($\bar{X}$=4.12, S.D. = 0.703), followed by the users of solar PV ($\bar{X}$=3.67, S.D. = 0.473), biogas ($\bar{X}$=3.34, S.D. = 0.556) and ICS ($\bar{X}$=3.34, S.D. = 0.556) [Chi-square, P=0.000] [Figure 7.15] in effective management and improvement of water resources. As more than 90% of the users of solar-wind micro grid reported neither positive nor negative impacts, the impacts of solar-wind micro grid on water resources has been considered neutral.

Figure 7.15 Perceived impact of DRETs on water resources



Source: Field Survey, 2018

The micro-hydro users think that the construction of micro-hydro has increased community’s access to water resources. One of the survey respondents in Darna said:

“Earlier, we could not benefit from our river as we had no structure or mechanism in place to use if for our greater good. Micro-hydro project has increased our access to river and enabled us to use it for different purposes such as irrigation and electricity production.”

Focus group participants in Darna restated that the construction of the micro-hydro project has enhanced their ability to make greater use of water resources to improve their livelihoods. One of the focus group participants in Darna said:

“For generations, casual fishing was the only benefit to us from this river. Micro-hydro project now provides us electricity and irrigation, which are much more valuable and useful to improve our livelihoods.”

The irrigation benefits offered by the micro-hydro project have been already discussed in section 7.3.2 of this chapter. Additionally, the infrastructure constructed for micro-hydro project contributes to river management by preventing floods and riverbank erosion. Gippner et al. (2013) also found a micro-hydro project offering similar advantages for river management in one of her case studies in Nepal.

While research participants associated micro-hydro with increased access and better management of water resources in their community, Sinclair (2003) and Sivongxay et al. (2017) have presented a contrary view, and argue that hydropower results in less availability of water for communities living downstream due to diversion and damming of the rivers. When this issue was raised with an expert at AEPC in Kathmandu, the expert mentioned that micro-hydro projects are designed in a way that least affects the local ecology and lifestyle, stating that:

"Unlike large hydropower, micro-hydro projects do not have big dams to store water. The amount of water to be diverted from a river or a stream is decided on a scientific basis. This ensures that there is no serious alteration of the physical, chemical and biological properties of the river. The water used is returned within a short distance downstream ensuring a healthy ecological flow even during the driest periods."

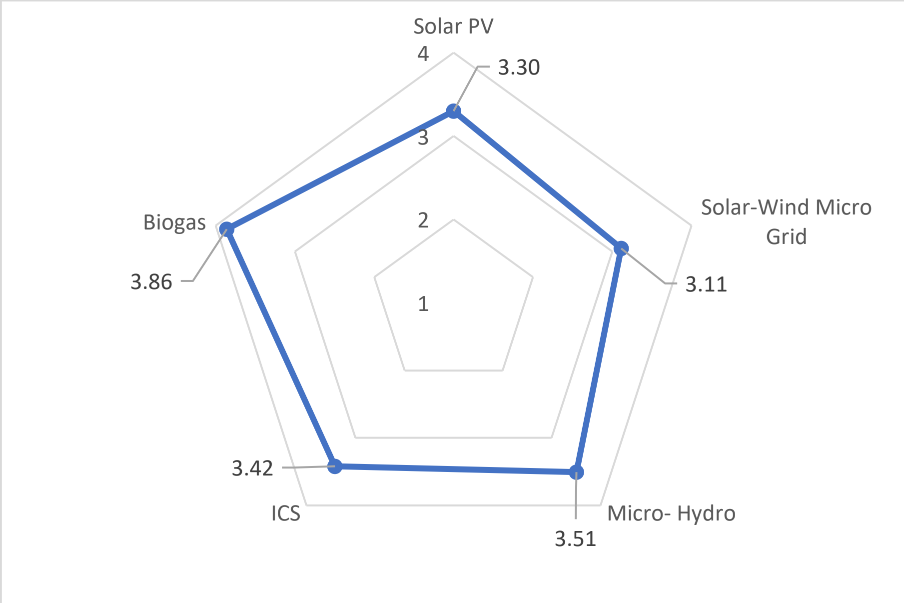
The expert further mentioned that as part of the micro-hydro design, local opinion and approvals are sought before deciding the volume of water to be diverted from river and the locations of canal, powerhouse and distribution lines. Diaz and Catalina (2015) and Sánchez and Izzo (2017) assert that a well-designed micro hydro project has a negligible negative impact on the environment.

In addition to micro-hydro, 68% surveyed users of solar PV also reported positive impacts on the management of water sources [Figure 7.15]. Those who reported positively provided examples of solar PV based drinking water project in Kamal Bazaar. The role of solar PV in addressing drinking water shortage in Kamal Bazar has been discussed in section 7.3.2 of this chapter. A few users of biogas (38%) and ICS (29%) also reported positive impacts of their DRETs in the improvement of water resources [Figure 7.15]. Those who reported positively think that biogas and ICS help in protecting and regenerating water sources by increasing forest cover [see section 7.3.2].

7.5.1.4 Aggregate impact of DRETs on natural capital

Overall, research participants reported several impacts of their DRETs in improving forest, land and water. After aggregating the perceived impacts, it is found that biogas ($\bar{X}$=3.86) has the highest net positive impact in the improvement of natural capital followed by micro-hydro ($\bar{X}$=3.51), ICS ($\bar{X}$=3.42), solar PV ($\bar{X}$=3.30) and solar-wind micro grid ($\bar{X}$=3.11) and [Figure 7.16].

Figure 7.16 Aggregate mean score of DRETs' impact on natural capital



Source: Field Survey, 2018

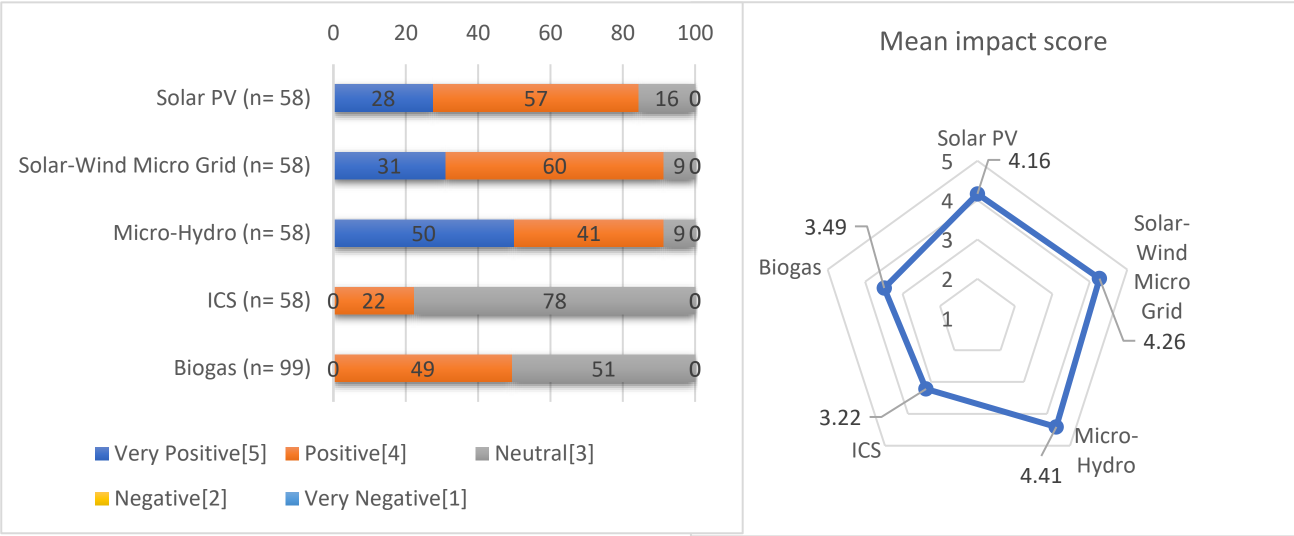
7.5.2 Impact on human capital

Human capital refers to knowledge, productive skills, ability to labour and good health of the people, which are essential for successful livelihood outcome (Burton et al. 2003). Good level of skills and education, better health and strong labour abilities together enhance adaptive capacity of the population (Baffoe & Matsuda 2018; Dulal et al. 2010). This study assessed the impact of DRETs on human capital by analysing DRETs' impacts on education, skills and human health.

7.5.2.1 Education and skills

Education and workplace skills are important for improving livelihood prospects and reducing vulnerability (Ellis 2000). Muttarak and Lutz (2014) underscore that educated and skilled individuals are better prepared to avoid the unwanted impacts of climate change. Survey respondents associated all the studied DRETs positively with the improvement in education and skills of household members. Of all the surveyed users of DRETs, micro-hydro users reported the highest net positive impact ($\bar{X}$=4.41, S.D. = 0.650) followed by the users of solar-wind micro grid (($\bar{X}$=4.26, S.D. = 0.548), solar PV ($\bar{X}$=4.16, S.D. = 0.616), biogas ($\bar{X}$=3.49, S.D. = 0.503) and ICS ($\bar{X}$=3.22, S.D. = 0.421) [Chi-square, P= 0.000] [Figure 7.17].

Figure 7.17 Perceived impact of DRETs on education and skills



Source: Field Survey, 2018

As seen on Figure 7.17, electricity producing DRETs have higher impact score in comparison to biogas and ICS. The users of the electricity producing DRETs mentioned that electric lighting helps them to improve education and skillset of their family members. Electric lighting enables children to study longer, late into the evening. The users of micro-hydro, solar PV, and solar-wind micro grid in Darna and Kamal Bazaar stated that before the availability of electric lighting, their children used to rely on *"Jharro"* candles and kerosene lamps for studying in the dark. Such lighting sources provided poor illumination while emitting hazardous black soot. Inefficient lighting in the past discouraged children from reading effectively or for longer hours. Moreover, poor illumination and harmful soot caused eye irritations, headaches and respiratory tract infections. One of the survey respondents in Darna elaborated the difficulty in reading under poor lighting as below:

"Kerosene lamp, candle and 'Jharro' provide minimal lighting. On top of that, a small force of wind blows them out. Hence, the light source has to be covered from one side, which further reduces the brightness. While studying under such a dim light, you have to be as close as possible to the source of the light. When you are close, you risk burning yourself, you inhale smoke, and causes irritation in your eyes. In addition to that, you get headaches because you have to strain to read and write letters under poor lighting. Coughing and blackening of nostrils because of smoke and soot are also common."

Electricity from DRETs has solved this issue, as modern electric lights are brighter and safe. Besides making studying easier for children, electric lighting helps parents to guide and supervise their children during their study. One of the focus group participants in Kamal Bazaar said:

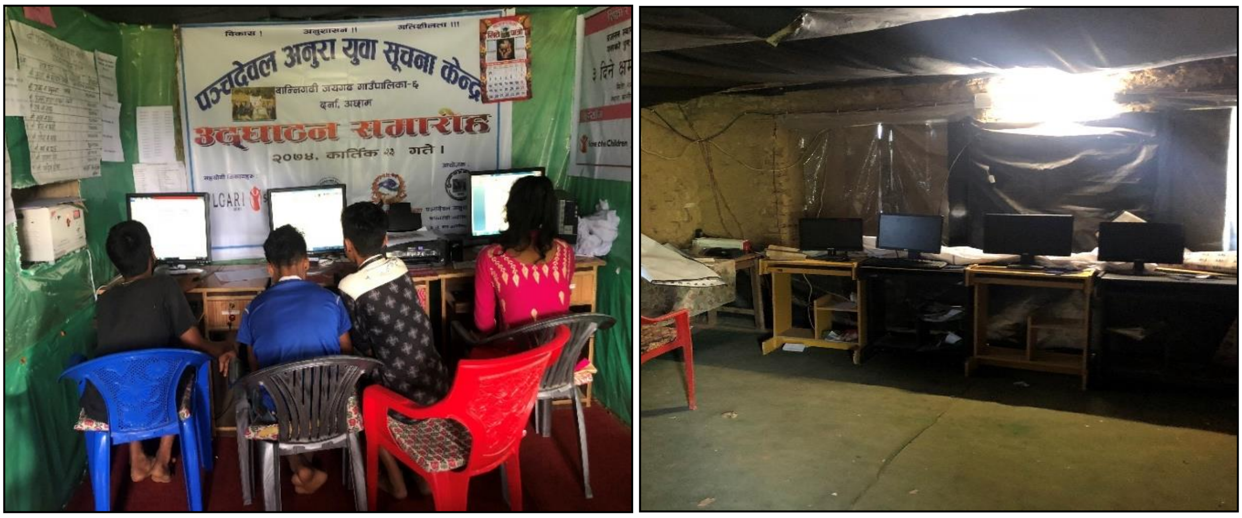
"Earlier, when children studied under kerosene or "Jharro" lamps, we could not observe their activity well. Children would take advantage of poor lighting and not concentrate on their books. However, with brighter lights, we can keep our eyes on them from distance and alert them if they divert their attention from studying."

The impact of electric lighting on childrens' study is reflected in their performances in school as well. One of the key informants in Darna, who was a teacher at a local school, mentioned that he has observed an improvement in the performances of children after the introduction of electricity in his village. In addition to that, the availability of electricity has allowed children to learn computer and internet skills in their schools. The teacher said:

"Today, the knowledge of computer and internet is as important as other subjects like maths and science. However, our children had no access to it because of the lack of reliable electricity. Electricity from micro-hydro has allowed us to launch computer and internet education programs in our school."

The local village council has also started a computer literacy program in Darna. According to a staff at the local council, the computer literacy program is aimed at producing skilled computer operators as the council plans to shift its regular paper-based services to online. Like micro-hydro, solar PV and solar-wind micro grid have facilitated computer and internet education programs at schools in Kamal Bazaar. Additionally, solar PV has facilitated the operation of a VET program called "Junior Technical Assistant" in Kamal Bazaar. The VET program trains local youths to produce skilled work force in agriculture. The role of solar PV in facilitating the operation of the program has been already discussed in section 7.3.5 of this chapter. Bhandari et al. (2017) and Jha et al. (2016) have also reported positive impacts of renewable energy technologies in the improvement of education.

Figure 7.18 Computer literacy program in Darna (left) and a computer study room in a school in Kamal Bazaar (right)



Source: Field Survey, 2018

In addition to computer literacy programs, DRETs have facilitated skills and capacity building activities in the study areas. The availability of electricity through micro-hydro in Darna has encouraged local residents to learn new skills such as mobile phone repairing, milling and husking, tailoring and broiler farming. For example, a teacher in a school in Darna has taken a tailoring lesson after the availability of electricity in her village. She said:

"I was looking for some opportunity to make extra income by working additional hours in the evening. I observed that we did not have a dedicated tailoring shop for women. There, I saw the opportunity. However, without proper lighting it was difficult to operate a tailor shop in the evening. Therefore, I had postponed my plans. After the construction of micro-hydro in the village, I took a women tailoring course and started a shop."

Similarly, another person in Darna mentioned that he took a mobile phone repairing course after the opportunity for a mobile repairing shop emerged with the availability of electricity in the village. According to an expert in Darna, the micro-hydro project itself has facilitated the training of four local residents for administration and maintenance of the micro-hydro project. The expert added that the micro-hydro project in collaboration with AEPC supports skills development program as part of 'Productive Energy Use' campaign in Darna. A survey respondent mentioned that 'Flour Mill Operation Training' organised by AEPC has enabled him to operate his own flour and rice mill in Darna. Like micro-hydro, solar-wind micro grid and solar PV have also encouraged people in Kamal Bazaar to undertake new training. An expert in Kamal Bazaar mentioned that the availability of electricity through solar PVs and solar-wind micro grid has facilitated the opening of banking, health, electronics and telecom services in his community. Opening of such services has encouraged local population to undertake trainings to grab new opportunities. The expert said:

"The availability of electricity has opened up many new service enterprises here. In order to be able to work in such enterprises, the local residents are now undertaking training on mobile phone repairing, computer and photocopy operation and solar home system installation. Additionally, students graduating from high school are now studying courses in health, nursing, business etc."

The local residents regard the growth in the uptake of higher education and skills-based training very positively. Focus group participants in Kamal Bazaar said:

"Prior to the availability of electricity, our community mostly had farmers and labourers. Today our community has skilled technicians and our children want to be professionals in future. It is good to have educated and skilled people in the community. For example having someone who is skilled as a "nurse" can be lifesaving at the time of need. Moreover, educated and skilled people can advocate better for the development of the community and inspire others to do the same."

Apart from electricity producing DRETs, few users of ICS and biogas also reported positive impacts of their technologies on education and skills improvement, although at a much lower scale [Figure 7.17]. Those who reported positively mentioned 'time saving' as the primary benefit, which helps in improving the study of their children. One of the ICS users in Darna said:

"It is common in our society to engage our children to collect firewood. With the use of ICS, the demand for firewood drops. Reduced demand for firewood means fewer trips to forests, which allows more study time to our children."

Biogas users in Sunder Bazaar had a similar opinion, with a focus group participant stating:

"Biogas reduces firewood demand, which means we do not need to make frequent trips to collect it. The time saved thus allows parents as well as children to spend more time for study."

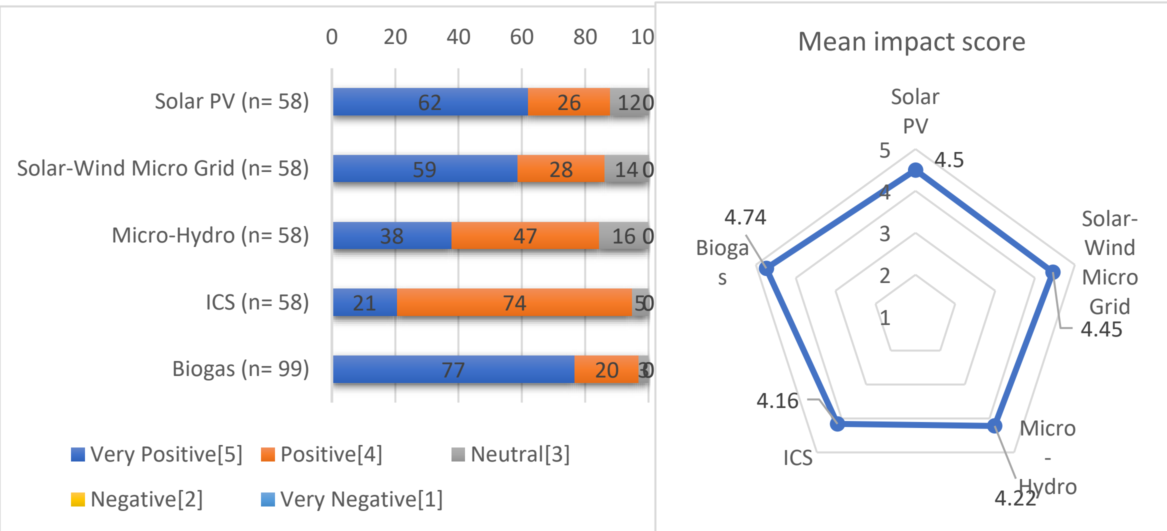
In a recently conducted study in Nepal, Meeks et al. (2019) found that biogas saved approximately 23% to 47% time in firewood collection, which was then invested by households in agriculture labour and education. Similar time saving benefits of ICS (Granderson et al. 2009; Habermehl 2008; Jan 2012) and biogas (Chand et al. 2012; Sapkota et al. 2014; Shrestha 2014) have been highlighted by other studies.

Overall, the users of DRETs discussed several benefits, with the users of electricity producing DRETs expressing highly favourable opinion about the benefits of their DRETs in the improvement of education and skills.

7.5.2.2 Human health and sanitation

Health influences labour productivity, which further influences livelihood outcome (Joffe 2007). Future climate projections however suggest potentially catastrophic risks to human health in different contexts (Watts et al. 2015). In a changing climate scenario, actions aimed at improving health are important aspects of building climate resilience (Watts et al. 2018). Survey participants associated all the studied DRETs positively with the improvement of health and sanitation in their household and communities. Of all the surveyed respondents, biogas users reported the highest net positive impact ($\bar{X}$=4.74, S.D. = 0.507) followed by the users of solar PV ($\bar{X}$=4.50, S.D. = 0.707), solar-wind micro grid ($\bar{X}$=4.45, S.D. = 0.730), micro-hydro ($\bar{X}$=4.22, S.D. = 0.702) and ICS ($\bar{X}$=4.16, S.D. = 0.489) [Chi-square, P= 0.000] [Figure 7.19].

Figure 7.19 Perceived impact of DRETs on health and sanitation



Source: Field Survey, 2018

According to the biogas users, the major health benefit offered by biogas is a smoke-free kitchen, which reduces irritation and burning sensation on eyes, headaches and respiratory tract infections previously caused by smoke from firewood. The elimination of smoke from kitchens is also the primary health benefit identified by the ICS users in Darna. Biogas users in Sunder Bazaar and ICS users in Darna mentioned that they used to have rudimentary firewood-based open cooking stoves, which produced a lot of smoke. A survey respondent in Sunder Bazaar said:

"Traditional firewood based cooking stove produces smoke, ash and soot on its use. The amount of smoke is higher when the firewood is wet during the rainy season. Without proper ventilation or chimney, the smoke and ash lingers around inside the house. Overtime, smoke, ash and soot deposit on walls and turn everything black. Biogas, however has no such issues. Biogas produces no smoke and hence there is no blackening of walls and other objects."

ICS users in Darna also narrated similar stories, with one user saying:

"Unlike traditional firewood stoves, ICS does not let any smoke escape into the kitchen. Therefore, there is no smoke and blackening of walls and other objects."

Research participants in Sunder Bazaar and Darna discussed the detrimental effects of smoke on their health. A survey respondent in Sunder Bazaar said:

"Earlier I used firewood for cooking. My kitchen used to be filled with smoke. Spending hours in the smoke-filled kitchen was not easy. I felt suffocated and at the end of the day, I felt a burning sensation in my eyes accompanied with headache. Also, coughing and eye irritation were equally common."

One of the focus group participants in Darna said that women generally suffer from smoke-related problems such as coughing and irritation of eyes, nose and throat as cooking is primarily considered women's responsibility. Gautam et al. (2017) highlight that the risk of respiratory problems because of traditional biomass based kitchen fuel is higher for women and children in Nepal as they spend comparatively longer time in kitchen. Mbatchou Ngahane et al. (2015) also found greater cases of respiratory issues and reduced lung function among women using firewood as cooking fuel in Cameroon. A medical staff in Darna said that the exposure to high levels of smoke could have serious health impacts on individuals with cardiovascular or respiratory conditions, elderlies, infants and young children. Studies have also associated cooking fuel smoke with problems such as chronic obstructive pulmonary disease, lung cancer, weakening of the immune system, and reduction in lung function (Gautam et al. 2017; Mbatchou Ngahane et al. 2015; Sana et al. 2019; Zhang & Smith 2007).

Biogas and ICS are cleaner substitutes to traditional cooking stoves. Biogas provides Methane (CH_4) through the decomposition of organic waste as cooking fuel, which produces little or no smoke during combustion (AEPC 2019). Although ICS uses firewood and produces smoke during its use, its innovative design does not let much smoke escape and instead directs it out through a chimney (AEPC 2019). Since biogas does not produce soot on burning, there is no blackening of walls and objects in the kitchen. Research participants mentioned that the use of biogas and ICS does not release black soot, which helps in keeping the household clean and tidy. One of the focus group participants in Sunder Bazaar said:

"When we used firewood-based open cooking stove, everything (utensils, walls and other objects) turned black. Our body parts and cloths got soot stains from walls. Everything looked dirty and untidy despite many attempts to keep them clean. However, with biogas it is different. Nowadays, every body's kitchen with biogas looks clean and tidy."

ICS users in Darna shared similar opinion regarding the cleanliness of their kitchens.

Figure 7.20 Kitchens with a traditional stove (left) and an improved cooking stove (right) in Darna

Source: Field Survey, 2018

For biogas users, the second major health benefit is waste disposal. Survey respondents in Sunder Bazaar mentioned that biogas has helped in proper management of cattle dung, household organic waste and encouraged them to construct *Pukka*[7] or modern toilets in their households. An expert in Sunder Bazaar explained how biogas expedited the construction of toilets in his village as:

"Building a pukka toilet is expensive. In the past, people did not want to invest big money just for a toilet. Therefore, the majority had no toilets. However, with biogas you could construct a pukka toilet at a fraction of the actual cost. When you build a toilet connected to biogas, you do not have to construct a separate septic tank for the toilet, which saves 50% of the cost. Moreover, connecting the toilet to biogas increases the gas output. Because of these dual benefits, many people started constructing toilets along with their biogas plants."

Focus group participants in Sunder Bazaar mentioned that biogas has played a crucial role in increasing the number of toilets and preventing open defecation in their community. One of the focus group participants said:

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[7] "Pukka" with reference to buildings and structure refers to strong, permanent and reliable structure made of cement and concrete in Nepali language

"Earlier, when we had no proper toilets, open defecation was common. Children would choose roadside and adults would chose a bush near a water source. Biogas construction initiated the first wave of building 'Pukka' toilets in our community. The construction of toilets by first few households put a social pressure on others. Now, it is rare to find any household without a toilet, and it is rare to find open defecation in our community. Our streets and water resources are now much cleaner than before."

Figure 7.21 A 'Pukka' toilet adjacent to a biogas plant in Sunder Bazaar

Source: Field Survey, 2018

Focus group participants mentioned that the decline in open defecation has reduced the number of flies, bad odours, pollution and contamination in their surroundings. They also mentioned that the cases of water-borne diseases such as Diarrhoea and Typhoid have reduced with the decline in open defecation. Further, biogas has contributed to the effective disposal of cattle dung and other organic waste in the community. According to focus group participants in Sunder Bazaar, prior to biogas, people did not care much about proper disposal of cattle and household waste, which polluted local surrounding and water sources. However, that changed after the introduction of biogas in the village. One of the focus group participants said:

"It was a common sight to find cattle dung and other organic waste (such as leftover food and cattle fodder) rotting at roadside. Such waste produced bad odours, attracted flies and

contaminated our water. However, with the introduction of biogas, this is no longer the case. As cattle dung and other organic waste are main raw material for biogas, people have stopped dumping them just anywhere. Instead, nowadays people collect the waste from roadside and other public spaces to use in their biogas. This has reduced the organic waste disposal problem in our area."

In addition to the benefits discussed above, four survey respondents mentioned that time saving due to the use of biogas allows them to invest more time in their personal hygiene and household sanitation. One of the survey respondents said:

"After constructing biogas, I am able to save time because I don't need to make frequent trips to forest as in the past. I use the time saved in taking additional showers, bathing my children and cleaning households."

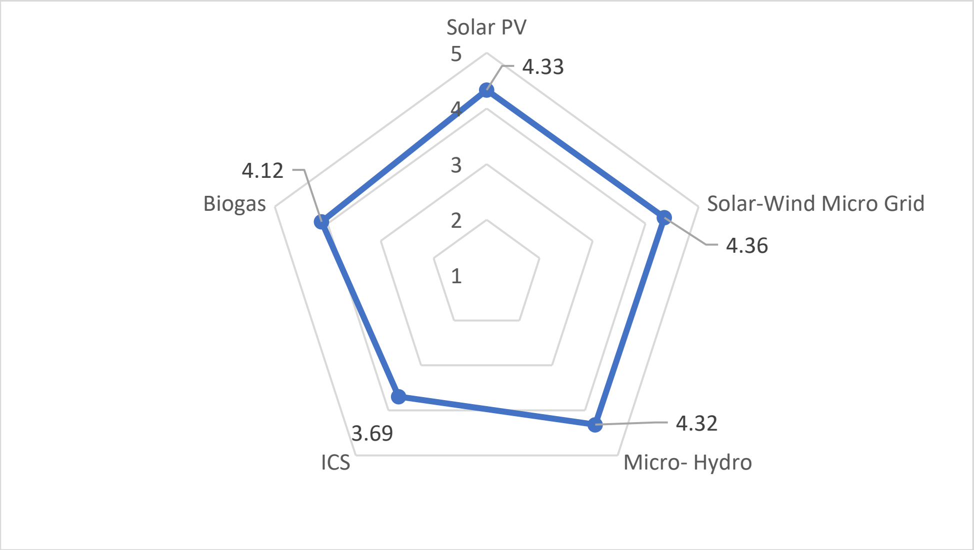
Shrestha (2014) also found household members investing more time on cleanliness and hygiene because of the time saved by the use of the biogas.

The users of the electricity generating DRETs such as solar PV, solar-wind micro grid and micro-hydro also reported positive impacts on health. The users mentioned that electricity has contributed in the displacement of hazardous '*Jharro*' and kerosene lamps, improved medical services in their local health centres, and facilitated the use of fans and fridges to deal with uncomfortable hotter temperatures. The contribution of electricity generating DRETs in the improvement of services at local health facilities have been already discussed in sections 7.3.1 and 7.3.4.

7.5.2.3 Aggregate impact of DRETs on human capital

Overall, research participants reported several impacts of their DRETs in the improvement of education, skills, human health and sanitation in their households and communities. After aggregating the perceived impacts, it is found that solar-wind micro grid ($\overline{X}$=4.36) has the highest net positive impact on human capital followed by solar PV ($\overline{X}$=4.33), micro-hydro ($\overline{X}$=4.32), biogas ($\overline{X}$=4.12) and ICS ($\overline{X}$=3.69) [Figure 7.22].

Figure 7.22 Aggregate mean score of DRETs' impact on human capital



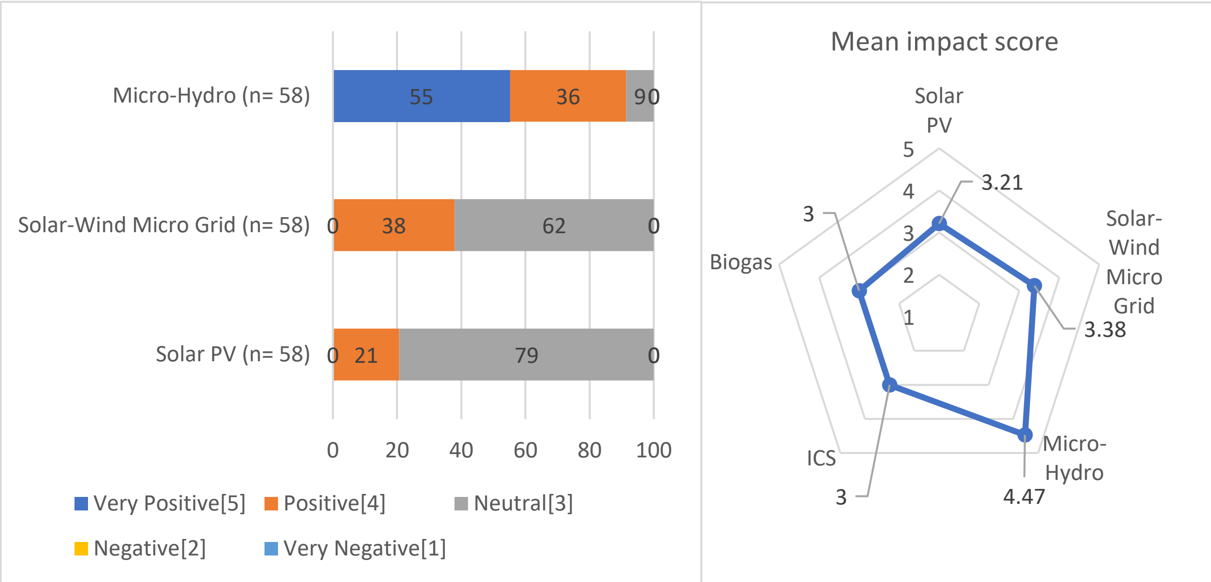
Source: Field Survey, 2018

7.5.3 Impact on social capital

Social capital is the range of social relationships and networks that are important in the operation of livelihood activities (Burton et al. 2003). Social networks such as family, friends, neighbours and organisations influence individual's attitude about climate change adaptation (Nam et al. 2012), increase awareness and knowledge on climate adaptation (Fankhauser et al. 1999), increase local capacity to identify potential risk and damages (Kane & Shogren 2000) and facilitate adoption of adaptive strategies (Kuang et al. 2019; Shinbrot et al. 2019). This study evaluated DRETs' impact on social capital by analysing the impacts in the improvement of social bond, trust and community collaboration.

The users of micro-hydro, solar-wind micro grid and solar PV reported positive impacts of their DRETs on social capital. Among the studied DRETs, the users of micro-hydro reported the highest net positive impacts ($\bar{X}$=4.47, S.D. = 0.655) followed by solar-wind micro grid ($\bar{X}$=3.38, S.D. = 0.489) and solar PV ($\bar{X}$=3.21, S.D. = 0.409) on social capital [Chi-square, P= 0.01] [Figure 7.23]. As more than 90% of the users of biogas and ICS reported neither positive nor negative impacts, their impacts on social capital have been considered neutral.

Figure 7.23 Perceived impact of DRETs on social capital



Source: Field Survey, 2018

The micro-hydro users mentioned that there has been a remarkable increase in social trust, confidence and community collaboration after the construction of micro-hydro project in Darna. One of the survey respondents in Darna said:

"The launch of micro-hydro project brought community members closer for development. Since then, we have strengthened our trust and community collaboration."

Similarly, a focus group participant in Darna said:

"We were able to build a development project worth millions of rupees. This is a massive project in terms of finance and scale for our community. Moreover, we are operating it in profit. This is a huge achievement for us. This project has given us a confidence that we can collectively deal with problems today and in the future. Our planned pump irrigation project in the future is an example of our collective effort to tackle declining water availability in our community."

An AEPC staff who advises the micro-hydro management committee also mentioned that he has observed a rise in positive attitude for community collaboration. He stated:

"Due to the nationwide trend of delay and failures in development projects, initially people were sceptic about the success of micro-hydro project. However, successful completion of the project with great community participation has set a good example in the community.

Locals now show greater interest and energy to collectively pursue development activities."

The AEPC staff further mentioned that the success of micro-hydro project has strengthened collective confidence to deal with community problems and provided examples of pump irrigation and cold storage that are being planned to deal with uncertain monsoon and increasing temperatures in the region. He mentioned:

"Earlier, for any problem, community members used to look for a ready-made project from government, NGOs and INGOS. Now, they are looking forward to solving problems themselves with locally available resources. This is an indicator of what has changed after the success of the micro-hydro project.

Sánchez and Izzo (2017) and Gippner et al. (2013) also found increases in community participation and collaboration because of micro-hydro projects in Dominical Republic and Nepal respectively.

In addition to the boost in confidence and community collaboration, the micro-hydro project has facilitated greater trust and support among its users. The micro-hydro project functions as a co-operative called "Shree Darna Micro-Hydro Co-operative Ltd". All the users of micro-hydro are shareholders, and therefore are members of the co-operative. According to co-operative's manager, apart from managing the micro-hydro project, the co-operative collects voluntary deposits from the users. The deposits along with net profit from the operation of micro-hydro are made available for borrowing to co-operative members at a lower rate of interest than is available in the local market. Since every household in Darna is a member of the co-operative, the entire village benefits from this scheme. The manager mentioned that the households that have a greater need are prioritised over others for the lending. The loans are provided without any collateral and solely based on trust. One of the members of the micro-hydro project management committee mentioned that the scheme of providing loans based on trust has enhanced social bonding and greater trust among each other in the village. He said:

"Earlier, when people helped each other with money, they used to charge hefty interest in fear that there was no guarantee of refund. Heavy interest and lack of trust among each other used to result in arguments, fights and broken relationships. However, the provision of loans without any collateral and solely based on trust has brought a positive change."

He added that the scheme has contributed in building positive impressions about each other in the community. He said:

"Since the co-operative provides cheap loans, there is now almost no demand for costly individual loans. Therefore, people who individually lent money earlier are now depositing their savings in the co-operative and making the funds available for others at a lower interest rate. With this, the depositors are now considered good friends and sometimes a saviour. This has very much helped in building trust and strengthening bonds between people in the community."

The manager of 'Shree Darna micro-hydro Co-operative Ltd' thinks that the co-operative is more like a big family to them. The manager said:

"The micro-hydro users are owners as well as consumers of this co-operative. We own it like a family and help each other as family members.

In addition to micro-hydro, the surveyed users of solar-wind micro grid (38%) and solar PV (21%) also reported positive impacts of their DRETs on social capital. The solar-wind micro grid users in Kamal Bazaar mentioned that the successful completion of the project has improved social cohesion and trust in the community. The president of the solar-wind micro grid construction and management committee said:

"The solar-wind micro grid project has moved us from darkness to light. A collective community effort made this possible. Everybody feels proud and part of the project. The successful completion of the project has improved social cohesion, trust and reliability among each other"

Similarly, the solar PV users also came together as a community to build a solar PV-based drinking water project to address water shortage problems in Kamal Bazaar. The successful completion of the project has enhanced community confidence. The president of the solar PV drinking water project management committee in Kamal Bazaar said:

"The successful completion of the project has set an example and increased confidence that common problems can be dealt with collective community actions"

The role of DRET projects in promoting community collaboration and improving social capital was also highlighted by an AEPC staff in Kathmandu. The staff mentioned that community participation in DRET projects enhance social trust, bonds and community collaboration apart from ensuring long-term sustainability of projects.

Research participants further associated electric lights and television as other important factors contributing to the improvement of social capital. The users of micro-hydro, solar-wind micro grid and solar PV linked electric lighting and television with increase in social interactions and connections in their communities. Focus group participants in Darna stated that electric lighting enables people to meet and interact until late night, which helps in enhancing social bonding in the community. A focus group participant said:

"Without proper lighting, we used to end our day early. We used to eat and sleep early. However, with electric lighting, we stay awake until late. We spend more time with neighbours in the evening. When you spend more time with people, you become good friends."

Similarly, focus group participants in Kamal Bazaar mentioned that electric lighting facilitates longer communal events into the night, which improves social cohesion. One of the focus group participants said:

"In the past, we used to wrap up communal gatherings like 'Bhajan' (collective religious singing) early because of the lack of proper lighting. Electric lighting has made longer Bhajan sessions possible. Such community events bring community members closer and build good relationships."

Vognild (2011) also found that solar PV-based electric lighting facilitated greater social gathering in India, similar to what was observed in the study sites. Like electric lights, televisions have also facilitated greater people-to-people interaction in the community. Focus group participants in Kamal Bazaar mentioned that places with television have become new hubs for people to gather and interact. One of the solar-wind micro grid users who also owns a TV said:

"Earlier without electricity and TV, people used to go to beds early. After I got a TV in my house, many of my neighbours started gathering at my house to watch TV together. This has allowed me and my neighbours to interact longer and to build friendly relation with each other. Now, I feel confident to ask for help with my neighbours."

Focus group participants in Darna also agreed that televisions have become a good medium to socialise and build stronger ties among each other in the community. One of the focus group participants even provided an example of how a young man and woman fell in love while watching TV together.

In spite of several positive impacts, the users of solar-wind micro grid and solar PV expressed dissatisfaction about the current plight of their DRET projects. At the time of this study, the solar-wind micro grid project was functioning at a partial capacity and the solar PV-based drinking water project was not functioning at all. The dissatisfied users mentioned that inefficient management of their DRET projects have eroded their confidence for future community collaborations. One of the dissatisfied user of solar-wind micro grid said:

"The solar-wind micro grid project was completed successfully, however, the project is not functioning well now. Looking at the plight of the project, I have lost confidence that we as a community yet do not have the capability to successfully operate a project."

Similarly, a dissatisfied user of solar PV-based drinking water project said:

"We invested our free labour and resources to build the project. The collective enthusiasm and collaboration had given a hope that our drinking water shortage would be fully addressed. However, the current situation of the project is no different from other government projects. This has eroded our confidence for future community efforts."

Micro-hydro users in Darna, however expressed no such dissatisfaction. These examples show that despite massive initial investments, inefficient management of DRET projects can result in poor outcomes.

Overall, the findings of this study show that micro-hydro, solar-wind micro grid and solar PV can build community confidence and generate improvement in social capital, thereby improving their adaptive capacity to deal with future environmental changes. However, the significant differences in the perceived impacts between micro-hydro with successful service delivery and failing solar-wind micro grid and solar PV indicate that efficient management of DRET projects post completion are rather important to generate long-term positive outcomes to the communities. In this context, it is crucial that DRET project donors and designers should also consider continuous monitoring and assistance instead of just constructing and handing over of the projects.

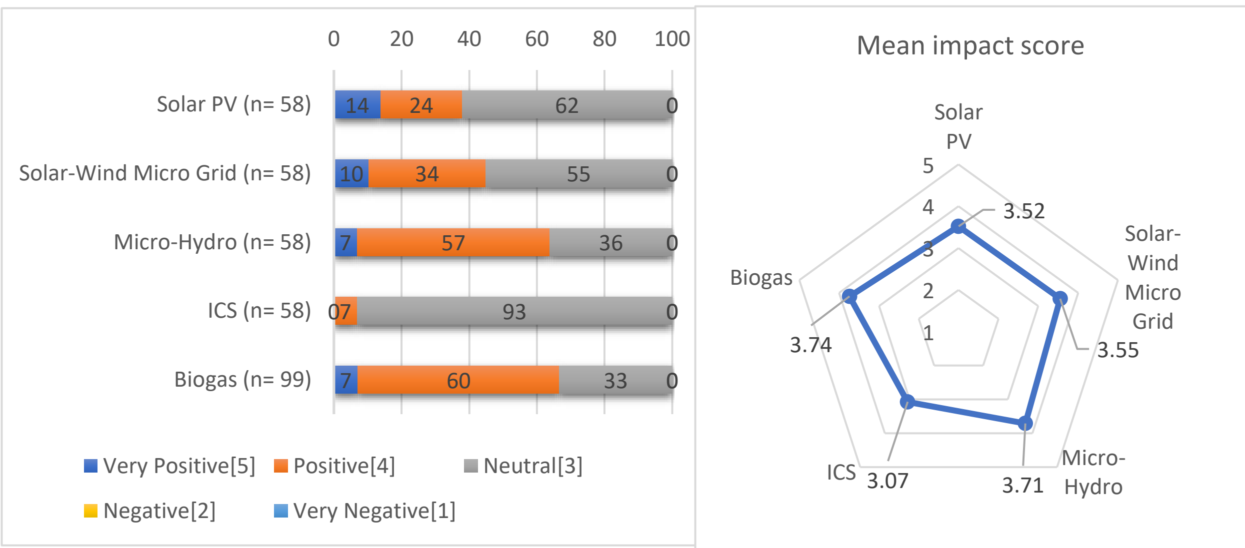
7.5.4 Impact on financial capital

Financial capital constitutes financial resources such as income, remittances, savings, access to credit etc., which are necessary for the pursuit of livelihood activities (Scoones 1998). Financial capital is essential as a means of production and for responding to the effects of different vulnerabilities (Burton et al. 2003). In order to assess the impact of DRETs on financial capital, this study focused on the impacts of DRETs in improving economic productivity, household savings and access to financial institutions.

7.5.4.1 Economic productivity and income

In a rural farming community, low farm productivity and limited access to non-farm income sources increase vulnerability of the poor households (Rigg 2006). Improved economic productivity and income diversification are therefore essential to strengthen adaptive capacity (Brooks & Adger 2005). Survey participants associated all the studied DRETs positively with economic productivity and household incomes. Among the users of DRETs, biogas users reported the highest net positive impact ($\bar{X}$=3.74, S.D. = 0.582), followed by micro-hydro ($\bar{X}$=3.71, S.D. = 0.593), solar wind micro gird ($\bar{X}$=3.55, S.D. = 0.680), solar PV ($\bar{X}$=3.52, S.D. = 0.731) and ICS ($\bar{X}$=3.07, S.D. = 0.256) [Chi-square, P= 0.000] [Figure 7.24].

Figure 7.24 Perceived impact of DRETs in improving economic productivity and household income



Source: Field Survey, 2018

According to the biogas users, biogas contributes to improvement in economic productivity primarily through the use of bio-slurry in farms. Focus group participants in Sunder Bazaar mentioned that they have observed a 30-40 percent increase in crop productivity after the use of bio-slurry (see section 7.3.5). Households that are not engaged in farming also derive economic benefits from bio-slurry by selling it as a fertiliser in local markets.

Biogas additionally helps in higher economic productivity by allowing users to save time. Biogas users mentioned that the use of biogas reduces the need to collect firewood from forest, which helps in time saving. The saved time is then invested in working longer hours in farms, business and trade. One of the biogas users who works as a blacksmith in Sunder Bazaar said:

"Earlier, my wife could not help me in my trade because she had to visit forest twice a week to collect firewood. However, after we built biogas, the gas is sufficient and therefore we no longer need firewood. She now helps me with the trade and as a result, my output has increased by 50%. Increased output has helped me to earn more money than in the past."

A few (7%) ICS users also mentioned that time saving through ICS has enabled them to earn extra income. An ICS user in Darna said:

"I do not visit forest as often as in the past, because the demand for firewood has reduced after the use of ICS. I use the additional time available in my farm to weed out plants, which helps in increasing crop yield."

In addition to biogas and ICS, the users of electricity producing DRETs also reported positive impacts of their DRETs in improving economic productivity, especially because they can work for longer hours with electric lighting. A micro-hydro user in Darna said:

"Earlier, without proper lighting, it was difficult to prepare meals. Therefore, my wife and I used to leave our farms early, at around 4 pm so that we could prepare and consume a meal before dark. With electric lighting, we do not need to worry about darkness. We can work long hours in our farms, which helps us improve our farm productivity.

Electric lighting has benefitted local business as well. One of the survey respondents with tailoring business in Kamal Bazaar said:

"*When we had no solar PV, we relied on kerosene lamp and Jharro. We mostly avoided working under them because these sources of light did not provide enough brightness and were risky to work with. They could burn you or the cloth that you were working on. Black soot from kerosene lamp and Jharro could damage new cloths. However, with solar-based electric lighting, we have no such issues. Solar lights are brighter, safe and enable us to work longer hours."*

The survey respondent added that solar PV- based lighting has enabled him to work on average 2-3 hours more per day, thereby increasing his income by 30%. He said:

"When I had no solar PV lights, I used to close my shop at around 5 PM. With solar lighting, I keep my shop open until 8 PM and during festive and wedding seasons, I work until 2 AM at my shop. Working extra hours provide additional income."

Other businesses such as restaurants, grocery store and blacksmith shared similar stories about the impacts of electric lighting in their economic productivity.

Figure 7.25 Electric lighting running on solar PV at a tailoring business in Kamal Bazaar

Source: Field Survey, 2018

The availability of electricity through DRETs has also facilitated the opening of several enterprises, thus creating new income opportunities for many households. New mobile phone shops, solar home system sales and maintenance shops, internet and photocopy shops, milling and grinding, poultry farming and butcher shops have opened in Kamal Bazaar and Darna. A survey respondent in Darna said that she started a poultry farm after micro-hydro came into operation in Darna. She said:

"I saw a business opportunity in raising broiler chickens and supplying it to the local market. However, without reliable electricity for lighting and heating, raising broiler chickens was not possible. After the start of micro-hydro in the village, we have god supply of electricity here. This has allowed me to start a poultry farm, and I am making good income."

Similarly, another survey respondent in in Darna said that he started milling and grinding business after high voltage electricity was available from the micro-hydro project. A survey respondent in Kamal Bazaar said that he started a mobile phone repairing shop after solar PV increased the number of mobile phone customers in Kamal Bazaar. The contribution of DRETs in improving skills and preparing local residents for new economic opportunities have been already discussed in section 7.5.2.1 of this chapter.

Figure 7.26 Electricity in use in a poultry farm (left) and a flourmill (right) in Darna

Source: Field Survey, 2018

Figure 7.27 A solar PV business (left) and a mobile repairing shop (right) in Kamal Bazaar

Source: Field Survey, 2018

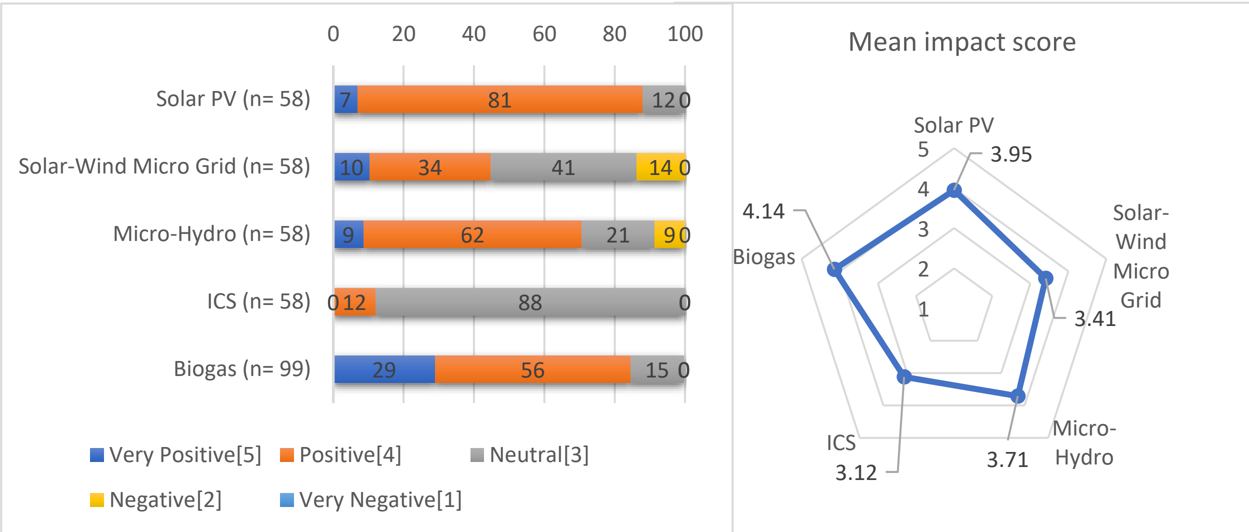
Additionally, the micro-hydro project has contributed to higher farm productivity through irrigation facility in Darna. Farmers benefitting from irrigation reported that the yearlong availability of water has enabled them to plant crops throughout the year and in underutilised land, which has improved their farm productivity and income (see section 7.3.2). In addition to economic benefits to households, the micro-hydro project has provided additional income to the community of Darna by selling excess electricity to a nearby ‘Kalagaun’ village. Not just at the study sites, national reports indicate that the promotion of DRETs creates numerous new jobs and opportunities nationwide. According to government records, the promotion of DRETs has created 30,000 direct and indirect jobs in design, manufacturing and in providing ancillary services of renewable energy technology industry in Nepal (MOEWRI 2018).

Overall, the findings of this study show that all the studied DRETs offer great benefits in terms of enhancing economic productivity. However, few survey respondents highlighted limited and unreliable power supply from solar PV and solar-wind micro grid as deterrent in achieving higher economic productivity. The dissatisfied users of solar PV and solar-wind micro grid said that the electricity from their DRETs is inconsistent and unreliable, which limits their abilities to achieve greater productivity. Mazzone (2019) also notes that the intermittency and the lack of grid reliability in solar-based grids is one of the deterring factors to making full and productive use of electricity.

7.5.4.2 Household savings

Household saving is defined as the difference between household's disposable income and consumption (Finlay & Price 2015). Higher levels of savings boost financial resources, which enable households to take necessary measures and manage for longer periods with limited incomes, such as during a time of crisis (Lockwood et al. 2015). Survey respondents associated all the studied DRETs positively with the improvement in household savings. Of all the surveyed respondents, biogas users reported the highest net positive impact ($\bar{X}$=4.14, S.D. = 0.655) followed by solar PV ($\bar{X}$=3.95, S.D. = 0.436), micro-hydro ($\bar{X}$=3.71, S.D. = 0.749), solar Wind Micro-Grid ($\bar{X}$=3.41, S.D. = 0.859) and ICS ($\bar{X}$=3.07, S.D. = 0.256) [Chi-square, P= 0.000] [Figure 7.28].

Figure 7.28 Perceived impact of DRETs on household savings



Source: Field Survey, 2018

The biogas users mentioned that biogas helps to improve household savings primarily by reducing their expenditure on kitchen fuel and chemical fertilisers. After investing initial capital in construction, there is virtually no cost in the operation and production of biogas. Cattle dung, human waste and household organic waste are the major raw material for biogas. Biogas produces Methane (CH_4) gas, which is a good substitute for firewood and other kitchen fuels such as kerosene and LPG. In most households, biogas has eliminated the need for other kitchen fuels. In a focus group discussion in Sunder Bazaar, 80% of biogas users mentioned that they do not spend any money in procuring kitchen fuels. In some cases, biogas alone is not enough for a household's needs and such households generally use agricultural residues and wood from trees in their compounds to bridge the gap. Like biogas, the ICS users who reported positively mentioned that ICS helps in household savings by reducing the demand and expenditure for firewood.

In addition to saving on kitchen fuel, biogas helps farming households by reducing the investment in chemical fertilisers. As stated earlier in section 7.3.5, bio-slurry, a by-product of biogas, can be readily used as manure in farms. Bio-slurry from biogas offsets the need for expensive chemical fertilisers. A biogas user in Sunder Bazaar said that he was able to reduce 25% of chemical fertilisers use after building a biogas plant. He said:

"Earlier, I mostly used synthetic chemical fertilisers in my field. After constructing a biogas plant, the availability of bio-slurry has reduced need for chemical fertiliser. This has decreased my expenses on chemical fertiliser and increased my savings."

In case of electricity producing DRETs, the users reported improvements in household savings due to reduction in expenditure on kerosene, candles, batteries and torchlights. The availability of electricity has either eliminated or reduced regular monthly spending on kerosene, candles, torchlights and lead-acid battery recharges. A business owner in Kamal Bazaar said:

"I used to spend a lot of money on candles and battery recharges. Because of lack of proper transport services, the average cost of every item including candles, kerosene and battery recharge is expensive here. Even after adjusting the regular tariff on the solar-wind micro grid, I make a good saving now."

A few dissatisfied users of solar-wind micro grid and micro-hydro however complained about costly monthly payments for their DRETs. Three percent of the surveyed solar-wind micro grid users and seven percent of the surveyed micro-hydro users mentioned that their household savings have declined because of their DRETs' costly and mandatory monthly payments. One of the dissatisfied micro-hydro users said:

"We have to pay a mandatory monthly minimum charge of NRs. 60 and extra for the usage. I think that is higher than my regular cost for kerosene and torchlights".

Similarly, another solar-wind micro grid user in Kamal Bazaar remarked:

"A monthly fixed cost of NRs.100 is costlier than my previous expenditure on candles and torchlights."

Additionally, two women focus group participants in Darna mentioned that their savings are declining because their husbands are now spending more on refrigerated alcoholic beverages after the introduction of fridges in the village. Their children also insist that their mothers spend more on cola drinks. One of the focus group participants said:

"My husband has stopped drinking locally produced cheap alcohol and instead is spending more on chilled beers. Children also want to spend more on colas. This has led to greater spending and less savings in my household."

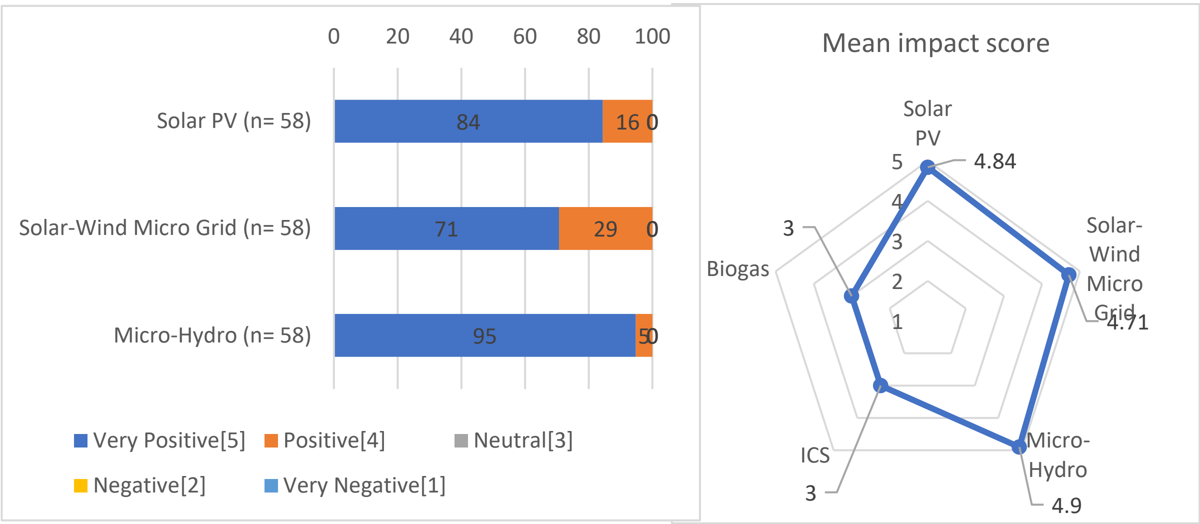
Those who complained about increased expenses on refrigerated drinks mentioned that the overall savings of households in the village could decline if the trend in purchasing beverages spreads and continues in the future.Despite opposing views by some users, a majority of survey respondents think that the benefits they get from electricity is worth the price.

7.5.4.3 Access to financial institutions

Access to financial institutions and their products such as credit is also one of the influencing factors for designing better livelihood strategies (Paudel Khatiwada et al. 2017). Bryan et al. (2015) argue that better access to credit allows households to borrow money to reduce financial risk, buffer variation in income, and increase access to technology. Thus, having better access to credit facilitates adaptation by overcoming financial barriers to adoption of adaptation options (Fenton et al. 2017).

Survey participants associated electricity producing DRETs positively with improvements in access to financial institutions and their products. Among the electricity producing DRETs, the micro-hydro users reported the highest net positive impacts ($\bar{X}$=4.9, S.D. = 0.447), followed by solar PV ($\bar{X}$=4.84, S.D. = 0.365), and solar-wind micro grid ($\bar{X}$=4.71, S.D. = 0.459) [Chi-square, P= 0.000] [Figure 7.29]. As more than 90% of the users of biogas and ICS reported neither positive nor negative impacts, their impacts on access to financial institutions have been considered neutral [Figure 7.29]

Figure 7.29 Perceived impact of DRETs on access to financial institutions



Source: Field Survey, 2018

The users of micro-hydro, solar PV and solar-wind micro grid mentioned that their DRETs have facilitated the opening of new banks, microfinance and co-operatives in their villages, which has increased their reach to formal financial institutions and their products such as loans and deposits. As stated in section 7.5.3, the micro-hydro project, which operates as a co-operative, provides savings and credit services to households. This has increased household's access to cheap credit in Darna. A micro-hydro user in Darna said:

"Earlier, borrowers faced hard time accessing credits and had to pay a high rate of interest. However, the launch of micro-hydro as a co-operative has very much changed the scene. The loans are now available much easily, without any collateral, and at a lower rate of interest. This is a big relief for poor and needy people."

Since all the households in Darna are members of the co-operative, entire village benefits from its financial services. Additionally, the availability of electricity in Darna has encouraged other financial institutions such as micro-finance to launch their operations. According to government regulations, micro-finance is a 'D' class financial institution that can provide savings and loan products in Nepal. One of the experts in Darna mentioned that two micro-finance organisations started operations after the availability of electricity increased business activities in Darna.

Apart from Darna, the availability of electricity has facilitated the establishment of financial intuitions in Kamal Bazaar. A bank and a micro-finance provide financial services based on electricity derived from solar PV and solar-wind micro grid in Kamal

Bazaar. Their services have increased community's access to cheaper and higher amount loans. One of the experts in Kamal Bazaar said:

"Until we had financial institutions in our village, getting a loan locally was expensive and difficult. Getting a higher amount in loans was even more difficult. We had to please the rich landlords. Without much choice, we were compelled to pay higher rate of interest and agree to any terms and conditions. However, with the opening of the micro-finance and bank, we can access cheaper and higher amount loans. The opening of the micro-finance and the bank have actually lowered the informal rate of lending as well."

Figure 7.30 The bank (left) and the micro-finance business (right) in Kamal Bazaar get electricity from solar PVs and solar-wind micro grid for their operation

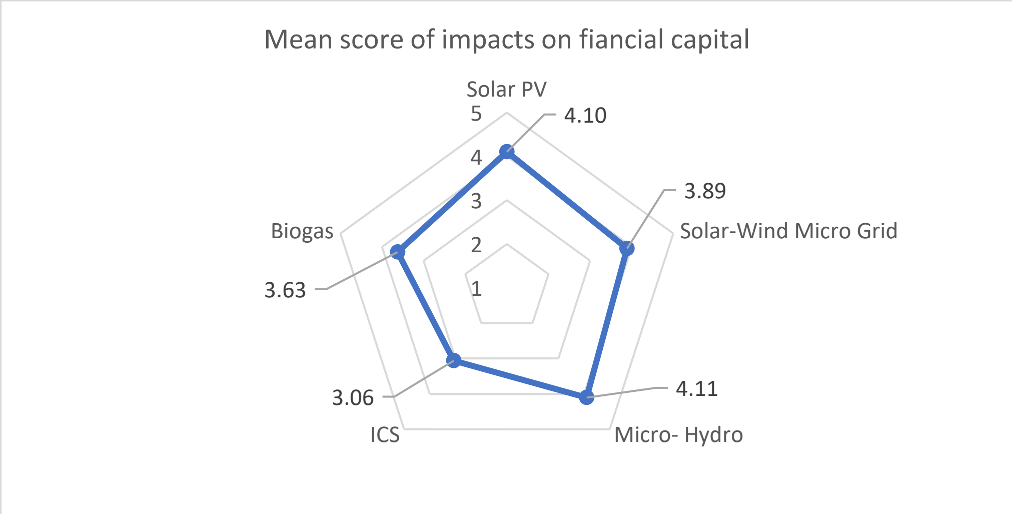
Source: Field Survey, 2018

In addition to providing deposit and loan products, bank and micro-finance provide remittance services to households in Darna and Kamal Bazaar. Remittance services allow households to collect money remotely from their relatives living and working in other parts of the country and abroad. The availability of the remittance service is especially helpful during emergencies. Focus group participants in Darna and Kamal Bazaar mentioned that the availability of loans and particularly remittance services have improved their access to funds and therefore they are less worried about managing cash during a time of crisis.

7.5.4.4 Aggregate impact of DRETs on financial capital

Overall, research participants discussed several impacts of their DRETs in improving economic productivity, household savings and access to financial institutions. After aggregating the perceived impacts, it is found that micro-hydro ($\bar{X}$=4.11) has the highest positive impacts followed by solar PV ($\bar{X}$=4.10), solar-wind micro grid ($\bar{X}$=3.89), biogas ($\bar{X}$=3.63) and ICS ($\bar{X}$=3.06) on financial capital [Figure 7.31].

Figure 7.31 Aggregate mean score of DRETs' impact on financial capital



Source: Field Survey, 2018

7.5.5 Impact on physical capital

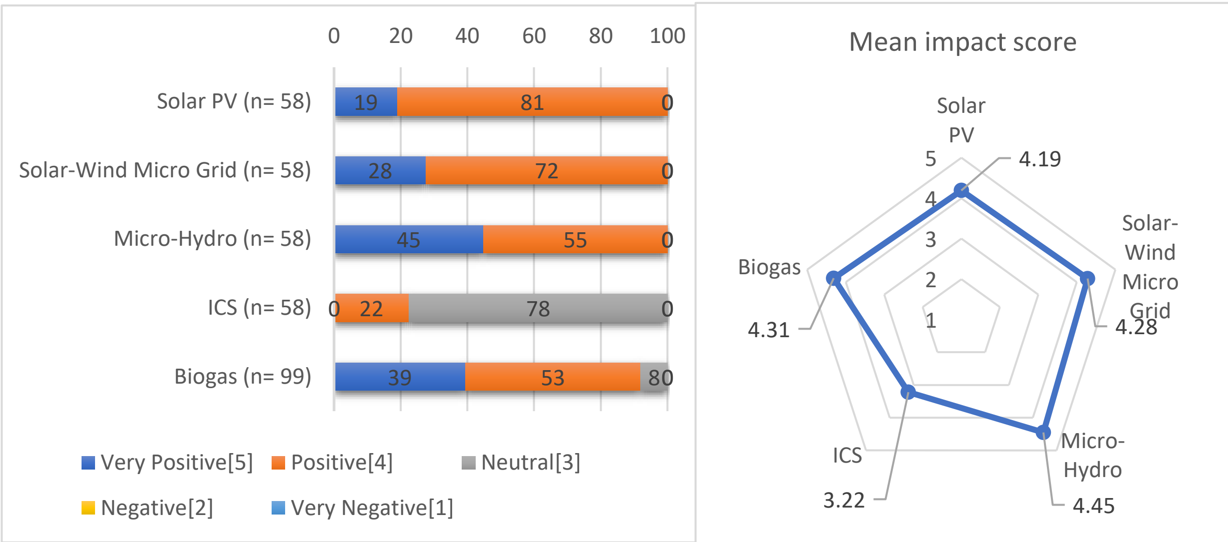
Physical capital is the set of basic infrastructure for transport, accommodation, communication, energy, water etc. that enable people to pursue their livelihoods (Burton et al. 2003). Access to reliable physical infrastructure promotes local economy and associated livelihoods (Ghosh 2017; Sahoo & Dash 2012), which further enhances the adaptive capacity of communities (Adger et al. 2007). In order to assess DRETs' impact on physical capital, this study evaluated the impact of DRETs on standard of housing and local physical infrastructure.

7.5.5.1 Standard of housing

Housing is an important part of the built environment. Modern and safe housing is essential for health, well-being, social life and economic productivity (Howden-Chapman 2004; Krieger & Higgins 2002). This study assessed the impacts of DRETs on housing standard by analysing their contribution in the adoption of modern and clean energy sources and by analysing the role of DRETs in facilitating construction of modern houses and toilets. Survey participants associated all the studied DRETs positively with the improvement in the standard of housing. Among the users of DRET, micro-hydro users reported the highest net positive impacts ($\bar{X}$=4.45, S.D. = 0.502) followed by biogas

($\bar{X}$=4.31, S.D. = 0.617), solar-wind micro grid ($\bar{X}$=4.28, S.D. = 0.451), solar PV ($\bar{X}$=4.91, S.D. = 0.395) and ICS ($\bar{X}$=3.22, S.D. = 0.421) [Chi-square, P= 0.000] [Figure 7.32].

Figure 7.32 Perceived impact of DRETs on the standard of housing



Source: Field Survey, 2018

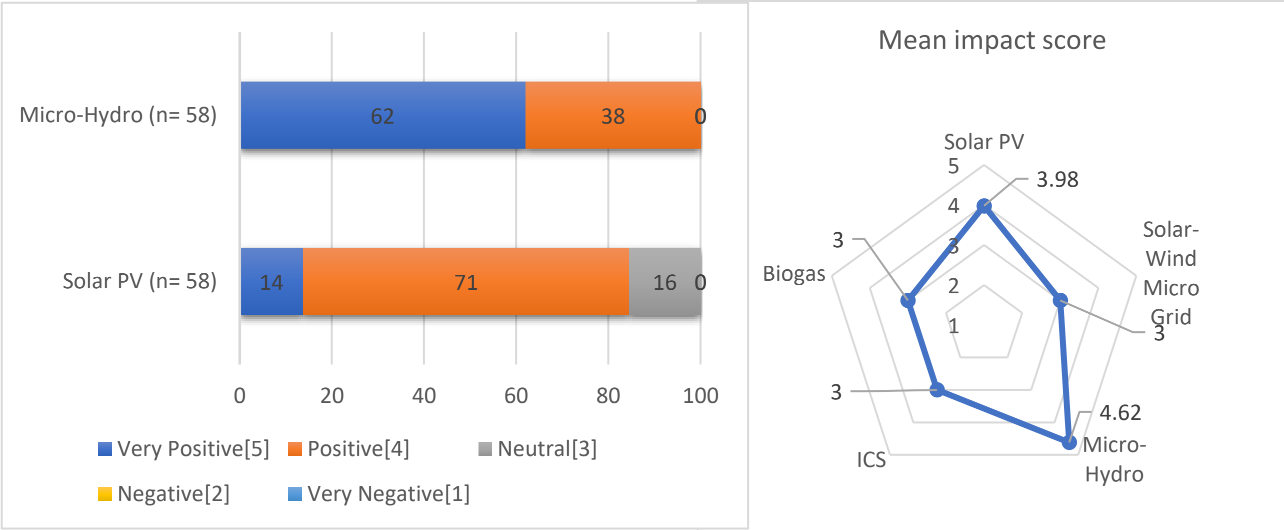
As discussed earlier in sections 7.5.1.1 and 7.5.2.1, the electricity producing DRETs have allowed households to replace rudimentary and polluting sources of lighting such as kerosene and *Jharro* lamps by electric lighting. Additionally, the availability of electricity has allowed households to use modern electrical equipment such as refrigerators, TVs, pressing irons, pumps etc. Focus group participants in Darna and Kamal Bazaar mentioned that the use of modern electrical appliances is making their life easier, and transforming their standard of living. Jha et al. (2016) also observed an improvement in the standard of living with the use of electrical appliances after the installation of micro-hydro and solar-wind micro grid in rural areas of Nepal. Biogas users mentioned that biogas contributes to better standard of housing by displacing traditional stoves and by facilitating construction of '*Pukka*' (modern) toilets. The role of biogas in displacing traditional stoves and facilitating construction of modern toilets has been already discussed in section 7.5.2.2. Like biogas, the ICS users who reported positively mentioned that ICS helps in improving housing standard by displacing traditional cooking stoves with cleaner and efficient ones (see section 7.5.2.2).

7.5.5.2 Water infrastructure

Water is our planet's lifeline (Ripl 2003). Water underpins our social and economic activity. Among the studied DRETs, only micro-hydro ($\bar{X}$=4.62, S.D. = 0.489) and solar

PV ($\bar{X}$=4.398, S.D. = 0.546) users reported net positive impacts on water infrastructure [Figure 7.33]. As more than 90% of the users of solar-wind micro grid, biogas and ICS reported neither positive nor negative impacts, their impacts on water infrastructure have been considered neutral [Figure 7.33].

Figure 7.33 Perceived impact of DRETs on water infrastructure



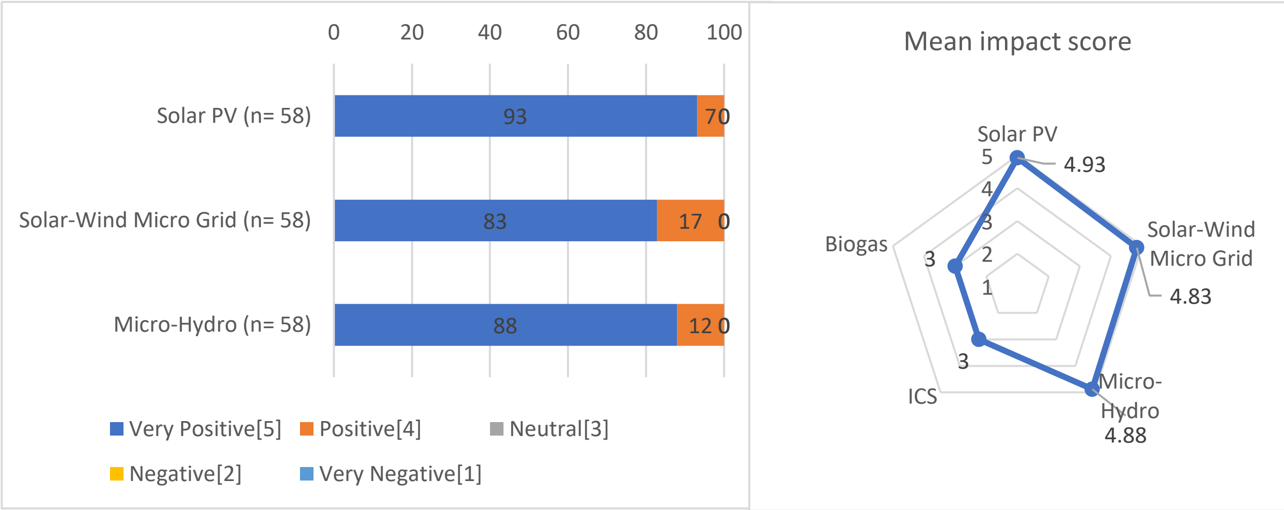
Source: Field Survey, 2018

Micro-hydro users mentioned that the construction of micro-hydro has added water related physical infrastructure such as dam, canal and embankments in their community. The construction of such infrastructure has improved water resource management and increased community's access to water resources in Darna. The micro-hydro project has facilitated irrigation and contributed to the prevention of floods and riverbank erosion in Darna (see section 7.3.2). Like micro-hydro, the users of solar PV also reported positive impacts of their DRET on water infrastructure. Solar PV users mentioned solar PV-based community drinking water project in their community as an example. The role of solar PV in improving drinking water infrastructure and addressing drinking water shortage in Kamal Bazaar has been already discussed in section 7.3.2.

7.5.5.3 Communication infrastructure

Information and communication technologies play a key role in climate adaptation by providing support to the process of information gathering, decision making, implementation and evaluation of climate adaptation activities (Ospina & Heeks 2017). Among the studied DRETs, only the users of electricity producing DRETs namely solar PV, solar-wind micro grid and micro-hydro reported net positive impacts in the improvement of communication infrastructure. The users of solar PV ($\bar{X}$=4.93, S.D. = 0.256), micro-hydro ($\bar{X}$=4.88, S.D. = 0.329), and solar-wind micro grid ($\bar{X}$=4.83, S.D. = 0.381) reported a similar level of impacts [Chi-square, P= 0.000] [Figure 7.34]. As more than 90% of the users of biogas and ICS reported neither positive nor negative impacts, their impacts on communication infrastructure have been considered neutral [Figure 7.34].

Figure 7.34 Perceived impact of DRETs on communication infrastructure



Source: Field Survey, 2018

The users of the electricity producing DRETs mentioned that the electricity derived from their DRETs has allowed the operation of telecom and internet services in their communities and has enabled them to operate devices such as mobile phones, TV, radios, and computers in their households. In Kamal Bazaar, two telecom operators (namely Nepal Telecom and Smart Cell) and one internet service provider company (World Link) provide telephone and internet services based on the power derived from solar PVs. Similarly, in Darna, the telecom infrastructure operates on electricity derived from micro-hydro. An expert in Kamal Bazaar mentioned that the communication infrastructure in his community got a great boost after solar PV and solar-wind micro grid were introduced. The expert said:

"Earlier, only few rich households had radios that operated on bulky batteries. Introduction of solar PV has increased household's access electricity operated radio devices. Few households even have TVs. Telecom companies provide mobile and internet services. Since their services operate on electricity derived from solar PV and solar-wind micro grid, we can attribute the development of communication infrastructure in our community to solar PV and solar-wind micro grid."

Similarly, focus group participants in Darna linked the improvements in communication infrastructure with the micro-hydro project. Like telephone and internet operators, individuals rely on electricity from solar PV, solar-wind micro grid and micro-hydro to operate their phones, radios and TVs. The role of electricity producing DRETs in facilitating better communication in Darna and Kamal Bazaar has been already discussed in section 7.3.3 of this chapter.

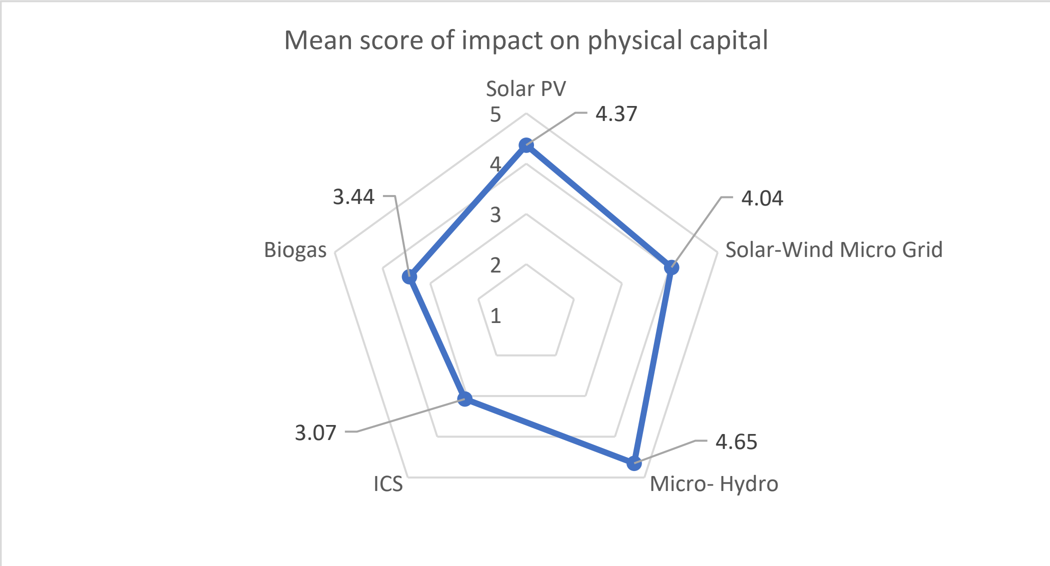
Figure 7.35 Internet and satellite TV receiver (left) in Kamal Bazaar and people watching TV (right) in Darna

Source: Field Survey, 2018

7.5.5.4 Aggregate impact of DRETs on physical capital

Overall, research participants reported several impacts of their DRETs on standard of housing, water infrastructure and communication infrastructure. After aggregating the perceived impacts, it is found that micro-hydro ($\bar{X}$=4.65) has the highest net positive impact followed by solar PV ($\bar{X}$=4.37), solar-wind micro grid ($\bar{X}$=4.04), biogas ($\bar{X}$=3.44) and ICS ($\bar{X}$=3.07) on physical capital [Figure 7.36].

Figure 7.36 Aggregate mean score of DRETs' impact on physical capital



Source: Field Survey, 2018

7.6 Overall impact on livelihood capitals

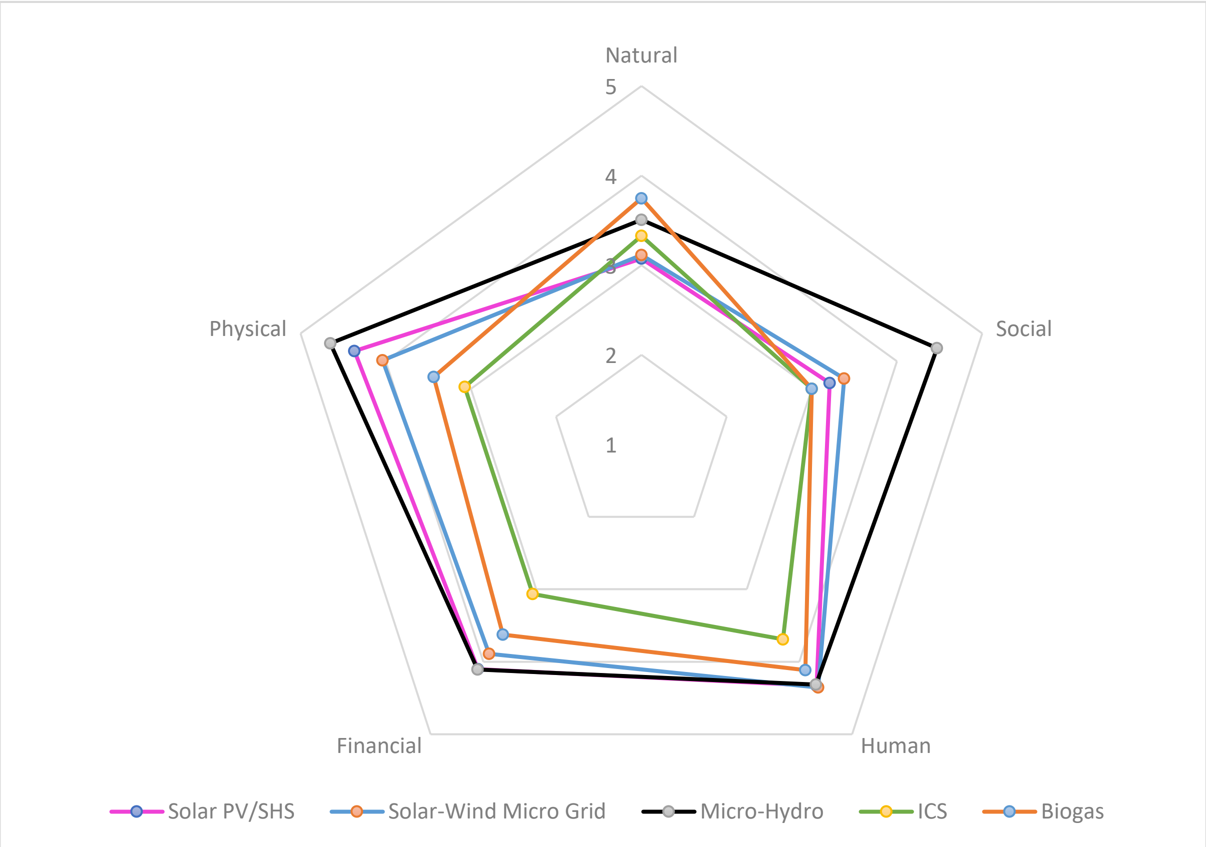
Based on the mean impact score, among the studied DRETs, micro-hydro ($\bar{X}$=4.21) has the highest aggregate impact on livelihood capitals followed by solar PV ($\bar{X}$=3.82), solar-wind micro grid ($\bar{X}$=3.76), biogas ($\bar{X}$=3.59) and ICS ($\bar{X}$=3.23) [Table 7.2, Figure: 7.37]. In case of micro-hydro, the highest impact is on physical capital ($\bar{X}$=4.65), followed by social capital ($\bar{X}$=4.47), human capital ($\bar{X}$=4.32), financial capital ($\bar{X}$=4.11) and natural capital ($\bar{X}$=3.51). In case of solar PV, the highest impact is on physical capital ($\bar{X}$=4.37) followed by human capital ($\bar{X}$=4.33), financial capital ($\bar{X}$=4.10), social capital ($\bar{X}$=3.21) and natural capital ($\bar{X}$=3.07). In case of solar-wind micro grid, the highest impact is on human capital ($\bar{X}$=4.36), followed by physical capital ($\bar{X}$=4.04), financial capital ($\bar{X}$=3.89), social capital ($\bar{X}$=3.38) and natural capital ($\bar{X}$=3.11). In case of biogas, the highest impact is on human capital ($\bar{X}$=4.12), followed by natural capital ($\bar{X}$=3.75), financial capital ($\bar{X}$=3.63), physical capital ($\bar{X}$=3.44) and neutral impacts on social capital ($\bar{X}$=3). In case of ICS, the highest impact is on human capital ($\bar{X}$=3.69), followed by natural capital ($\bar{X}$=3.33), physical capital ($\bar{X}$=3.07), financial capital ($\bar{X}$=3.06) and social capital ($\bar{X}$=3). Among the livelihood capitals, the combined impact of the studied DRETs is highest on human capital ($\bar{X}$=4.16), followed by physical capital ($\bar{X}$=3.91), financial capital ($\bar{X}$=3.76), social capital ($\bar{X}$=3.41) and natural capital ($\bar{X}$=3.35) [Table 7.2, Figure: 7.37].

Table 7.2 Mean score of DRETs' impacts on livelihood capitals

	Natural Capital	Social Capital	Human Capital	Financial Capital	Physical Capital	Total
Solar PV	3.07	3.21	4.33	4.10	4.37	**3.82**
Solar-wind micro grid	3.11	3.38	4.36	3.89	4.04	**3.76**
Micro-hydro	3.51	4.47	4.32	4.11	4.65	**4.21**
ICS	3.33	3	3.69	3.06	3.07	**3.23**
Biogas	3.75	3	4.12	3.63	3.44	**3.59**
Total	**3.35**	**3.41**	**4.16**	**3.76**	**3.91**	

Source: Field Survey, 2018

Figure 7.37 Mean score of DRETs' impacts on livelihood capitals



Source: Field Survey, 2018

7.7 Conclusion

This chapter discussed the climate adaptation benefits of DRETs in the study sites. In doing so, the chapter provided a detailed account of the direct and indirect climate adaptation benefits of DRETs.

The direct climate adaptation benefits discussed DRETs' direct contributions in addressing the observed environmental changes and their associated impacts in the study areas. For example, the electricity producing DRETs such as solar PV, solar-wind micro grid and micro-hydro have enabled households to use electric fans and refrigerators to deal with increasing temperatures. The micro-hydro project in Darna has facilitated irrigation, which helps households to deal with uncertain monsoon and declining water availability. A solar PV based project in Kamal Bazaar has addressed drinking water shortages by supplying electricity to pump water from distant sources. A solar PV-based weather monitoring system provides early warning for extreme weather events in Kamal Bazaar, which helps households to prepare for disasters. Additionally, the communication infrastructure, which is very vital for disaster management and during the time of crisis, operates on solar PV, solar-wind micro grid and micro-hydro in Darna and Kamal Bazaar. Electricity from DRETs have improved the provision of medical services, vaccines and medicines at health facilities in Darna and Kamal Bazaar, which according to research participants are important to deal with increasing health related problems in their community. Overall, the chapter discussed several examples of DRETs' direct engagement in addressing the problems of increasing temperatures, uncertain monsoon and declining water availability, disasters, human health and agriculture in the study areas.

The chapter further discussed the indirect climate adaptation benefits of DRETs by evaluating the impacts of DRETs on livelihood capitals. Survey results show that DRETs generally have positive impacts on livelihood capitals. Those who reported positively mentioned that their DRETs improve the stock of natural capital by contributing to protecting forest, conserving water resources, and improving soil quality; contribute to the improvement of social capital by facilitating an increase in community collaboration, social gatherings, bonding, collective actions, trust and confidence amongst each other; and improve human capital by contributing to the improvement of health, sanitation, education and skills. Similarly, DRETs contribute to the improvement of financial capital by maximising economic productivity, increasing household savings and by improving access to financial institutions; and improve physical capital by facilitating the development of water infrastructure, communication infrastructure and by improving housing standard in the study areas. A few survey respondents reported negative impacts such as decline in household savings due to costly monthly payments for DRETs and felling of trees for the construction of micro-hydro and distribution lines.

Overall, the findings of this study confirm that, although not primarily designed for climate adaptation, DRETs contribute to reducing climate vulnerability by directly addressing climate and by improving socio-economic factors of vulnerability. The next chapter discusses the implications of this research in relation to climate change, sustainable energy planning and climate-resilient development.

8 The role of decentralised renewable energy technologies (DRETs) for sustainable development in a changing climate

8.1 Introduction

This study has revealed the complexity of climate change impacts upon the climate sensitive livelihood systems of rural communities in the mountains of Nepal and has highlighted the role of DRETs in reducing vulnerability to those impacts. The findings of this study have a range of important implications for theory, policy and practice in relation to sustainable energy planning, climate change and climate-resilient development in Nepal and other developing countries, which will be elaborated in detail in this chapter.

8.2 Contribution to knowledge on livelihood systems, climate change, and vulnerability in the Nepali mountains

This research has contributed to the expansion of knowledge on climate change, livelihood systems and vulnerability in rural mountain communities. Communities in the Nepali mountains are experiencing significant climatic change. The statistical analysis of the climate data collected from meteorological stations close to study sites indicates a warming and a declining precipitation trend [see section 5.3.1 and 5.3.2]. The warming and declining precipitation trend suggested by the statistical analysis are consistent with local perceptions at the study sites [see section 5.4.2 and 5.4.3]. Further, the statistical analysis of national monsoon onset and withdrawal data indicates a high inter-annual variability with a trend towards delay, which is also consistent with local perceptions at the study sites [see sections 5.3.3 and 5.4.4]. These findings ascertain that the climatic changes are increasingly becoming evident in the mountains of Nepal as have been argued by other scholars (DHM 2017; Khatiwada et al. 2016; Krishnan et al. 2019; Nogués-Bravo et al. 2007; Pandey & Bardsley 2015; Salinger et al. 2014; Shrestha et al. 2019).

The observed climatic changes in the study sites were linked to a broad range of impacts such as hot summer days and nights, declining water availability and increasingly erratic monsoon onset and withdrawal. Additionally, research participants noted increases in invasive species, increases in insect pests, changes in flowering, fruiting and relocation of species, and changes in the frequency of natural hazards in their region. Such environmental changes are having profound impacts on local lifestyles, production systems and livelihoods [see section 5.5].

The evaluation of the livelihood systems shows that local livelihoods are heavily reliant on natural environments. For example, agriculture, which is the most common primary occupation in the study sites, is still predominantly rain fed, and the majority of households in the study sites are still reliant on local forests for the supply of firewood. The heavy reliance on the natural environments make households in the study sites vulnerable to the changes in their local environments. For instance, households that rely on rain-fed agriculture face major disruptions in their pattern of seasonal labour migration to India due to an increasingly erratic monsoon. This disruption results in the loss of crucial cash income for many households. In Kamal Bazaar, where households rely on local springs, the households are facing severe shortage of water for drinking and household uses due to declining water availability because of reduced rainfall, reduced snowfall and earlier melting of snow. Similarly, the increase in invasive plant species such as *Lantana camara* and *Ageratina adenophora* have resulted in substantial loss of forage and pasture for cattle and loss of non-timber forest products such as fruits, berries, mushrooms and medicinal plants for households in the study sites. These examples show that, as argued at the beginning of this thesis [section 2.2.2], poor communities and particularly those in developing countries, which rely heavily on primary sectors such as fishery, forestry, and agriculture are hit harder due to climate change (Adger et al. 2003; Gentle & Maraseni 2012; Gentle et al. 2014; IPCC 2014b; Islam & Winkel 2017; Skoufias 2012). Similar to the findings by this research, Pandey and Bardsley (2015) note that agro-based livelihood systems in Nepali mountains that rely highly on exploiting natural resources such as land, forests, water or pastures for their livelihoods are generally more vulnerable to climatic variability and change.

While the local livelihoods are at risk, local communities are not effectively equipped to deal with such changes. For example, farmers in the study sites mentioned that they do not have any tangible plan to deal with increasing invasive species, insect pests and variability in monsoon arrival and withdrawal. Although few coping measures such as reduced and efficient water usage to deal with declining drinking water availability and adjusting crop calendar to deal with uncertain monsoon are being practiced, such measures alone are not enough. Gentle and Maraseni (2012) also note that limited household efforts are not enough in adapting with the climate change impacts in the Nepali mountain communities.

Additionally, poor physical infrastructure and the lack of resources [see chapter 4] limit households' ability to deal and adapt to the changes observed in the study sites. For example, although rivers and springs located below the settlements of Kamal Bazaar could address local water shortage problems, the community does not have enough financial and technical resources to design and implement such projects. One such donor-funded project is already present, however, the lack of financial resources for repairing the technology has left the project in ruins. Poor transport infrastructure in the study sites, particularly in Kamal Bazaar and Darna remarkably increases the cost and challenges of building climate adaptation projects. Additionally, the lack of adult and skilled workforce in the study sites hinders the design and implementation of climate adaptation actions. At the household level, the lower level of education, lack of skills, poor savings and poor access to credit prevent families from diversifying their livelihoods and investing in new adaptation measures.

Overall, the findings of this study show that the increasing climatic and environmental changes, heavy dependence of local livelihoods on natural environments, and limited capacity to deal with the changes have together contributed to a high vulnerability in the study areas. Gentle and Maraseni (2012) and Pandey and Bardsley (2015) have also noted higher climate change vulnerability in the Nepali mountains. The higher levels of vulnerability with limited economic, technical and human capacities, thus indicate a greater need for adaptation in the Nepali mountain communities (Gentle & Maraseni 2012; Gentle et al. 2014; Pandey & Bardsley 2015).

8.3 DRETs for sustainable energy planning

The case studies of five DRETs: solar PV, solar-wind micro grid, micro-hydro, ICS and biogas, presented in this research show that DRETs could be very effective in providing modern and clean energy access in remote mountain communities. For example, the remote communities of Kamal Bazaar and Darna were previously reliant on poorly illuminated and polluting sources of light such as *'Jharro'* and kerosene lamps for lighting in the absence of electricity. Households there could not utilise diesel-based generators for electricity because of the higher operating cost and challenges in procuring diesel due to poor transport infrastructure. However, electricity producing DRETs such as solar PVs and a solar-wind micro grid project in Kamal Bazaar and the micro-hydro project in Darna are now providing affordable electricity to households. In Sunder Bazaar, biogas plants have displaced firewood and are providing an inexpensive and cleaner substitute for kitchen fuel. In Darna, improved cooking stoves have reduced firewood demand and indoor pollution in kitchens.

The availability of electricity and cleaner cooking fuel in these communities has several socio-economic and ecological advantages, which have further improved living standards and local livelihoods [see section 7.5]. These examples demonstrate that DRETs can be very effective for energy access, particularly for isolated communities in remote regions (Mainali & Silveira 2012; Oyedepo et al. 2018; Sharma 2018; Thompson 2017). Globally, there are still around 860 million people without access to electricity and around 2.6 billion people without access to clean cooking fuel (IEA 2019b). Most of this population lives in remote regions in poor countries, where the extension of the centralised energy distribution system is challenging due to underlying challenges such as high costs of supply to remote areas, lack of power generation capacity, poor transmission and distribution infrastructure and the lack of affordability (Parajuli 2011; Thompson 2017; World Bank 2018a). For those off-grid communities, the role of DRETs in providing energy access and achieving United Nation's Sustainable Development Goal (SDG 7) of "ensuring access to affordable, reliable, sustainable and modern energy for all" (UNDP 2015) could be vital.

In addition to access, it was observed that DRETs offer advantages of autonomy, reliability and energy independence through the use of locally available energy sources. In a centralised energy distribution system, where all the consumers are reliant on a single centralised infrastructure, disturbance in any part of the production or distribution infrastructure disrupts the flow of energy supply to everyone. For example, any interruption in the supply of coal, diesel or natural gas to a power plant can disrupt power supply to thousands of homes connected to the single plant. In addition, any damage to the transmission and distribution infrastructure due to natural disasters such as cyclones, floods or landslide can again disrupt electricity and fuel supply to number of cities and millions of residents. Disruption to electricity and petroleum supplies during the 2015 earthquake in Nepal is one such example. The centralised energy distribution system is also vulnerable to geopolitical manoeuvres. For example, an unofficial economic blockade in 2015 led to an acute shortage of petroleum products in Nepal. Another, critical disadvantage in a centralised energy distribution system is that the most important stakeholder or consumers generally have a little say or no control in the functioning of the system. The national electricity grid connected households in Sunder Bazaar reported that despite having a major hydropower plant located in their locality, they have no control over the operation of the hydropower plant.

DRETs on the other hand rightly address such issues of agency in decision-making. DRETs as the name indicates, are decentralised, small-scale renewable energy production units, located close to the point of consumption (Vezzoli et al. 2018). Since DRETs are based on locally available renewable energy sources, DRETs are normally immune to external shocks and disturbances. For example, the biogas users in Sunder Bazaar reported little or no impact during the earthquake and fuel crisis in 2015, when other households reliant on kerosene and LPG struggled to obtain cooking fuel for their kitchen. Hussain et al. (2019) and Vezzoli et al. (2018) note that DRETs in remote regions have shown themselves to be more reliable and resilient than the centralised system of energy distribution. The decentralised nature of DRETs offers greater autonomy over the control and functioning of the energy systems, which often empowers and benefits users. As it was observed in Darna, every consumer is a part owner based on the co-operative model of the micro-hydro project, who elect the micro-hydro management committee. The committee has a full control over the operation of the project, and such an arrangement has enabled the community of Darna to avoid load shedding when the national electricity grid connected households in the other parts of the country were facing up to 16 hours of load shedding a day. Additionally, the successful management of the micro-hydro project has earned additional income for the community by selling excess electricity to a nearby village. Like micro-hydro, other studied DRETs also offer full autonomy to the user households and community. Dhakal et al. (2019) has suggested community based DRETs as an important measure to maximise autonomy and energy independence in the mountains of the HKH region. These examples together suggest that DRET-based local energy systems offer greater autonomy, resilience and independence in comparison to the centralised energy distribution systems.

The advantages discussed above clearly indicate DRETs as a better alternative for the expansion of energy services. The dominant approach for energy access however, has generally focused on the extension of fossil fuel based centralised energy distribution system (Levin & Thomas 2016). In the light of changing climate and increasing calls for sustainable development outcomes, such an energy development approach needs a critical re-thinking. Scholars argue that energy development pathways should also focus on ecological, social, cultural, political, and behavioural factors, while emphasising on significant societal goals such as wellbeing improvement and environmental sustainability (Broto et al. 2017; Fankhauser & Jotzo 2018; Sovacool 2014; Sovacool et al. 2016). Sustainability experts are recommending a shift from conventional, top-down energy development models to sustainable, low-carbon and self–sufficient energy systems (Bhattacharyya 2007; Goldthau 2014; Johansson & Goldemberg 2002; Klein 2015; Nepal & Jamasb 2012; Sen et al. 2016; Sovacool et al. 2016; Vezzoli et al. 2018). In such a scenario, this research has added to the increasing set of evidences that renewable energy technologies in general, and DRETs in particular offer for sustainable energy planning. It is expected that the findings of this research will encourage a greater uptake of DRETs, which has the potential to bring a paradigm shift in the energy sector not only in Nepal, but also in other countries looking to avoid the constraints and mistakes of the conventional, dominant, fossil fuel based energy development model.

8.4 DRETs as a tool for climate change adaptation

Policy makers generally view small-scale DRETs only in terms of a tool for energy access and poverty alleviation (Ley 2012). In Nepal, the national renewable energy policy introduced in 2006 promotes DRETs explicitly for energy access (AEPC 2016; Steinbach et al. 2015), and falls short of acknowledging other potential advantages. While the mitigation benefits are clear, the case for DRETs as effective measures for adaptation is less obvious (Perera et al. 2015; Venema & Rehman 2007). In such a context, the findings from this study have offered a greater understanding of the multiple benefits offered by renewable energy technologies in general and DRETs in particular. This study has shown that DRETs contribute to climate adaptation by directly addressing climate risks and by improving the socio-economic drivers of vulnerability [see chapter 7].

The study offers empirical evidence, which should encourage policy makers and practitioners to acknowledge, promote and upscale DRETs as an effective climate change adaptation tool in the future. Additionally, the suitability of DRETs as an effective climate adaptation tool can open up new avenues of funding. Currently, DRET projects in Nepal receive donor funding primarily for their role in improving energy access (AEPC 2018; Steinbach et al. 2015). The global funding for climate action is expected to increase. For example, Article 9 of the Paris agreement 2015 has committed to mobilize $100 billion a year in climate action by 2020, and agreed to continue mobilizing finance at the level of $100 billion a year until 2025 (UNFCCC 2015). The findings of this research puts DRETs on a spotlight for such funding as this study has demonstrated that DRETs not only address energy access and climate mitigation, but also support climate adaptation in rural communities.

Further, this study has important implications for arguments that seek to re-evaluate adaptation framed within current development paradigms (Eriksen et al. 2015). Development practitioners have generally focused in addressing specific impacts rather than building capacities to adapt and transform (Ensor et al. 2015). Traditionally, adaptation interventions have tended to focus directly on climate impacts, while overlooking the underlying causes of vulnerability that are linked to social structures, the distribution of power, economic relations and access to resources (Eriksen et al. 2015; Vincent et al. 2013). Even at present, engineered and technological adaptation options remain the most common adaptive responses (Noble et al. 2014). However, policy makers need to understand that adaptation is much more than merely a response to a negative condition (Wilk et al. 2015). Bardsley and Wiseman (2016) argue that any effective intervention to deal with socio-ecological challenges in the Anthropocene needs to extend beyond direct interventions targeting particular climate change impacts. The climate adaptation approaches suggested by Eriksen and O'Brien (2007) and McGray et al. (2007) also indicate that adaptation measures can and should extend beyond addressing climate risk alone. In such a context, the outcome of this research shows that DRETs offer climate adaptation opportunities beyond specific impact-focused technological interventions. DRETs are development tools primarily aimed at energy access and poverty alleviation in rural areas, and although they are not primarily designed or targeted to reduce climate risks, they still contribute to climate adaptation. Thus, this research firmly supports the argument that climate adaptation measures can extend beyond addressing specific climate impacts. Additionally, the outcome of this research positions DRETs as an appropriate development tool to integrate goals for sustainable outcomes.

8.5 DRETs for climate-resilient development

Development and climate change are inter-linked with a reciprocal and circular relationships between the two (Downing et al. 2003; Huq et al. 2006; Munasinghe & Swart 2005). The nature of development actions and their related GHG emissions determine the magnitude of climate change and the capacity of communities to mitigate and adapt to climate change in the future (Downing et al. 2003; Olsson et al. 2014b). The current dominant fossil-fuel-based global development pathways driven by the desire for rapid economic growth are likely to fuel the dynamics of vulnerability over time (IPCC 2014b). The critical question therefore is, will the current development paradigm prepare us for adaptation in future that generates vulnerability in the first place? The development as usual approach is not enough (Eriksen et al. 2015). A new climate-resilient approach, which integrates climate concerns, while addressing the developmental needs in order to realise the goal of sustainable development is essential (Denton et al. 2014; Roy et al. 2018). In such a context, the outcome of this research has added to the increasing evidence of opportunities that renewable energy technologies and DRETs in particular offer for climate resilient development.

A well-designed DRET project offers a triple dividend by addressing developmental needs, while supporting climate change mitigation and adaptation. Given that energy deprivation is increasingly considered a root cause of under-development and eco-system degradation, energy access lies at the core of the sustainable development goals (IEA 2018a). The potential of DRETs in addressing global energy access and promoting sustainable development is discussed in section 8.3. The climate mitigation benefit of DRETs is well established and in-fact, renewable energy technologies are at the core of the global climate mitigation efforts (IRENA 2019). The case for DRETs as effective measures for climate adaptation, however is less obvious (Perera et al. 2015; Venema & Rehman 2007); which this research has now addressed. This research has shown that DRETs support climate adaptation by directly addressing climate risks and by improving socio-economic drivers of vulnerability [see chapter 7]. The role of solar PV in addressing drinking water shortages and minimising disaster losses through early warning system and the role of the micro-hydro project in addressing an increasingly erratic monsoon by facilitating irrigation offer few examples of how DRETs can reduce climate change vulnerability by directly addressing climate risks. Similarly, DRETs' role in improving economic productivity, social trust, management of local forest, services at local health facilities etc. show how DRETs can contribute to climate adaptation by improving socio-economic drivers of vulnerability. Thus, this research supplements the increasing set of evidence to demonstrate DRETs as an important driver of climate resilient development.

In section 2.2.3, the difficult choice for governments and especially for developing countries in achieving higher economic growth while simultaneously addressing the problem of climate change was identified as one of the major challenges in mainstreaming climate change with development (Robinson 2019). In addressing energy requirements of a nation, governments are often faced with difficult choices of either conventional fossil fuels or renewables based energy generation systems. This research positions DRETs as an appropriate choice for such situations, particularly in the context of remote communities such as those in mountains and deserts; as with DRETs, governments can achieve development goals while simultaneously addressing climate mitigation and climate adaptation. DRETs - a simple and affordable technology, therefore, offer an excellent option for countries looking forward to generate climate resilient solutions to address energy access and development in remote off-grid communities. Moreover, the popularity of DRETs reflected by the level of satisfaction [see Chapter six] in the study sites indicate that governments can easily roll out DRET projects with possibly no opposition from local communities in the remote regions. The level of satisfaction for different DRETs however is not uniform, therefore the level of acceptance for different DRETs might differ. Among the studied DRETs, the popularity of micro-hydro was found to be highest, followed by biogas, solar PV, solar-wind micro grid and ICS.

8.6 Limitation of decentralised renewable energy technologies

In spite of multiple advantages for sustainable energy planning and climate resilient development, a few limitations of DRETs have been identified. Research participants noted intermittency, scale and reliability of DRETs as major shortcomings. In Kamal Bazaar, solar PV and solar-wind micro grid users expressed dissatisfaction about uncertainty of power availability during foggy, cloudy and rainy days. The users also complained about the inability to use electrical appliances of their choice such as TVs and refrigerators, and the lack of consistent supply because of limited capacity of their DRETs [see chapter 6]. The ICS users in Darna complained about the inability of ICS to warm the kitchen space and to roast food items as can be done with traditional stoves. The biogas users in Sunder Bazaar expressed dissatisfaction about the inability to use chemicals for cleaning biogas-connected toilets and about decreasing availability of dung to operate biogas plants. The shortcomings in relation to intermittency and reliability of decentralised renewable energy technologies have been acknowledged by other studies as well (Elliott 2007; Ghimire & Kim 2018; Yaqoot et al. 2016). While the reported shortcomings certainly caused inconvenience for users, it should be noted that, with increased global funding, research and interest in renewable energy technologies, such limitations are expected to be gradually addressed in the future (Fares 2015; Gaw 2019; Jacobson et al. 2015; Kline 2018; Maïzi et al. 2018; Yaqoot et al. 2016).

Another important observation was the high subsidy-led adoption of DRETs in the study sites. Every DRET studied received some level of installation subsidy [see chapter 6]. The subsidy in itself is not counter-productive, however, it raises questions about the long-term sustainability of DRETs’ uptake in Nepal, where DRET promotion programs are mostly donor funded [see (AEPC 2018)]. What happens once the donor funding dries up? Will the poor households and communities continue to adopt and service DRETs without any ongoing support? The cases of the donor-funded solar PV drinking water project and solar-wind micro grid project in Kamal Bazaar, both waiting external funding for repairs within the first year of operation shows that such a funding model may not be always sustainable. In order to address this issue, it may be necessary to rethink the current donor-funded, subsidy-led DRET promotion model. A transformation towards a market-based and credit-supported model could be a way forward. Mainali and Silveira (2011) have argued proper access to credit is an important requirement for sustainable DRET growth for rural electrification in Nepal. The successful case of Grameen Shakti micro-credit program for solar home system distribution in Bangladesh also indicates market-based credit lending as an appropriate financing model for sustainable uptake of DRETs (Khandker et al. 2014). In this direction, the government of Nepal has made attempts through the 'Renewable Energy Subsidy Policy and Subsidy Delivery Mechanism (2016)', which aims to gradually reduce and readjust the level of subsidy over time to shift support to a lending credit model (AEPC 2018). There is a need to expedite the implementation of such reforms to ensure long-term sustainability of DRETs uptake in rural areas.

Finally, another critical observation has been about support in the operation and management of community level DRET projects. It was observed that regular follow-up and support in the operation by project developers such as AEPC are vital for the success of such projects. Often, community members in rural areas are not equipped with skills and experience to operate and manage community level DRET projects. Capital funding alone will not always deliver the desired result. The case of the non-functional solar PV based drinking water project and the semi-operational solar-wind micro grid project in Kamal Bazaar demonstrate that despite massive initial investments, the lack of monitoring and support from the builders of the projects can result in poor and unexpected local results [see section 6.2]. On the other hand, consistent follow-up and assistance from AEPC to enable the timely overhaul of the governance and operation model of the micro-hydro project in Darna have enabled the project to exceed its primary goal [see section 6.3.1]. It is therefore very important for community level DRET project planners to not disconnect from the project immediately after its inauguration and rather continue to follow up on the progress and provide support as needed for long term sustainability of the project.

8.7 Conclusion

Overall, this chapter discussed the implications of this research on policy and practice in relation to climate change, sustainable energy planning and climate-resilient development in Nepal and other developing countries. In the context of changing climate and high vulnerability in remote off-grid communities, the findings of this research position DRETs as an effective development tool for sustainable energy planning and climate-resilient development outcomes in Nepal and elsewhere. The next chapter concludes the thesis by synthesising the key findings and summarising the contributions of this research.

9 Conclusion

9.1 Introduction

The aim of this study was to evaluate climate adaptation benefits of DRETs in rural mountain communities in Nepal. The evaluation of the climate adaptation benefits is based on primary data collected through a questionnaire survey of 331 households, 9 focus group discussions and 20 in-depth interviews with local and national experts. Secondary data such as weather records, census records and government documents provided additional input to the analysis. The evaluation found that DRETs provide direct and indirect benefits in reducing climate vulnerability in the case study areas.

This chapter concludes the study in three main sections. The first section summarises the key findings. The second section discusses the contributions of this research. The third section discusses the areas for future research. The chapter ends with a concluding remark.

9.2 Key findings of the study

This study was driven by inquiries into five main research questions. This section provides an overview of the key findings related to each of the five research questions.

9.2.1 What is the status of local livelihoods in the case study areas?

Chapter four provided a detail description of livelihood systems in the study sites. The analysis of the livelihood systems was based on the assessment of five livelihood capitals. In addition to presenting information about livelihood capitals, a comparison between study sites was made, where possible.

In order to assess natural capital, the study analysed the status of land possession and access to forest resources. Every surveyed households possessed land, with 5-10 ropanis being the most common land holding size. Similarly, every surveyed households reported access to forest. For human capital, the proportion of economically active population at individual study sites, the highest level of education in households and access to education and health services in the community were analysed. The share of the economically active population in Darna, Kamal Bazaar and Sunder Bazaar was 57.8%, 54.5% and 54% respectively. The literacy rate was 57.7%, 59.5% and 70.7% in Darna, Kamal Bazaar and

Sunder Bazaar respectively. Sunder Bazaar had the highest number of households with university degrees. For social capital, ethnic or caste make up and the presence of community-based organisation in the study sites were analysed. Darna had the highest ethnic homogeneity followed by Kamal Bazaar and Sunder Bazaar. Similarly, Darna also had the highest number of community-based organisations followed by Kamal Bazaar and Sunder Bazaar. For financial capital, households' primary occupation, annual income and access to financial institutions were analysed. Crop-livestock agriculture was reported as the most common primary occupation followed by business, wage labour and overseas migration. The average annual household income was highest for Sunder Bazaar (NRs.166, 426) followed by Kamal Bazaar (NRs. 131,586) and Darna (NRs. 124,323). Sunder Bazaar had the highest number of registered financial institutions followed by Kamal Bazaar and Darna. For physical capital, the status of local transport infrastructure, communication infrastructure, housing and toilet, electricity and drinking water infrastructure were analysed. While Kamal Bazaar and Darna had poor transport facility, Sunder Bazaar had metalled roads and multiple transport options to travel to other parts of the country. Every surveyed household in the study sites had at least one mobile telephone in their household. The possession of TV and computer was highest in Sunder Bazaar and lowest in Kamal Bazar. The possession of radio was highest in Kamal Bazaar and lowest in Sunder Bazaar. In terms of houses by roof types, Sunder Bazaar had the highest share of concrete and tin roofs followed by Kamal Bazaar and Darna. Every surveyed households in the study sites had a toilet. In every study sites, survey respondents reported tap or piped water as the most common source of drinking water followed by springs and river. Electricity was available in all three study sites, however, the supply of electricity in the study sites was not uniform.

Overall, the analysis of livelihood system shows that local livelihoods are made up of complex combination of ecological and socio-economic factors.

9.2.2 What is the extent of change in key climatic parameters in the case study areas? How are locals perceiving climatic trends and experiencing the impacts of environmental change on their livelihoods?

Chapter five presented a detailed description of changes in key climatic parameters such as temperatures and precipitation and its impacts on local livelihoods in the case study areas. The statistical analysis of climate data and local perceptions at the study sites indicate a warming and a declining precipitation trend [see section 5.3.1, 5.3.2, 5.4.2, and 5.4.3]. The analysis of the monsoon arrival and withdrawal data indicates a high inter-annual variability with a trend towards delay, which is also consistent with local perceptions [see section 5.3.3 and 5.4.4].

Increasing temperatures, increases in invasive species, reduction in water availability, increases in insect pests, changes in flowering, fruiting and relocation of species, increasing variability in monsoon onset and withdrawal and changes in the frequency of natural hazards were identified as the major environmental changes observed in the study areas. The observed climatic and associated environmental changes have broad range of impacts on local socio-ecological systems and livelihoods. Hot days and uncomfortable nights during summer, early melting of snow leading to water scarcity during the dry season, increases in number of mosquitoes and decline in farm productivity were reported as major impacts of increasing temperatures. The decline in rainfall and water availability has led to water shortages for household and agricultural usage. Increasing variability in monsoon arrival and withdrawal affects local crop calendar, disrupts seasonal migration and causes income loss to farming households. The increase in invasive species has resulted in the decline of grazing land and forage for cattle, additional weed growth in farms, difficulty in walking through narrow trails, increase in labour input for farmers and decline in the supply of non-timber forest products. The growth in the number of insect pests have increased the cases of insect bites and food spoilage, caused more damages to crops and livestock, and increased household expenses on pesticides, insecticides and medicines. Research participants were also worried that the rise in the number of mosquitoes would increase the cases of deadly diseases such as Malaria, Kala-azar, and Chikungunya in their communities. Banana and mango trees have started yielding fruits and *Saal* trees (*Shorea robusta)* are now available at higher elevation. Both are welcoming change for households as such changes have increased the availability of banana and mango fruits and timber from *Saal* trees in the region. The occurrence of natural hazards such as landslides and hailstones have increased, which causes human injuries and death, loss of income and damages to private and public properties.

Overall, the findings show that the rural mountain communities are experiencing increasing climatic variability and changes in their environment. These changes affect socio-ecological systems and livelihoods in multiple ways, and with limited capacity to adapt, the rural mountain communities remain highly vulnerable to such changes.

9.2.3 What is the level of access to DRETs in the study sites?

Chapter six provided a detail description of DRETs present in the case study areas. The chapter introduced individual DRET and discussed in detail about their size or capacity, cost, available subsidies, their usage, operational expenses, and the level of satisfaction among the users.

Households in Kamal Bazaar have access to two electricity-producing DRETs: solar PV and solar-wind micro grid. Solar PV in individual households are called solar home system and provide 20W to 90W of power. Solar-wind micro grid provides 100W power to the grid connected household and up to 1500W power to the grid connected businesses. Apart from households, schools, banks, offices, the local telecom infrastructure, a drinking water project and a health facility among others rely on solar PV and solar-wind micro grid for electricity in Kamal Bazaar. Households in Darna have access to two DRETs: a micro-hydro and ICS. The micro-hydro project has a designed peak output capacity of 83 KW and supplies electricity to households, schools, offices, businesses and to the local telecom infrastructure in Darna. The households in Darna also have access to ICS, which helps in reducing firewood demand and indoor pollution through efficient combustion of biomass. Households in Sunder Bazaar have access to biogas technology. Four and six cubic meter were the most common size of household biogas plants in Sunder Bazaar. Biogas plants provide a convenient and economical substitute to expensive cooking fuel such as firewood, kerosene and liquefied petroleum gas through the decomposition of organic waste. Among the studied DRETs, the level of user's satisfaction was found to be highest for micro-hydro and lowest for ICS.

9.2.4 How are DRETs contributing to directly addressing climate risks and associated impacts?

The first section of chapter seven discussed the direct climate adaptation benefits of DRETs in detail. For this research, the direct contributions in addressing the environmental changes and associated impacts observed in the study sites are considered as direct climate adaptation benefits. The study found several such contributions. For example, solar PV, solar-wind micro grid and micro-hydro have helped households to deal with hotter temperatures by powering electric fans and refrigerators in Kamal Bazaar and Darna. The micro-hydro project has helped households to deal with uncertain monsoon and declining water availability by facilitating irrigation in Darna. A solar PV-based water-lifting project has addressed the problem of drinking water shortages in Kamal Bazaar by supplying electricity to pump water from distant sources. A solar PV-based weather monitoring system has been set up in Kamal Bazaar, which provides early warning to households about extreme weather events, thus allowing households to prepare early for likely disasters. In Darna and Kamal Bazaar, the communication infrastructure and devices such as TV, radio and mobile phones, which are very crucial during a time of disaster or crisis, operate on electricity supplied by solar PV, solar-wind micro grid and micro-hydro. In Sunder Bazaar, biogas plants provided a continuous supply of kitchen fuel while the supply of other fuels such as firewood, kerosene and LPG were disrupted and therefore difficult to obtain during the 2015 earthquake and 2015 fuel crisis. The electricity from DRETs have enhanced the provision of medical services, vaccines and medicines locally, which according to research participants have been vital in dealing with increasing health problems in their communities. Solar PVs have facilitated the operation of an agriculture lab and a vocational training institute in Kamal Bazaar, which produces skilled workforce locally to address the impacts of climate change on agriculture in the region.

Overall, DRETs have directly contributed in the management of many of the environmental changes observed in the study sites. The findings of this study demonstrate that DRETs, although not primarily designed to address climate change impacts, can still address climate risks and thus reduce climate change vulnerability in the DRET connected households and communities.

9.2.5 How are DRETs indirectly contributing to climate adaptation? What are DRETs contributions in the improvements of livelihoods through broader changes in ecological and socio-economic conditions?

The second section of chapter seven presented a detailed analysis of DRETs' indirect climate adaptation benefits. For this research, DRETs' contributions in the improvements of livelihood capitals (Carney 1998; DFID 1999) through broader changes in ecological and socio-economic conditions are considered as indirect climate adaptation benefits. Except in a few cases, research participants generally reported positive impacts of DRETs on livelihood capitals.

DRETs improve natural capital by improving forest and water resources management and by improving soil quality. DRETs contribute to social capital by improving community collaboration, social gatherings, bonding, collective actions, trust and confidence between local residents; and improve human capital by contributing to better sanitation, health and education services, and by facilitating the uptake of new skills. Similarly, DRETs improve financial capital by maximising economic productivity, increasing household savings and by improving access to financial institutions; and improve physical capital by improving water infrastructure, communication infrastructure and the standard of housing. Based on the average score of survey responses, the users of micro-hydro reported the highest level of net positive impacts on livelihood capitals followed by solar PV, solar-wind micro grid, biogas and ICS. Among the livelihood capitals, the impact of DRETs was found to be highest on human capital, followed by physical capital, financial capital, social capital and natural capital.

Research participants, who reported negative impacts, mentioned about the decline in household savings due to increased expenditure on DRETs. A few micro-hydro and solar PV users think that micro-hydro and solar PV destroy more trees than they protect because of the need to clear forest and fell tress to construct distribution lines and to build mount for solar panels.

Overall, the findings show that DRETs have a net positive impact on livelihood capitals. Since the improvements in livelihood capitals can be associated with higher adaptive capacity and lower vulnerability (Block & Webb 2001; Li et al. 2017; Moser & Satterthwaite 2010; Nelson et al. 2010a; Paul et al. 2016; Su & Shang 2012; Thulstrup 2015), the observed contribution of DRETs' in improving livelihood capitals in the study sites could be thus considered as an outcome, which strengthens adaptive capacity and reduces vulnerability to climate change.

9.3 Contributions of this research

9.3.1 Contributions to theories and concepts

This research has contributed to the expansion of knowledge on climate change, sustainability and climate resilient development opportunities in rural mountain communities. The findings of this study show that rural mountain communities in Nepal are experiencing increasing climatic variability and changes in their environment [see sections 5.3, 5.4 and 5.5]. The observed climatic and environmental changes have profound impacts on local socio-ecological systems and livelihoods [see section 5.5]. While the local livelihoods and socio-ecological systems are at risk, local communities are not effectively equipped to deal with such changes, reflecting a poor adaptive capacity and high vulnerability to climate change in rural mountain communities. Therefore, this study has highlighted a greater need for adaptation in poor mountain communities.

Against such a background, this study has evaluated the climate change adaptation benefits of DRETs in Nepali mountains. The findings of this research reveal that DRETs contribute to climate adaptation by directly addressing climate risk and by improving the socio-economic factors of vulnerability [see chapter 7]. The outcome of this study has important implications for the argument that seeks to re-evaluate adaptation approaches framed within traditional development paradigms (Eriksen et al. 2015). Traditionally adaptation interventions have generally focused on technological interventions to climate impacts, while overlooking the underlying causes of vulnerability that are linked to social structures, the distribution of power, economic relations and access to resources (Eriksen et al. 2015; Vincent et al. 2013). In such a context, this research has shown that there are climate adaptation opportunities beyond climate impact focused interventions. This research have demonstrated that DRETs, though not primarily designed or targeted at climate risks, still contribute to climate adaptation. Thus, this research firmly supports the argument that climate adaptation measures can and should extend beyond addressing the climate impacts alone.

Further, this research advances the concept of sustainable development by arguing DRETs as an important measure for sustainable energy planning and climate resilient development. The findings of this research show that DRETs are an effective tool for energy access and a greater uptake of DRETs could potentially lead to a paradigm shift from conventional, top-down energy development models to sustainable, low-carbon and self–sufficient energy systems in Nepal and elsewhere [see section 8.3]. While the climate change mitigation and development benefits are clear, the case for DRETs as effective measures for climate adaptation is less obvious (Perera et al. 2015; Venema & Rehman 2007), which this research has now addressed. This research has shown that a well-designed DRET project offers a triple dividend by addressing developmental needs while simultaneously supporting climate mitigation and climate adaptation. Thus, the findings of this research have contributed scientific and empirical knowledge within the field of decentralised renewable energy systems and climate adaptation with a focus on opportunities for climate resilient development.

9.3.2 Contributions to methods

In order to achieve the objective of this study, a mix of methodological strategies and a socio-ecological framework integrating sustainable livelihoods approach (Carney 1998; DFID 1999; Ellis 2000), Eriksen and O'Brien (2007) and McGray et al. (2007) was applied. The framework allowed the systematic evaluation of direct and indirect impacts of DRETs in reducing climate change vulnerabilities. The framework contributes to the discipline of human geography by facilitating successful assessment of inter-relationships between human, environment and technology in an attempt to design an effective climate adaptation response.

Two important methodological strategies, i) mixed methods approach and ii) case study approach were applied in this research. The mixed methods approach has benefited this research in two ways. First, it allowed the researcher to evaluate the changes in environment and their impacts on local livelihoods from different angles, using physical climate data as well as local perceptions and experiences of environmental change, and thus providing rich information on the topic. Second, the mixed methods approach allowed the results of statistical analysis be better explained with local experiences, and the qualitative data collected through interviews and focus group discussions to be backed by the findings from statistical analysis, which has helped in enhancing the validity of this research (Creswell & Creswell 2017). Overall, the use of the mixed methods approach facilitated a holistic understating of climate change scenario in Nepali mountains, which also addresses the concerns raised by scholars about the lack of comprehensive climate change studies integrating instrumental records and people’s perceptions in developing countries (Roco et al. 2015) and in Nepali mountains (Shrestha et al. 2019). Thus, this research supports and contributes to the argument that although qualitative and quantitative methods can be conflicting in their epistemological position, the mixed methods approach can be a distinct research methodology and a strategy for inquiry in its own right (Clark & Creswell 2008).

The research is based on case studies of five different DRETs in three different communities in Nepali mountains. The use of case study approach facilitated a greater understanding of complex and non-linear relationships between DRETs, livelihoods and environment change in the study sites. The case study approach facilitated detailed answers to how environmental changes impact local communities, and how DRETs contribute to deal with such impacts in rural mountain communities. The case study approach was useful in understanding actions, motives and larger social complexities of actors in their everyday settings (Feagin et al. 1991). Thus, this research adds to the validity of case study approach as one of the tools of empirical enquiry that is suitable for answering the ‘how’ and ‘why’ questions (Baxter & Jack 2008).

9.3.3 Contributions for policy and practice

This research makes important policy contributions in the field of sustainable energy planning, climate change adaptation and climate resilient development. Policy makers generally view DRETs only as a tool for energy access and poverty alleviation (Ley 2012). In Nepal, the national renewable energy policy introduced in 2006 as ‘Rural Energy Policy 2006’ promotes DRETs for energy access, however falls short of acknowledging other potential advantages (AEPC 2016). While the climate change mitigation benefits are clear, and are also acknowledged by national policy documents such as Nationally Determined Contributions 2016, the Low Carbon Economic Development Strategy, and Climate Policy 2019 (Shrestha & Dhakal 2019), DRETs’ potential roles in supporting climate adaptation are still being overlooked. In such a context, this research has shown that DRETs contribute to climate adaptation in addition to providing modern energy access [see chapter 7]. Thus this research has offered a greater understanding of the multiple benefits offered by renewable energy technologies in general and DRETs in particular for policy makers in Nepal and elsewhere. The outcome of this study is expected to encourage policy makers and practitioners to acknowledge, promote, and upscale DRETs as an effective climate change adaptation tool in future. The promotion of DRETs as an effective climate adaptation tool is also expected to open up new avenues of funding as currently DRET projects are generally funded only for their role in improving energy access in remote areas (AEPC 2018; Steinbach et al. 2015).

This research contributes to the policy agenda by emphasizing that unlike conventional policy intentions, the forthcoming development and climate policies must recognize the need for approaches that simultaneously address both: development and climate change while promoting the broader goals of sustainable development (Denton et al. 2014). The findings of this research show that a well-designed DRET project addresses the concerns of development as well as climate change. DRETs are an effective tool for sustainable energy development [see section 8.3], and also support climate mitigation and climate adaptation [see section 8.5]. Thus, this research positions DRETs as an excellent option for countries looking forward to generate climate resilient solutions to address energy access and development in remote off-grid communities.

9.4 Furthering the research

This research has attempted to evaluate climate adaptation benefits of DRETs in remote mountain communities. Many questions still need to be framed and answered to broaden our understanding of the main issue that this study has raised. Some of the prominent ideas suggested for future research are:

- Although this research did collect information about demographic characteristics such as ethnicity, age and gender, no detailed analysis of demographic characteristics was performed due to time limitation. Future research can focus on the assessment of climate adaptation benefits of DRETs on different age groups, gender and ethnic groups.
- While this research has analysed the climate adaptation benefits of DRETs in a rural mountain setting, future research can focus on areas such as rural plains, desert and urban slums.
- This research focused on climate adaptation benefits of DRETs on households and communities. Importantly, there is a need to identify the level of climate change impacts on DRETs and their resilience to climate change. The absence of such analysis risks future loss of DRETs' effectiveness due to climate change.
- Last but not least, there is also an opportunity to understand the greater role of DRETs in generating resilience to issues beyond climate change, such as energy insecurity in a land locked country like Nepal.

9.5 Concluding remarks

This study has comprehensively analysed climate adaptation benefits of DRETs in rural mountain communities in Nepal. The study used a mixed-methods and a case study approach to answer the key research questions. This study focused on the cases of five DRETs namely solar PV, solar-wind micro grid, micro-hydro, ICS and biogas in three villages namely Kamal Bazaar, Darna and Sunder Bazaar in the mountain region of Nepal.

The findings of this study indicate that the households in the study sites are experiencing increasing climate variability and environmental changes. These changes have a broad range of impacts on local lifestyle, production systems and livelihoods. Unfortunately, the households and communities are not effectively equipped to deal with such changes and their associated impacts, reflecting the need for additional climate adaptation measures.

This study found that the DRETs, although not primarily designed to address climate risks, still contribute to climate adaptation. DRETs contribute to reducing climate vulnerability by directly addressing climate risks and by improving the socio-economic factors of vulnerability. The findings of this study have important implications for theory, policy and practice in relation to climate change, sustainable energy planning and climate-resilient development in Nepal and other developing countries.

Overall, this study concludes that DRETs provide climate adaptation benefits in addition to fulfilling their primary goal of providing energy access in remote mountain communities. However, this research also cautions that achieving the maximum benefits out of DRET projects requires crucial attention to operation, monitoring, and regular follow-up of the DRET projects.

10 Appendices

Appendix 1: Household survey questionnaire schedule

Title: Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies (DRETs) in Nepali mountains

Please circle the appropriate response or fill the space provided.

A: Questionnaire details					
1.Village code:		2. Date:		3.Questionnaire serial number:	
4. Questionnaire code:		5. Enumerator code:			

B: Demographic Details						
1.Interviewee name (optional):		2.Age		3.Gender		
4. Ethnicity:	Brahmin	Chhetri	Dalits	Janajatis	Other:	
5. Education	None	Up to 5th grade	5-10th grade	10-12th grade	Bachelor and above	
6.Number of family members:	Total:	Male:	Female:			
7.Highest level of education in family	None	Up to 5th grade	5-10th grade	10-12th grade	Bachelor and above	
8.Annual household income (NRS):	0-24,000	24,001-60,000	60,001-1,20,000	1,20,001-1,80,001	1,80,001-3,00,000	>3,00,000
9. Primary occupation in household:	Agriculture/ Livestock	Own a business	Wage labourer	Salaried job	Migrant worker	More than one sources of income: Y/N
10.Total land size in (Ropani)	None	Less than 2	More than 2 to 5	More than 5 to 10	More than 10 to 20	More than 20
11. Land size based on type	Khet:	Baari:	Ghaderi:	Paakho/other:		

C: DRET Details					
1: Owner/Connected to	Micro-Hydro	Biogas	ICS	Solar Home System (SHS)	Solar-Wind Micro Grid
2. Size/Capacity of the DRET					
3.Amount Paid for installation/connection					

4.Funding	Self:	Borrowed:	Subsidy:	Yes, Amount:	No

5. What are the uses of your DRET? ………………………………………………………………………………………………..
6. How much does it cost to operate your DRET? ………………………………………………………………………………………………..
7. How satisfied are you with your DRET? i) Very satisfied ii) Satisfied iii) Neither satisfied nor dissatisfied iv)Dissatisfied v) Very dissatisfied
8. What is the reason for your response to question 7? ……………………………………………………………………………………………….

D: Climate change and associated impacts

1. Please share your observations / experiences in regards to changes in temperature, rainfall and environment in your region for last 25-30 years.

	Codes:1= No Change, 2= Not Sure, 3= Some Change, 4= Change 5= Considerable Change	**Circle one of the following**				
a. Temperature & Rainfall						
i)	Temperature is changing [Increase/Decrease]	1	2	3	4	5
ii)	Annual average rainfall is changing [Increase/Decrease]	1	2	3	4	5
iii)	Monsoon arrival/withdrawal is changing [Early/Late]	1	2	3	4	5
b. Hazards						

i)	Floods are more frequent/damaging	1	2	3	4	5
ii)	Landslides are more frequent/damaging	1	2	3	4	5
iii)	Hailstones are more frequent/erratic	1	2	3	4	5
iv)	Forest Fires are more frequent	1	2	3	4	5
c. Environment						
i)	Decline in water availability	1	2	3	4	5
ii)	Invasive plant species have appeared or increased	1	2	3	4	5
iii)	Some plant species have relocated or started/stopped yielding flowers/fruits	1	2	3	4	5
iv)	New insect pest in plants, livestock and surroundings has been identified/increased	1	2	3	4	5
v)	**Would you like to add anything to the list?...**					

2. Please provide additional details for cases where you have circled either **3 or 4 or 5**. How are these changes/issues affecting your daily lives and livelihoods (Both positive and negative aspects)?

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………..

E: DRETs' Direct role in addressing the observed climate risk

1. How do you think your DRETs have been helpful/useful in dealing with the observed environmental changes and their associated impacts?

Changes/Impact	Description of DRETs direct engagement
a.	
b.	
c.	

2. Is your DRET contributing to any of the below mentioned adaptation practices?

Sectors	Practices	DRETs contribution
Water and energy Resources	Rainwater harvesting	
	Reuse/ Recycle of water/energy sources	
	Increase water/energy use efficiency	
	Identification of new sources	
	Would you like to add anything to the list?..	
Livelihood and Agriculture	Introduction of new crop/livestock variety	
	Shift to new/cash crop/crop calendar	
	Introduction/enhancement of irrigation system	
	Integrated farming (mixing crops/fruits/vegetables)	
	Introduction of new technology/fertilisers	
	Training on new farming practices	
	Minimising dependency on farming/alternate livelihood	
	Crop and livestock insurance	
	Migration/Remittance	
	Campaign/Advocacy/Liaison with N/GOs for support	
	Would you like to add anything to the list?..	
Forest and Biodiversity	Afforestation/Forest conservation	
	Community forestry practices	
	Increased use of agricultural residue as fodder	
	Management of alien/dominating species	
	Would you like to add anything to the list?..	
Climate	Preparedness/Management of disasters/crisis	

Induced Disaster/ Crisis	Disaster management plan/actions	
	Flood/Landslide/Storm proof housing structure	
	Would you like to add anything to the list?...	
Public Health	Improved health education	
	Improved sanitation and pest control	
	New health facilities/services	
	Vaccination program	
	Installed added heating/cooling/mosquito nets	
	Would you like to add anything to the list?...	

F: DRET's impacts on livelihood capitals

1. Social Capital

a. Could you please provide a list of committee/self-help groups that you are engaged in? Is there any DRET related committee/group? How do committee/group members help each other during difficult times?

Name of Group	How do committee/group members help each other
1.	
2.	
3.	

b. What do you think is the impact of your DRET in the improvement of social trust, bond, and network and community collaboration?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?

………………………………………………………………………………………
………………………………………………………………………………………
…………………………

2. Natural Capital

a. What are the common plant, animal and bird species in your forest?

Common species	
1) Plant Species	
2) Animal Species	
3) Bird Species	

b. What products do you rely on/collect from your forests? How do you use them?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

c. What do you think is the impact of your DRET on forest management?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

d. What do you think is the impact of your DRET on water resources management?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

e. What do you think is the impact of your DRET on land and soil quality?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

f. How are forest/other natural resources useful during crisis?

………………………………………………………………………………………
………………………………………………………………………………………
……………………….

3. Human Capital

a. What do you think is the impact of your DRET in the improvement of education, knowledge and skills?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

b. What do you think is the impact of your DRET on health and sanitation?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

4. Physical Capital

a. What is the ownership status of your house?

Self-Owned	Rented	Belongs to relatives/Guthi/others

b. What type of roof do you have on your house?

Thatch/Straw	Slate/Tile	Tin	Concrete/RCC

c. Do you have to toilet in your household?

i) Yes ii) No

d. What is the primary source of your drinking water?

Tap/Piped Water	Hand Pump	Open/Closed Well	Spout/Spring	River/Stream

e. Which of the following communication equipment do you have in your house?

Computer/Internet	Television	Radio	Mobile Phone

f. What do you think is the impact of your DRET on transport infrastructure?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………

g. What do you think is the impact of your DRET in improving housing standard (eg. modern concrete buildings, toilets, modern and clean lighting and cooking fuel)?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
……………………………………………………………………………………………
……………………………………………………………………………………………
…………………………

h. What do you think is the impact of your DRET on drinking water and irrigation infrastructure?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

i. What do you think is the impact of your DRET on information and communication infrastructure?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

5. Financial Capital

a. What do you think is the impact of your DRET on economic productivity/output/ income?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

b. What do you think is the impact of your DRET in the improvement of household savings?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

c. What do you think is the impact of your DRET in improving access to financial institutions and their products such as loans and deposits?

i) Very Positive ii) Positive iii) Neutral

iv) Negative v) Very Negative

Could you please explain why?
………………………………………………………………………………………
………………………………………………………………………………………
…………………………

Thank you for time and inputs.

Appendix 2: Focus group discussions and expert interview questionnaire schedule

Title: Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies (DRETs) in Nepali mountains

A: Environmental changes and associated impacts

(Please share your observations/ideas with examples)

1) What has been your observation about the changes in temperature in the past three decades? How have such changes affected lives and livelihoods?

2) What has been your observation about the changes in rainfall amount and duration? How have such changes affected lives and livelihoods?

3) What has been your observation about the changes in monsoon arrival and withdrawal? How have such changes affected lives and livelihoods?

4) Has the frequency and intensity of extreme weather events and hazards such as flood, landslide, forest fires and hailstorm changed in recent years in comparison to 2-3 decades ago? How have such changes affected lives and livelihoods?

5) What has been your observation about the availability of water resources in your region? How have such changes affected lives and livelihoods?

6) What has been your observation about flowering, fruiting and relocation of species? How have such changes affected lives and livelihoods?

7) What has been your observation about the changes in the number of invasive species? How have such changes affected lives and livelihoods?

8) What has been your observation about the changes in the number of insect pests? How have such changes affected lives and livelihoods?

B: DRET's role in directly addressing environmental changes and impacts
(Please share your observations/ideas with examples)

9) How do DRETs contribute in addressing following environmental changes and their associated impacts?

Environmental Changes		DRET's role in addressing the changes and impacts
d. Temperature & Rainfall		
i)	Changes in temperatures	
ii)	Changes in rainfall amount and duration	
iii)	Changes in monsoon arrival and withdrawal	
e. Hazards		
i)	Changes in flood frequency/intensity	
ii)	Changes in landslide frequency/intensity	
iii)	Changes in hailstone frequency/intensity	
iv)	Changes in forest fires frequency/intensity	
f. Environment		
i)	Decline in water availability	
ii)	Increases in invasive plant species	
iii)	Relocation and changes in flowering and fruiting	
iv)	Increases in insect pest in plants, livestock and surroundings	
v)	**Would you like to add anything?...**	

C: DRET's role in improving livelihood capitals

(Please share your observation/ideas with examples)

10) Do DRETs improve social bonding and community collaboration? How? Do DRETs facilitate the formation of self-help groups and committees? Please provide examples.

11) How do DRETs contribute in the improvement/deterioration of local forests, water resources and land/soil quality?

12) How are local forest/other natural resources helpful for prevention and management of crisis?

13) How do DRETs contribute to the improvement/deterioration of education and skills?

14) How do DRETs contribute to the improvement/deterioration of health services, hygiene and sanitation?

15) Do DRETs contribute to the improvement/deterioration of transport infrastructure? How?

16) Do DRETs improve the standard of living/housing (e.g. modern housing, better lighting, heating, cooling, modern energy sources, use of toilets etc.)? How?

17) How do DRETs contribute in the improvement/deterioration of local communication infrastructure (e.g. TV, Radio, and Telecommunications)?

18) How do DRETs contribute in the improvement/deterioration of economic productivity?

19) How do DRETs increase/decrease household savings?

20) Do DRETs improve access to formal financial institutions and their products such as loan and deposits? Please provide details.

D: FGD Participant Details

Topics of

Discussion____

S.N.	Participant’s Name	Organisation (if representing)	Sex: M or F

Thank you for your time and cooperation.

Appendix 3: Participant information sheet for household surveys

PROJECT TITLE: **Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: **H-2018-018**
PRINCIPAL INVESTIGATOR: **Dr. Douglas Bardsley**
STUDENT RESEARCHER: **Govinda Pathak**

Dear Participant,
I am Govinda Pathak, a PhD student at the University of Adelaide, Australia. I am undertaking a research titled: '**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains'** as part of my PhD. The research is funded by The University of Adelaide. The overall goal of this study is to analyse the suitability of Decentralised Renewable Energy Technologies (DRETs) as one of the effective adaptation measures for better energy and climate policy planning in future. DRETs are the renewable energy technologies such as Biogas, Mini/Micro Hydro, Solar Photovoltaics (PVs) and Improved Cooking Stoves that are located off grid and produce energy closer to the point of consumption. This questionnaire seeks to collect information about your household, livelihood, installed/connected DRETs and environmental issues to identify climate adaptation advantages offered by DRETs. This survey takes approximately 30-40 minutes.
There are no foreseeable risks for participating in this survey and you have the right to withdraw from the survey at any time. Information regarding individual participation will be kept confidential. You have the option of providing your name on the survey form if you are willing to participate in possible future follow up interviews. A copy of transcript and findings can be made available to you upon request. The outcome of the survey will be used in writing PhD thesis and published in academic journals and conferences. The information collected will be stored safely in university drives and storages with access limited to three researchers from the project (Dr. Douglas Bardsley, Dr. John Tibby and Govinda Pathak) for five years from the date of publication of thesis. Your participation in this research can help government and other development agencies to formulate appropriate energy and climate change policies and actions in your region. No financial or personal benefits for participation can be assured.
Please note:

- With your permission, the interview will be audio recorded.

- With your permission photographs of installed Decentralised Renewable Energy Technology, physical infrastructure and livelihood activities will be taken.
- If you agree to participate in the study, you will be asked to sign a consent form

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2018-018). This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (2007). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant, please contact the Human Research Ethics Committee's Secretariat on:

Phone: +61 8 8313 6028

Email: hrec@adelaide.edu.au

Post: Level 4, Rundle Mall Plaza, 50 Rundle Mall, ADELAIDE SA 5000

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

Yours Sincerely,

Dr. Douglas Kenneth Bardsley	**Dr. John Tibby**	**Govinda Pathak**
University of Adelaide	University of Adelaide	University of Adelaide
Adelaide, SA 5005, Australia	Adelaide, SA 5005, Australia	Adelaide, SA 5005, Australia
douglas.bardsley@adelaide.edu.au	john.tibby@adelaide.edu.au	govinda.pathak@adelaide.edu.au
Ph. Number: +61 831 34490	Ph. Number: +61 831 35146	Research Student
Research Supervisor/ Principal Investigator	Research Co-Supervisor	

Appendix 4: Participant information sheet for focus group discussions

PROJECT TITLE: **Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: **H-2018-018**
PRINCIPAL INVESTIGATOR: **Dr. Douglas Bardsley**
STUDENT RESEARCHER: **Govinda Pathak**

Dear Participant,
I am Govinda Pathak, a PhD student at the University of Adelaide, Australia. I am undertaking a research titled: '**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains'** as part of my PhD. The research is funded by The University of Adelaide. The overall goal of this study is to analyse the suitability of Decentralised Renewable Energy Technologies (DRETs) as one of the effective adaptation measures for better energy and climate policy planning in future. DRETs are the renewable energy technologies such as Biogas, Mini/Micro Hydro, Solar Photovoltaics (PVs) and Improved Cooking Stoves that are located off grid and produce energy closer to the point of consumption. This focus group discussion seeks to collect information about your household, livelihood, installed/connected DRETs and environmental issues to identify climate adaptation advantages offered by DRETs.
This discussion takes approximately 1.5 hours. There are no foreseeable risks for participating in this discussion and you have the right to withdraw from the discussion at any time. Information regarding individual participation will be kept confidential. A copy of transcript and findings can be made available to you upon request. The outcome of the discussion will be used in writing PhD thesis and published in academic journals and conferences. The information collected will be stored safely in university drives and storages with access limited to three researchers from the project (Dr. Douglas Bardsley, Dr. John Tibby and Govinda Pathak) for five years from the date of publication of thesis. Your participation in this research can help government and other development agencies to formulate appropriate energy and climate change policies and actions in your region. No financial or personal benefits for participation can be assured.
Please note:

- With your permission, the interview will be audio recorded
- If you agree to participate in the study, you will be asked to sign a consent form

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2018-018). This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (2007). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant, please contact the Human Research Ethics Committee's Secretariat on:

Phone: +61 8 8313 6028

Email: hrec@adelaide.edu.au

Post: Level 4, Rundle Mall Plaza, 50 Rundle Mall, ADELAIDE SA 5000

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

Yours Sincerely,

Dr. Douglas Kenneth Bardsley	**Dr. John Tibby**	**Govinda Pathak**
University of Adelaide	University of Adelaide	University of Adelaide
Adelaide, SA 5005, Australia	Adelaide, SA 5005, Australia	Adelaide, SA 5005, Australia
douglas.bardsley@adelaide.edu.au	john.tibby@adelaide.edu.au	govinda.pathak@adelaide.edu.au
Ph. Number: +61 831 34490	Ph. Number: +61 831 35146	Research Student
Research Supervisor/ Principal Investigator	Research Co-Supervisor	

Appendix 5: Participant information sheet for expert interviews

PROJECT TITLE: **Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: **H-2018-018**
PRINCIPAL INVESTIGATOR: **Dr. Douglas Bardsley**
STUDENT RESEARCHER: **Govinda Pathak**

Dear Participant,
I am Govinda Pathak, a PhD student at the University of Adelaide, Australia. I am undertaking a research titled: '**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains'** as part of my PhD. The research is funded by The University of Adelaide. The overall goal of this study is to analyse the suitability of Decentralised Renewable Energy Technologies (DRETs) as one of the effective adaptation measures for better energy and climate policy planning in future. DRETs are the renewable energy technologies such as Biogas, Mini/Micro Hydro, Solar Photovoltaics (PV) and Improved Cooking Stoves that are located off grid and produce energy closer to the point of consumption. This interview seeks to collect information about your household, livelihood, installed/connected DRETs and environmental issues to identify climate adaptation advantages offered by DRETs. This interview takes approximately one hour.
There are no foreseeable risks for participating in this interview and you have the right to withdraw from the interview at any time. Information regarding individual participation will be kept confidential. However, due to the limited number of experts and the specified nature of the interview, it can be difficult to guarantee anonymity for some of the key-informants such as high ranking public officials or well-known practitioners who can be indirectly identified. A copy of transcript and findings can be made available to you upon request. The outcome of the interview will be used in writing PhD thesis and published in academic journals and conferences. The information collected will be stored safely in university drives and storages with access limited to three researchers from the project (Dr. Douglas Bardsley, Dr. John Tibby and Govinda Pathak) for five years from the date of publication of thesis. Your participation in this research can help government and other development agencies to formulate appropriate energy and climate change policies and actions in your region. No financial or personal benefits for participation can be assured.
Please note:

- With your permission, the interview will be audio recorded
- If you agree to participate in the study, you will be asked to sign a consent form.

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2018-018). This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (2007). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant, please contact the Human Research Ethics Committee's Secretariat on:

Phone: +61 8 8313 6028

Email: hrec@adelaide.edu.au

Post: Level 4, Rundle Mall Plaza, 50 Rundle Mall, ADELAIDE SA 5000

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

Yours Sincerely,

Dr. Douglas Kenneth Bardsley
University of Adelaide
Adelaide, SA 5005, Australia
douglas.bardsley@adelaide.edu.au
Ph. Number: +61 831 34490
Research Supervisor/ Principal Investigator

Dr. John Tibby
University of Adelaide
Adelaide, SA 5005, Australia
john.tibby@adelaide.edu.au
Ph. Number: +61 831 35146
Research Co-Supervisor

Govinda Pathak
University of Adelaide
Adelaide, SA 5005, Australia
govinda.pathak@adelaide.edu.au
Research Student

Appendix 6: Consent form for household surveys

Human Research Ethics Committee (HREC)

1. I have read the attached Information Sheet and agree to take part in the following research project:

Title:	**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
Ethics Approval Number:	**H-2018-018**

2. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

3. I have been given the opportunity to have a member of my family or a friend present while the project was explained to me.

4. Although I understand the purpose of the research project, it has also been explained that involvement may not be of any benefit to me.

5. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.

6. I understand that I am free to withdraw from the project at any time.

7. I agree to the photographs of installed Decentralised Renewable Energy Technologies, surroundings, physical infrastructures and livelihood activities being taken.

   Yes ☐ No ☐

8. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ______________________Signature:__________________ Date: _____________

Researcher/Witness to complete:

I have described the nature of the research to______________________

(print name of participant)

and in my opinion she/he understood the explanation.

Signature: _______________________Position:________________ Date: ______________

Appendix 7: Consent form for focus group discussions

Human Research Ethics Committee (HREC)

1. I have read the attached Information Sheet and agree to take part in the following research project:

Title:	**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
Ethics Approval Number:	**H-2018-018**

2. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

3. I have been given the opportunity to have a member of my family or a friend present while the project was explained to me.

4. Although I understand the purpose of the research project, it has also been explained that involvement may not be of any benefit to me.

5. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.

6. I understand that I am free to withdraw from the project at any time. I agree to the discussion being audio recorded.

   Yes ☐ No ☐

7. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ____________________ Signature: ______________________

Date: ______________________

Researcher/Witness to complete:

I have described the nature of the research to

____

(print name of participant)

and in my opinion she/he understood the explanation.

Signature: _________________ Position: ________________________

Date: ______________________

Appendix 8: Consent form for expert interviews

Human Research Ethics Committee (HREC)

1. I have read the attached Information Sheet and agree to take part in the following research project:

Title:	**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
Ethics Approval Number:	**H-2018-018**

2. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

3. Although I understand the purpose of the research project, it has also been explained that involvement may not be of any benefit to me.

4. I understand that due to the limited number of experts and the specified nature of the interview, it can be difficult to guarantee anonymity for some of the key-informants such as high ranking public officials or well-known practitioners who can be easily indirectly identified.

5. I understand that I can withdraw from the interview at any time.

6. I agree to the interview being audio recorded. Yes ☐ No ☐

7. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ______________________ Signature: ________________________

Date: ________________________

Researcher/Witness to complete:

I have described the nature of the research to

____

(print name of participant)

and in my opinion she/he understood the explanation.

Signature: ___________________ Position: __________________________

Date: ________________________

Appendix 9: Contacts for information and complaints

The University of Adelaide

Human Research Ethics Committee (HREC)

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

Project Title:	**Climate Change Adaptation Benefits of Decentralised Renewable Energy Technologies in Nepali mountains**
Approval Number:	**H-2018-018**

The Human Research Ethics Committee monitors all the research projects which it has approved. The committee considers it important that people participating in approved projects have an independent and confidential reporting mechanism which they can use if they have any worries or complaints about that research.

This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (see http://www.nhmrc.gov.au/publications/synopses/e72syn.htm)

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project co-ordinator:

Name:	**Dr. Douglass Kenneth Bardsley, Senior Lecturer (Primary contact)** **Govinda Pathak, PhD Candidate (Alternate contact)**
Phone:	**+61 8 831 34490**

2. If you wish to discuss with an independent person matters related to:

    - making a complaint, or
    - raising concerns on the conduct of the project, or
    - the University policy on research involving human participants, or
    - your rights as a participant,

    contact the Human Research Ethics Committee's Secretariat on phone (08) 8313 6028 or by email to hrec@adelaide.edu.au

Appendix 10: Human research ethics approval

THE UNIVERSITY of ADELAIDE

RESEARCH SERVICES
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
THE UNIVERSITY OF ADELAIDE

LEVEL 4, RUNDLE MALL PLAZA
50 RUNDLE MALL
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TELEPHONE +61 8 8313 5137
FACSIMILE +61 8 8313 3700
EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

Our reference 32317

06 February 2018

Dr Douglas Bardsley
School of Social Sciences

Dear Dr Bardsley

ETHICS APPROVAL No:	H-2018-018
PROJECT TITLE:	Climate change adaptation benefits of decentralised renewable energy technologies in Nepal

The ethics application for the above project has been reviewed by the Low Risk Human Research Ethics Review Group (Faculty of Arts and Faculty of the Professions) and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants.

You are authorised to commence your research on: 06/02/2018
The ethics expiry date for this project is: 28/02/2021

NAMED INVESTIGATORS:

Chief Investigator:	Dr Douglas Bardsley
Student - Postgraduate Doctorate by Research (PhD):	Mr Govinda Pathak
Associate Investigator:	Associate Professor John Tibby

CONDITIONS OF APPROVAL: The revised application provided 01.02.2018 has been approved.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled Annual Report on Project Status is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/research-services/oreci/human/reporting/. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the information sheet and the signed consent form to retain. It is also a condition of approval that you immediately report anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol or project investigators; and
- the project is discontinued before the expected date of completion.

Yours sincerely,

Dr Anna Olijnyk
Convenor

The University of Adelaide

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