Energy and Food Security using Geothermal Energy: A Case Study of Chumathang, Union Territory of Ladakh, India

Thesis of 60 ECTS credits submitted to the School of Science and Engineering at Reykjavík University in partial fulfillment of the requirements for the degree of
Master of Science (M.Sc.) in Sustainable Energy Engineering

August 2020

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Kunzes Dolma

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Abstract

Energy and food are the two essential requirements for national security of any country. India is the third largest consumer of oil in the world, the fourth largest oil refiner and a net exporter of refined oil products. India is dependent on import of fossil fuel for meeting its energy demands which was 80% in 2018. Heating, Ventilation, and Air Conditioning (HVAC) accounts for 60% of the electricity demands of the country. The dependence on fossil fuels can be reduced by using locally available renewable energy sources like wind, solar and geothermal. A solution is also required to the problem of energy access in remote areas where a reliable supply from the national grid is not available. This thesis investigates the feasibility of utilizing low enthalpy geothermal energy to provide energy and food security specially in remote areas. A case study of the Chumathang village located at 3,950 masl in Union Territory of Ladakh shows the socio-economic impact of geothermal utilization in remote areas by using a low enthalpy geothermal and how it can solve the current problem of food and energy security. A 5 MW binary power plant would solve the electricity problem of the area and provide reliable and clean energy which could replace the current installed 20 kW diesel generator. A commercial greenhouse of 1,000 m^2 would be able to supply year-round fresh vegetables. With an average cost of 1.5 USD/kg for vegetables, and a tariff of 0.07 USD/kWh for the electricity, the NPV is positive with 2.26 MUSD and breakeven point after 9 years of project operation. The case study shows that such projects lead to employment opportunities, prevent migration of people in search of jobs, add to food and energy security of the region, and improves the health of people. This is especially important for women in the region who bear most of the burden of domestic work and are most impacted due to not having access to energy. Such a model can be replicated in any low temperature geothermal remote areas worldwide.

Jarðhiti til eflingar orku- og fæðuöryggis: Dæmi frá Chumathang, Ladakh, Indlandi

Kunzes Dolma

Ágúst 2020

Útdráttur

Orka og matur eru tvær grundvallarkröfur þjóðaröryggis hvers lands. Indland er þriðji stærsti olíuneytandi heims, fjórði stærsti framleiðandi unninna olíuvara og nettó útflytjandi slíkra vara. Indverjar eru háðir innflutningi jarðefnaeldsneytis til að uppfylla orkuþörf sína og nam sá innflutningur 80% árið 2018. Upphitun, loftræsting og loftkæling stendur fyrir 60% af raforkuþörf landsins. Hægt er að gera Indland minna háð jarðefnaeldsneyti með því að nýta endurnýjanlega orkugjafa sem eru til staðar eins og vind, sól og jarðhita. Einnig þarf að leysa vandamálið varðandi aðgang að raforku á afskekktum svæðum þar sem ekki er hægt að tryggja áreiðanlegan aðgang að landsnetinu. Ritgerð þessi kannar möguleika og hagkvæmni þess að nýta jarðhita (lághita) til að efla orku- og fæðuöryggi, sérstaklega á afskekktum svæðum. Tilviksrannsókn á þorpinu Chumathang, sem er staðsett í 3.950 m.y.s. í Ladakh, Indlandi, sýnir samfélags- og efnahagsleg áhrif jarðhitanýtingar frá lághitasvæðum á afskekkt svæði og hvernig það getur leyst núverandi vandamál varðandi orku- og fæðuöryggi. Ef sett væri upp 5 MW tvívökva virkjun myndi það leysa rafmagnsvandamál svæðisins og veita áreiðanlega og hreina orku sem gæti komið í staðinn fyrir núverandi 20 kW dísilrafstöð. Gróðurhús rekið á viðskiptalegum grunni, 1.000 m^2 að stærð, gæti útvegað ferskt grænmeti allt árið. Miðað við að verð á grænmeti sé 1,5 USD/kg og raforkuverð 0,07 USD/kWst reiknast hreint núvirði slíks verkefnis (NPV) jákvætt sem nemur 2,26 MUSD og að núllrekstri (breakeven) sé náð eftir 9 ára rekstur gróðurhússins. Tilviksrannsóknin sýnir að slík verkefni leiða til atvinnutækifæra, koma í veg fyrir brottflutning fólks í atvinnuleit, eflir orku- og fæðuöryggi svæðisins og bætir heilsu fólks. Þetta er sérstaklega mikilvægt fyrir konur á svæðinu sem bera mestu byrðarnar af heimilisstörfum og verða fyrir mestum áhrifum þess að hafa ekki aðgang að orku. Sambærileg verkefni er hægt að setja á fót á öðrum afskekktum svæðum með aðgengi að jarðhita víða um heim.

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August 2020

date

Kunzes Dolma
Master of Science

I dedicate this to all sentient beings of the universe.

Acknowledgments

"More fossil fuel remains where they should be – in the ground"
Antonio Gutterres, UN Secretary-General

This thesis would not have been possible without the help and contribution from people across different sectors of profession. I thank one and all around the globe who were part of my journey in the two years of my master's program starting from my family, friends who supported me emotionally while I was away from home, the public representatives and bureaucrats who took time from their busy schedule for interviews, spiritual teachers who helped me get through difficult times and my supervisors who guided and shared their knowledge with me. The COVID-19 pandemic started when I was halfway through my thesis and it was a testing time mentally as well as physically. Without you all, this thesis was not possible. Thank you to UNESCO GRÓ-GTP for the scholarship to pursue the master's program in Sustainable Energy Engineering at Reykjavik University, Iceland.

Special thanks to the UNESCO GRO-GTP family, Luðvik Georgsson, Guðni Axelsson, Vigdís Harðardóttir, Ingimar Haraldsson, Markús Andri and the most precious wonder woman Málfríður Omarsdóttir, and all the wonderful fellows. Thanks to all the staff and my batch mates at Iceland School of Energy, learned a lot from you all.

Gratitude to my supervisors Árni Ragnarsson, Juliet Newson and William Harvey for sharing your experience and knowledge.

Preface

This dissertation is original work by the author, Kunzes Dolma.

Contents

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List of Abbreviations

ACC	Air Cooled Condenser
BPCL	Bharat Petroleum Corporation Limited
CAPEX	Capital Expenditure
COVID-19	Coronavirus Disease 2019
DIHAR	Defence Institute of High-Altitude Research
DRDO	Defence Research and Development Organization
ESMAP	Energy Sector and Management Assistant Program
FAO	Food and Agricultural Organization
FIES	Food Insecurity Experience Scale
GCF	Green Climate Fund
GSI	Geological Survey of India
HPCL	Hindustan Petroleum Corporation Limited
IOCL	Indian Oil Corporation Limited
IRENA	International Renewable Energy Association
ISOR	Iceland GeoSurvey
JKPDC	Jammu and Kashmir Power Development Corporation
KREDA	Kargil Renewable Energy Development Agency
LEDeG	Ladakh Ecological and Development Group
LREDA	Ladakh Renewable Energy Development Agency
MNRE	Ministry of New and Renewable Energy
NIWE	National Institute of Wind Energy
NPV	Net Present Value
OPEX	Operational Expenditure
SECI	Solar Energy Corporation of India
UT	Union Territory
USDOE	United States Department of Energy
UNSDGs	United Nations Sustainable Development Goals

Symbols

Symbol	Description	Units/Values
E	Energy	J
T	Temperature	°C
θ	Porosity	%
ρ	Density	kg/m^3
h	Enthalpy	J/kg
V	Volume	m^3
C	Heat capacity	J/K
s	Entropy	J/K
ŋ	Efficiency	%
U	Thermal transmittance	W/m^{2}K
R	Thermal resistance	m^{2}K/W
λ	Thermal conductivity or k-value	W/mK
A	Area	m^2
C_p	Specific heat capacity	J/kg°K
P	Power potential	MWe
P_f	Power plant factor	
Q_T	Total thermal energy of reservoir	kJ
T	Temperature	°C
W_{turb}	Turbine work	MWe
W_{acc}	Power consumption for fan of ACC	kW
W_p	Power consumption by pump	kW

Introduction

The ambitious goal of fulfilling the Paris Agreement means integrating different kind of renewable energy technologies in the energy mix of the country. India has a commitment of cutting greenhouse gas (GHG) emissions intensity by 33 to 35 percent below 2005 levels by 2030 and generating 40 percent of its installed electricity capacity from non-fossil sources by the same year (Figure 1.1). India has made a great addition in solar, wind and biomass (Figure 1.2). India's solar energy capacity has jumped 1,000-fold from a mere 17 megawatts (MW) in 2010 to more than 23 gigawatts (GW) in 2018 (National Resources Defence Council et al., 2018).

India is a fast-growing economy whose energy demand has been increasing tremendously over the past few years. The growth in the energy intensive industries has led to a surge in the imports of coal. Much of India has temperatures up to 50°C in summer which makes it desirable to have cooling equipment at home and work places and an increase in the disposable income of the middle classes has led to a surge in demand for air conditioning. There is also a cooling demand from the agriculture sector for storage of vegetables and fruits. It is estimated that 60% of electricity goes into the heating and cooling demand of the country (Lalit & Kalanki, 2019).

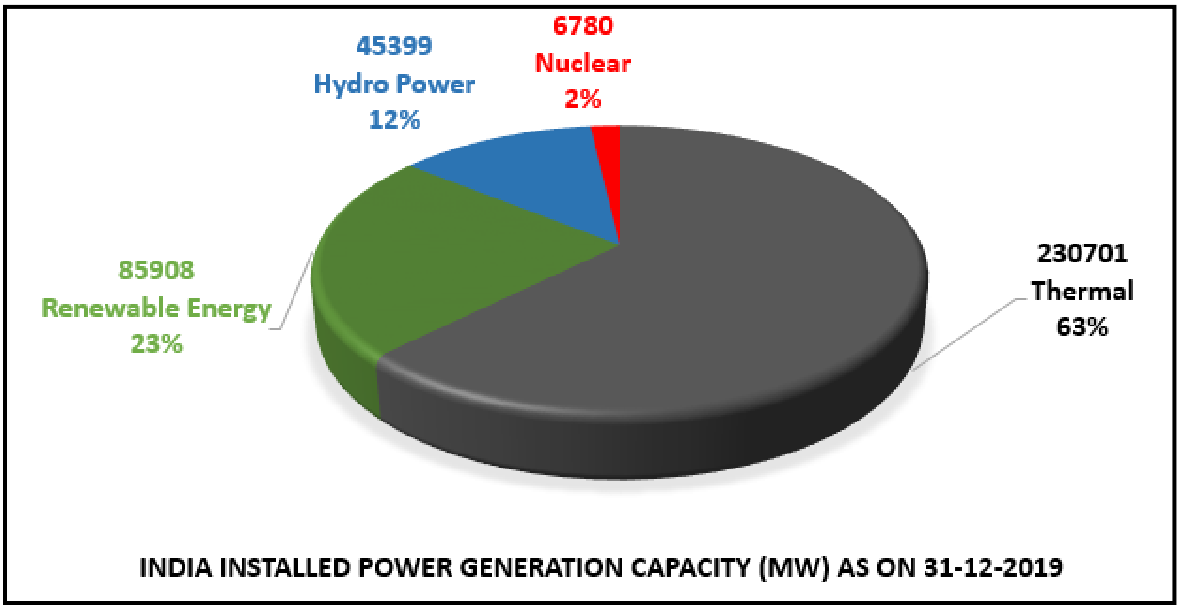

Figure 1.1: The Installed Power generation capacity from different energy sources as on 31.12.2019 (Ministry of New and Renewable Energy, Government of India, 2020).

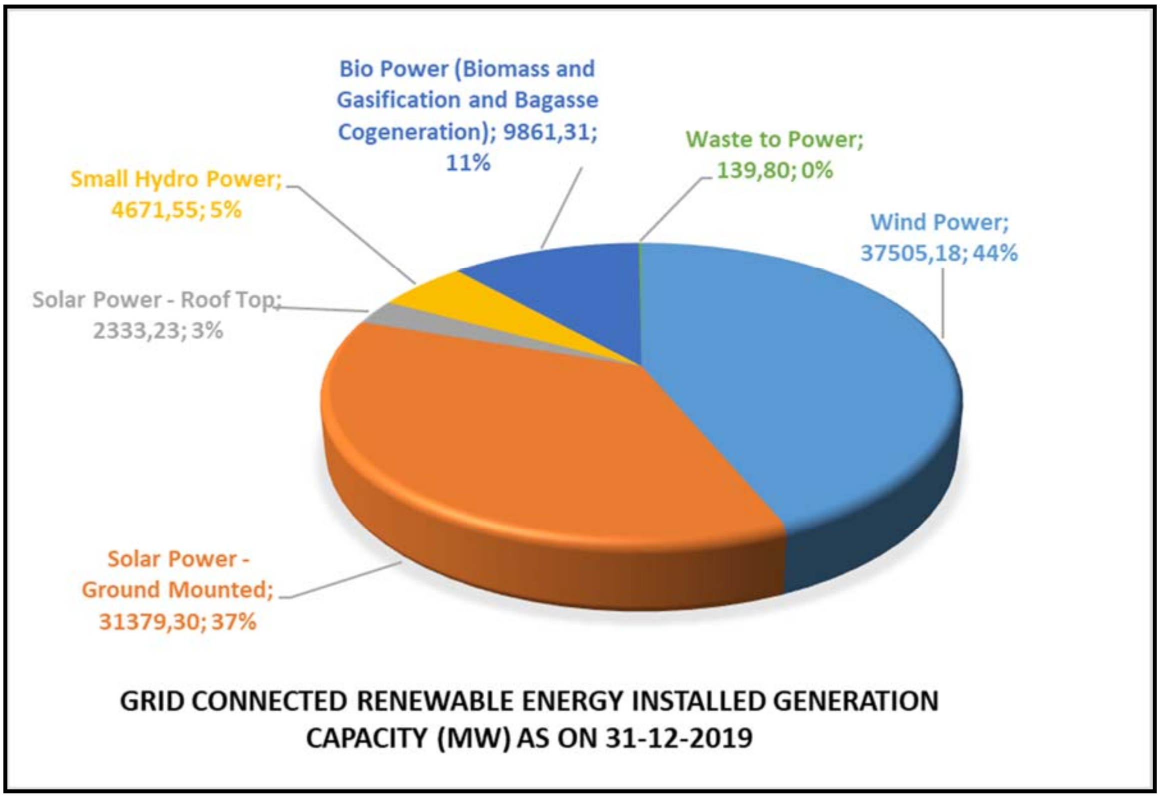

Figure 1.2:Total installed capacity of Grid connected Renewable Energy sources in MW as on 31.12.2019 (Ministry of New and Renewable Energy, Government of India, 2020).

Geothermal is an energy source which is reliable and can act as base load. The use of existing low enthalpy systems for direct utilization like greenhouses, cooling, cold storage, and recreation could increase the renewable energy mix, create employment opportunities as well as increase the economy of the region. This thesis investigates the possibility of utilizing low temperature geothermal source in order to provide electricity and heat, thus enhancing the quality of living in remote areas.

Chapter 1 describes visits to geothermal sites in India to document the current situation and the practicality of the utilization. The selection of sites was done on the basis of location in different states of India and then the safety of travel of the female author to these locations. The main finding was that religious beliefs surrounding the geothermal manifestations have led to the construction of temples nearby or around the hotsprings.

Chumathang (one of the sites visited) was found to be the best site for case study due to the following reasons:

- Ladakh requires energy to solve two of the major issues among many others, food security and energy security.

- It borders with China, thus a very strategic location from national security point of view.

- This site is free of religious buildings, hence there will not be much resistance from people while carrying out developmental activities in this area like drilling or construction of power plant.

- Migration of people to cities in search of jobs and better living conditions is a problem.

- The author is a native of the region and hence has more understanding of the needs of the area.

The Case Study: The union territory of Ladakh has a great potential for renewable energy like solar, geothermal and hydro. The Ministry of New and Renewable Energy, Government of India, through the State Nodal Agencies (SNA) namely Kargil Renewable Energy Development Agency (KREDA) and Ladakh Renewable Energy Development Agency (LREDA) has implemented many projects to promote the utilization of renewable energy in Ladakh. Some of the projects are solar photovoltaics, solar water heater, concentrated solar cooker, solar greenhouses, solar lanterns, micro-hydropower projects. Despite these efforts, the energy scenario of the region has not changed as there are frequent outages and many of the villages still have no connectivity to the grid and rely on a diesel generator for electricity provided for five to six hours in the evening. There is no reliable electricity source available at present and due to the isolation of the region from rest of India for seven months in winter, there is no access to fresh vegetable supply.

Chapter 2 outlines the resources and current energy and food security situation of Ladakh where the case study area is situated. Chumathang is a village 140 km south-east of Leh at an altitude of 3,950 masl. There are 127 households with a population of 641 people (District statistics and Evaluation office, Leh, 2017-18). The thesis presents the concept of using the geothermal resource in the Chumathang village to improve the living standard of the people and thereby solving energy and food security issues. Currently the villagers use either Liquid Petroleum Gas (LPG) or wood to cook and keep the house warm; this LPG is transported from the plains of India in diesel trucks which adds to the carbon footprint. Once the villagers have electricity, they can use electrical appliances which will ease their life, especially of the women who do all the household work. They will get more time to work to build financial security for example by setting up food processing, pashmina industries, greenhouses and working at the power plant.

Food security is a major issue in Ladakh due to its heavy dependence on the import of food materials from the plains of India. Due to the harsh climatic conditions only a few varieties of fruits and vegetables are produced in the summer months and nothing in the winter months. The national highway is the only way to transport fuel and food supply into the region. This means that even the imported fresh fruit and vegetable supply is cut off which is why people mainly eat dried vegetables and meat during this period. The closure of the road during the winter months lead to a deficiency in the supply of commodities, especially fresh food. There has been an increase in the number of diseases related to nutrient deficiency like anemia and vitamin deficiency (Personal communication, Dr Tashi Thinlas, Physician, Public Hospital, Leh, July 2019). Having commercial greenhouses near the geothermal sites will ensure a year-round supply of fresh vegetables and solve the nutrient deficiency to some extent. This project can be an example of how utilizing the locally available resource can make a village not only sustainable but developed by providing employment opportunities and thus not having to migrate to other towns.

The project evaluates whether the geothermal resource in the village can support a power plant and greenhouse to meet power and food security. The power plant will provide the village with electricity for 24 hours per day compared to the 5 hours currently available.

Chapter 3 investigates the size of the potential resource of Chumathang geothermal field, followed by

Chapter 4 is a design for an appropriately sized 5 MW Binary power plant at Chumathang and Chapter 5 outlines design for greenhouses to provide fresh produce for the area. Chapter 6 and 7 focus on an economic and social impact analysis, respectively.

The utilization of the geothermal field of Chumathang will address some of the United Nations Sustainable Development Goals (SDGs) like the energy security (SDG 7), food security (SDG 2), employment (SDG 9) and gender upliftment (SDG 5) of the region.

Chapter 1

Geothermal sites visited

This chapter gives an overview of the geothermal sites visited by the author. These descriptions are included to provide background information on the nature of the geothermal resource in India.

The aim was also to present reasons by way of comparison why Chumathang is the best selection for a case study. This is by describing the social, cultural and religious uses of geothermal energy and the general conditions at each site. From these descriptions, we can say that Chumathang is most suitable for a case study.

A research grant provided by UNESCO GRÓ GTP was used to visit the maximum number of geothermal sites possible in a period of one month. A summary is given about the condition of each sites. The prevailing temperature at most of these sites was between 38°C to 45°C during the time of visit in May- June 2019.

1.1 Geothermal sites visited

India is the seventh-largest country in the world, with a total area of 3,287,263 km^2 extending from Tamil Nadu in the south to Jammu and Kashmir in the north over a distance of about 5,000 km and from Gujarat in the west to Arunachal Pradesh in the east over a distance of 4,000 km. (Wikipedia, 2020) with a land frontier of 15,200 km and a coastline of 7 517 km. Physiographically India is divisible into three distinct geographical units viz. the Extra Peninsular Region, Indo-Gangetic Plain, and the Peninsular Region.

India has more than 300 hotsprings spread across the country (Figure 1.1). The temperatures of these springs range from 35°C to the boiling point of the area, i.e. for Puga the highest temperature of the hot spring is 85°C while for Tattapani, it is 98°C, both these temperatures representing the boiling point of water in these respective areas. More recently the springs have been classified based on their location in specific geotectonic settings and grouped under different Geothermal Provinces (Geological Survey of India, 2002) (Figure 1.2).

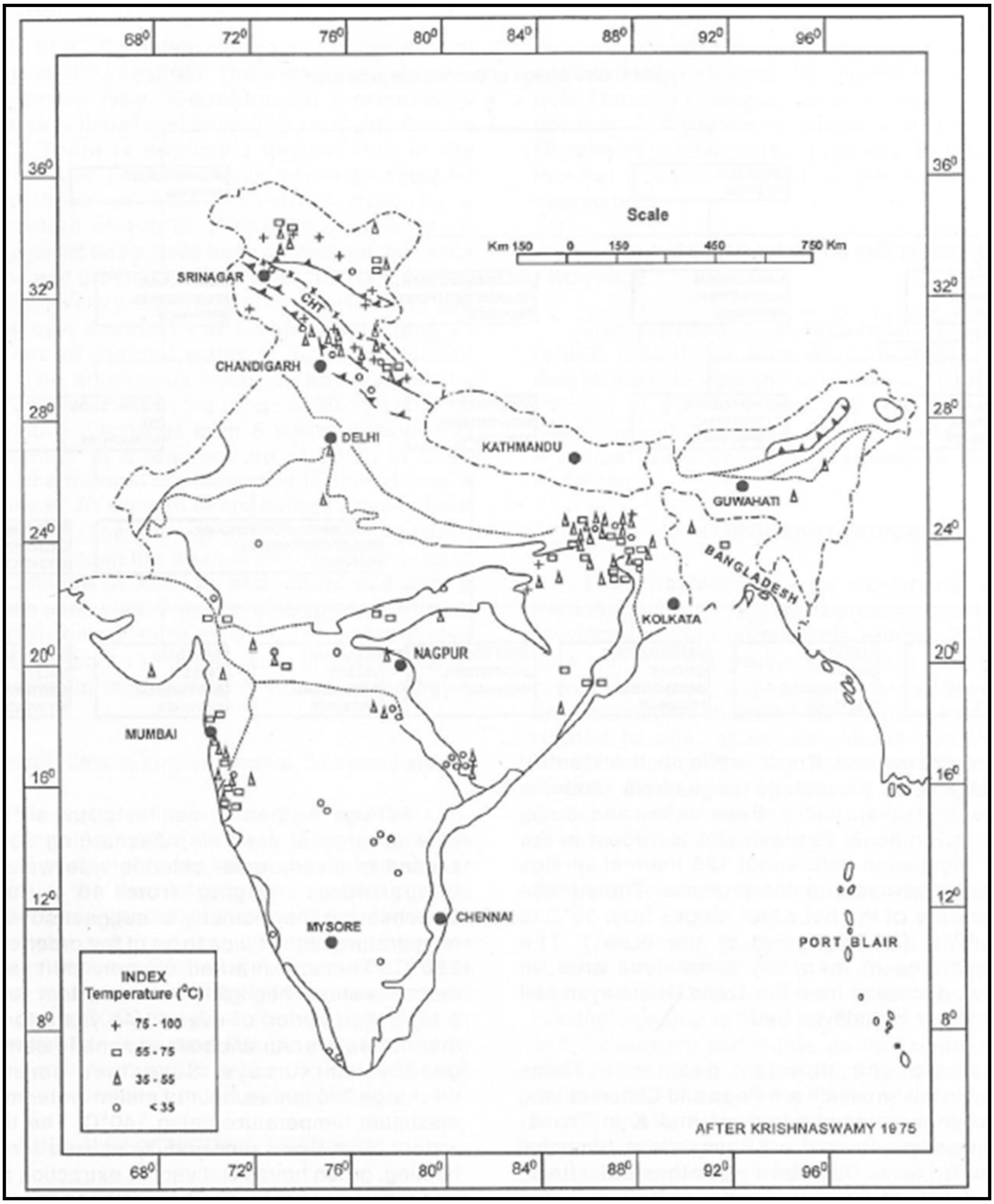

Figure 1.1: Hot springs of India (Geological Survey of India, 2002).

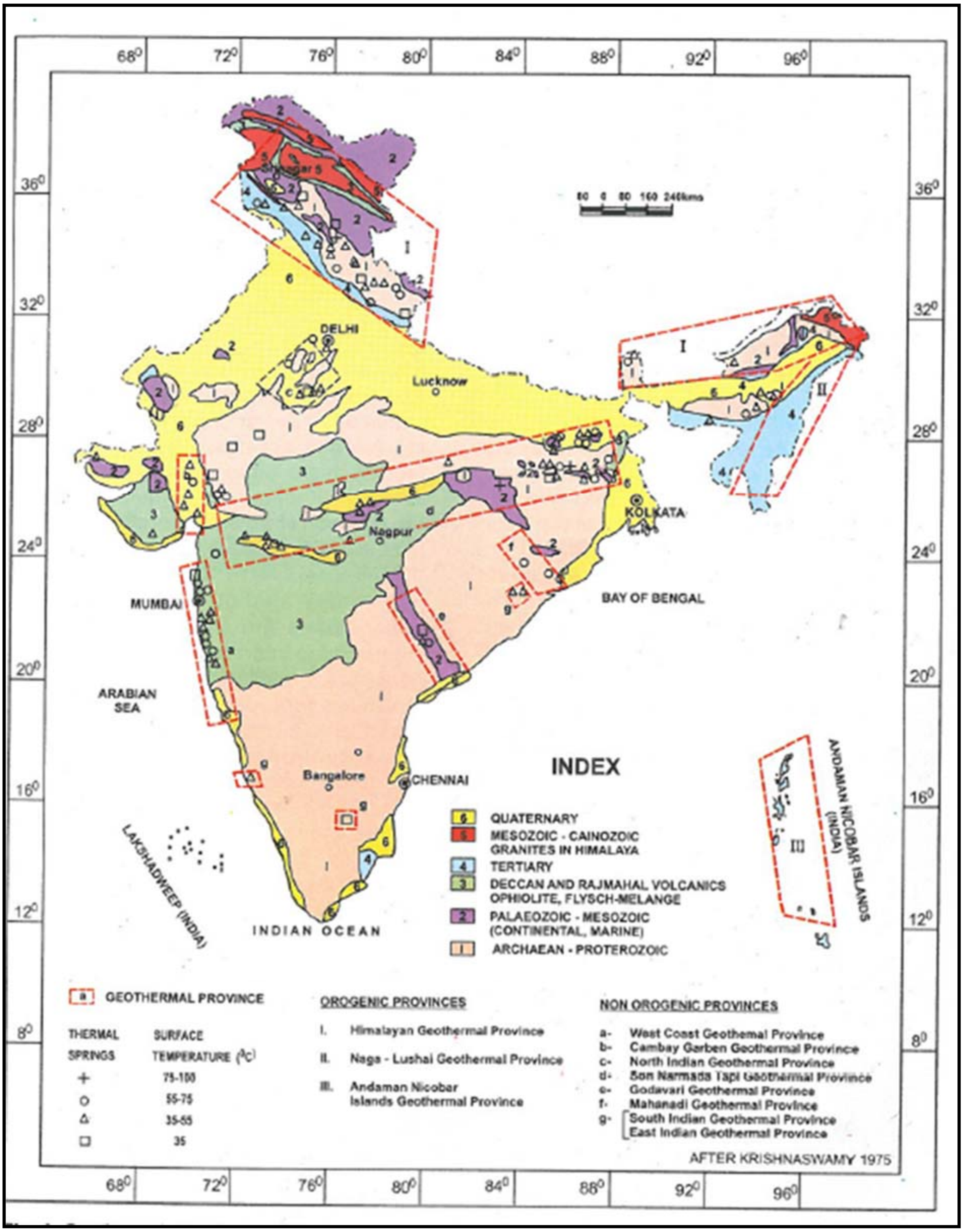

Figure 1.2: Geothermal provinces of India (Geological Survey of India, 2002).

In order to document the current situation site visit were made to the geothermal hotsprings of Dholera in Gujarat, Ratnagiri, Tural and Ganeshpuri in Maharashtra, Rajgir in Bihar, Manikaran in Himachal Pradesh, Sohna in Haryana, Chumathang, Panamik and Puga in Ladakh (Figure 1.3 and Figure 1.4). These sites were selected because these covered a significant portion of India and these were considered safe as the author was travelling alone.

Figure 1.3: Distance traveled over a month during the site visits.

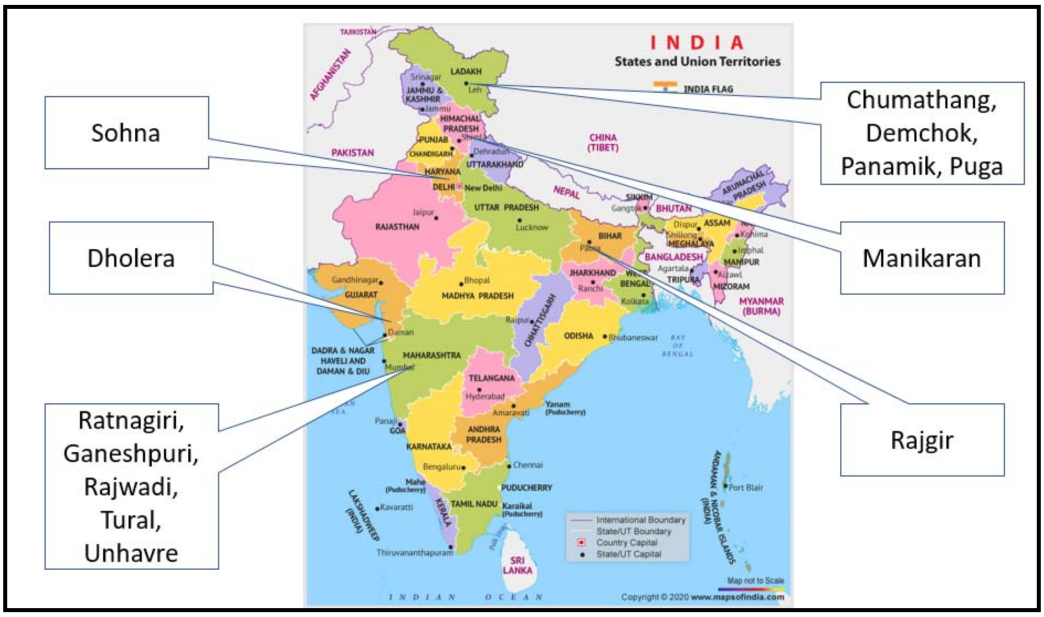

Figure 1.4: Geothermal site location in various states of India.

1.1.1 Demchok hot spring

Demchok is 280 km from the main capital of Ladakh, Leh. This is the last village on the India-China border as can be seen from Figure 1.5. This village is not accessible to the tourists due to security reasons. This village is situated at an altitude of 4,300 masl and is an important army post. There are army settlements on both sides of the border. The cold temperatures most of the year makes use of heating inevitable. This is met by fossil fuels like kerosene. The geothermal water could be used for heating.

The temperature of the hot spring ranged from 40°C to 60°C as measured in Nov 2019. This geothermal site is heavily used by locals for its medicinal properties for treatment of diseases like arthritis (Personal communication, Amchi Palmo, Ladakh Nuns Association, Nov 2019). There are bathing rooms which is used by the patients as well as the army personnel throughout the year.

As is the case with many regions of the world, hot springs are considered sacred in Ladakh. This is the reason prayer flags can be seen on the hot spring sites as in Figure 1.6.

Figure 1.5: Location of Demjok village and hot springs on the Indo-Chinese border. There is no physical wall separating the two countries, rather it is pasture patch grown on the path where the hot spring water flows. This pasture is used as grazing for animals by the nomads from both sides of the border.

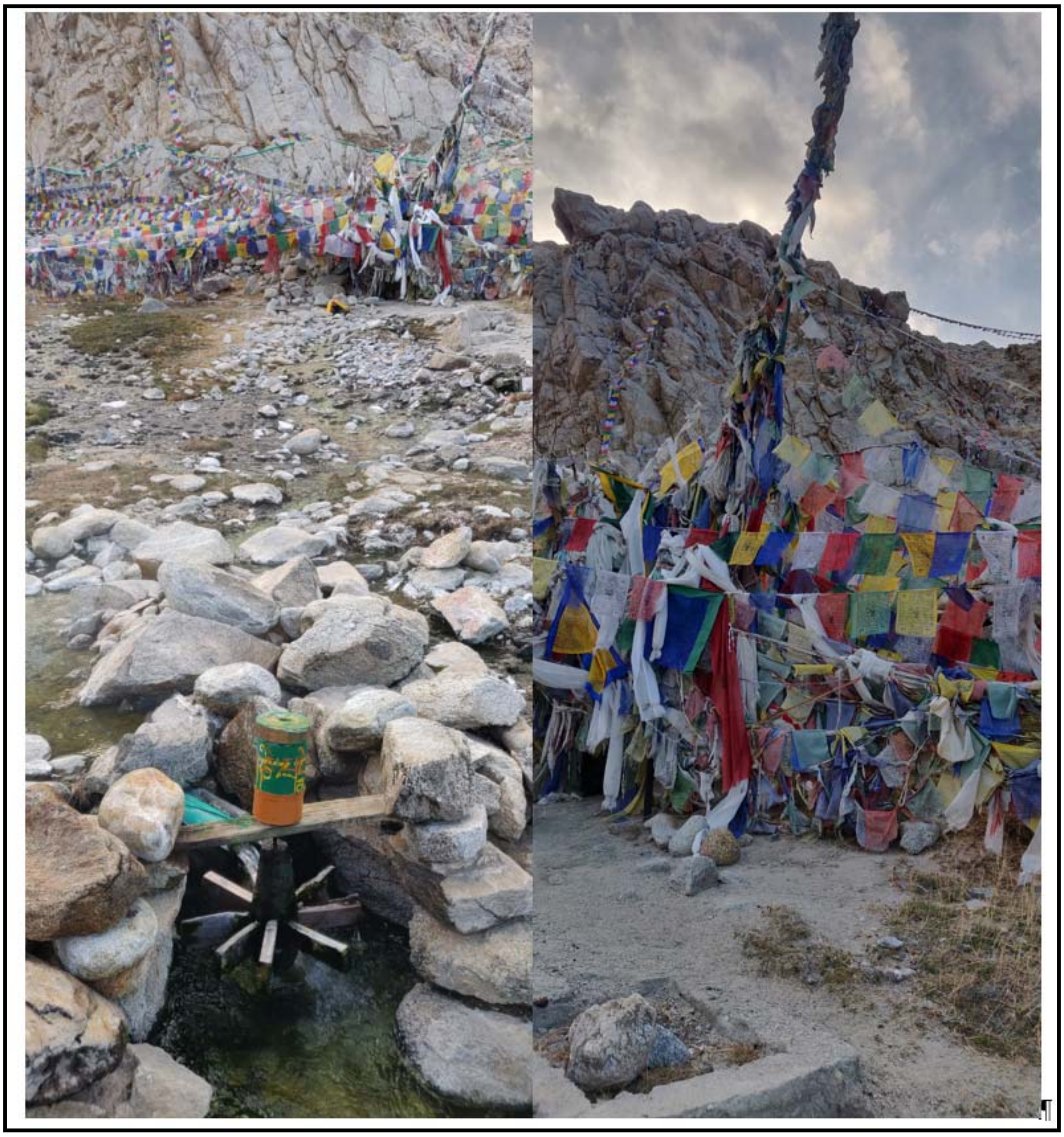

Figure 1.6 Buddhist prayer flags at Demchok hot springs depicting the sacredness of the site for the local people.

1.1.2 Panamik hot spring

Panamik village is located on the famous Silk Route. Travelers used to take a bath in the hot springs of Panamik for the various medicinal properties. At present, there are several government guests houses and bathrooms available for the public as seen in Figure 1.7. The temperature of this hot spring ranges from 65° to 75°C as recorded in July 2019.

The book on Ladakh by author Parvez Diwan mentions the hot springs of Panamik saying that people from all over the district visit the hot springs for their curative qualities. During the period when the Silk Route was open, the travelers from Yarkand (a county and historical town in Xinjiang Uyghur Autonomous Region, China) visited these hot springs as the scaling waters were said to cure rheumatism and syphilis. The author first visited Ladakh in 1981 and in those days venereal disease (VD or STD) was generally syphilis or gonorrhea. STD was rampant in some of the neighboring hills but was unknown in Ladakh. (Parvez Dewan´s Jammu, Kashmir, and Ladakh) This was attributed to the minerals present in the geothermal water of Panamik as seen in Figure 1.8, but is unlikely to be the true explanation (which is outside the scope of this thesis).

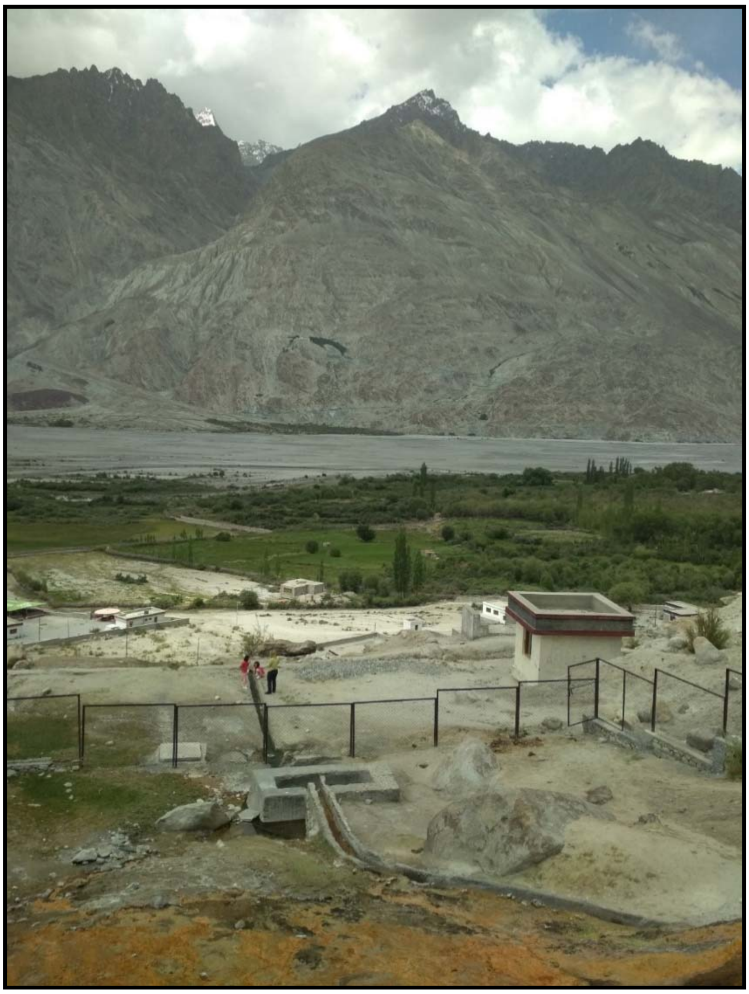

Figure 1.7: Panamik hot springs overlooking the village. The white buildings are government guest houses that are using the hot water directly through pipes for bathrooms.

Figure 1.8: Minerals and algae at Panamik hot springs.

1.1.3 Puga hot spring

Puga is the most widely known and researched hot spring in India. It is also considered the most potential site for power generation with an expected temperature of 200°C at 2,000 m depth (Geological Survey of India, 2002). The Geological Survey of India had demonstration projects on mushroom farming, poultry (Figure 1.9) and borax mining in the 1970s. A total of 35 wells were drilled with the deepest well reaching 350 m. Most of the wells were closed but some remain open and discharging warm water, although they are in a state of dis-repair (Figure 1.11).

As with the other hot springs, people visit the Puga hot springs for treatment of arthritis, etc. Figure 1.12 shows an elderly person soaking in the manmade pool.

Figure 1.9: Present state of the demonstration poultry and mushroom farm at Puga which was successfully implemented by the Geological Survey of India in the 1970s but now abandoned.

Figure 1.10: Condenser at Puga, June 2019.

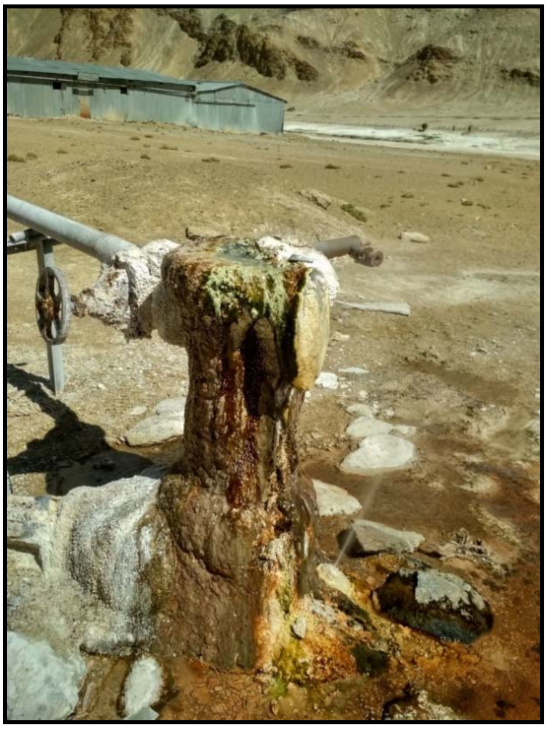

Figure 1.11: The condition of one of the wells at Puga (June 2019). This well was used to heat the poultry farm and the mushroom farm which can be seen in the background. The geothermal fluid was directly circulated in pipes inside the sheds for heating.

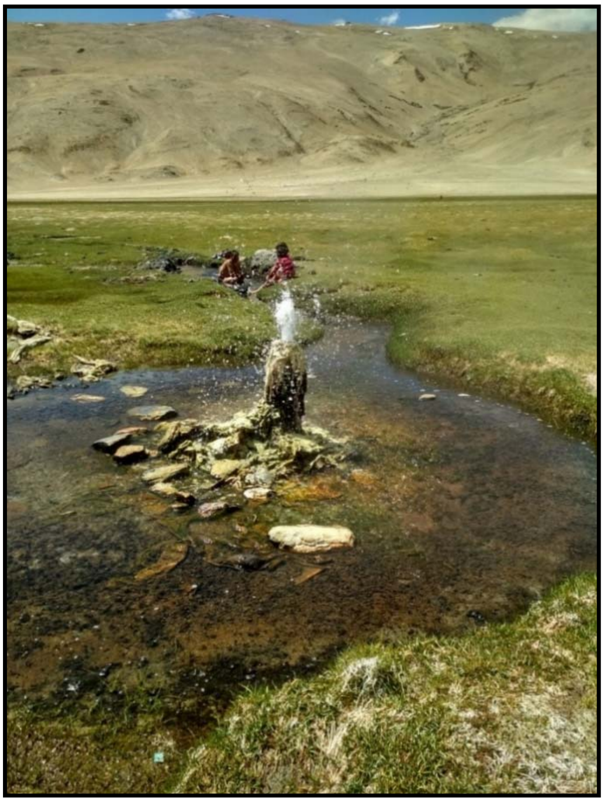

Figure 1.12: An elderly person soaking in the manmade hot spring pool beside the exploratory well drilled in the 1970s (June 2019).

1.1.3.1 Importance of geothermal hot springs in traditional Sowa-Rigpa medicine

Sowa-Rigpa is one of the oldest known ancient medical systems which was practiced in the entire Trans-Himalayan region and Amchi is the one who practices Sowa-Rigpa medicine. The term Sowa-Rigpa means 'Knowledge of Healing' and is derived from the Bhoti language. It is currently practiced in the Himalayan societies of Ladakh, Lahoul and Spiti in Himachal Pradesh. Darjeeling in West Bengal, Sikkim, and Arunachal Pradesh. Internationally it is practiced in Bhutan, Mongolia, and Russia (Ministry of AYUSH, Government of India, 2019). The person who practices this form of medicine is called Amchi in Ladakh. There are some people from Ladakh who trust in Sowa-Rigpa more than in modern medicine. The fundamental principles of Sowa-Rigpa are in Sanskrit language and are called "rGyud-bZi" (Chatush Tantra) which was translated into Bhoti language around 8^{th}-12^{th} Century. These fundamental principles are based on Jung-wa-nga (Pancha mahabutha), Nespa-sum (Tridosha), Luszung-dun (Sapta dhatu) and do´s and don'ts´s, dietary guidelines, pulse examination, etc. which are like Ayurveda.

All the medicines used in Sowa-Rigpa are made of natural herbs found in the Himalayas. Hydrotherapy is an important form of treatment used for many diseases like indigestion, headache, arthritis, skin diseases, etc. Since ages, the hot springs of Panamik, Demchok, Chumathang and Puga in Ladakh has been used in Sowa-Rigpa by the Amchis for treating patients. For example, Puga hot springs are used for the treatment of rheumatoid arthritis, inflammation and the hot springs of Demchok are used to treat indigestion. The time of the treatment depends on some astronomical calculations and is mostly done in either spring or autumn season (Amchi Thinley Namgyal, Yuthog medical clinic, Ladakh, personal communication, 18 February 2020).

1.1.4 Manikaran

Manikaran geothermal site is in is in Manikaran village in the state of Himachal Pradesh situated at an altitude of about 1,700 masl. The village has a population of 6,136 people with 1,295 houses. The nearest town is Bhuntar which is about 45 km away. The geology of this field consists of three sets of shear joints in the form of quartzite with an average spacing of 0.3 to 0.5 m. There are a total of 35 hot springs, 25 of which are located on the right bank of the Parbati river with temperature ranging from 34°C to 96°C. Ten hot springs present on the left bank of the river have temperature in the range of 28°C to 37°C (Geological Survey of India, 2002)

There is a total of 35 hot springs, 25 are located on the right bank of river Parbati with temperature ranging from 34°C to 96°C and 10 hotsprings are on the left bank with temperature range of 28°C to 37°C (Geological Survey of India, 2002). Figure 1.13 shows the geology and the location of hot springs of Manikaran.

Many times the superstition of the people takes precedence over the development of the resource for other types of utilization using machinery. Some examples can be seen in Figure 1.14 and Figure 1.15.

According to the priests at the temple it is believed that Manikaran is connected to Lord Shiva and his divine consort, Parvati, who lost her earrings here which gave birth to hot waters on the bank of Parvati river. This is the reason people from all parts of the country visit this place and take back the hot water and the rice cooked in this water as Prasad for their friends and relatives. This influx of people has let to opening to shops, restaurants, guest houses in this area hence creating economic opportunity for many villagers.

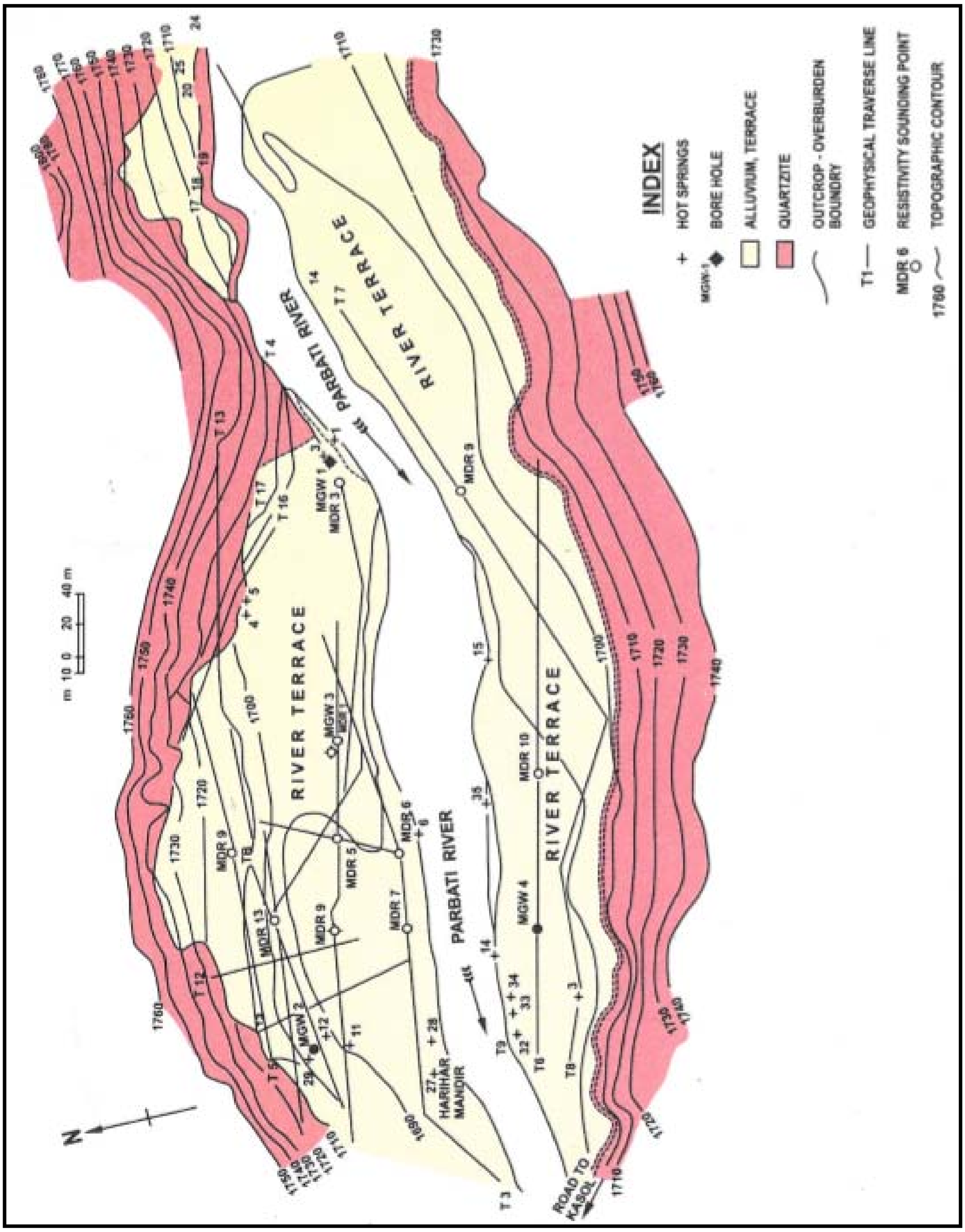

Figure 1.13: Map of Manikaran showing geology, location of hot springs, boreholes and geophysical traverse lines (Geological Survey of India, 2002).

Figure 1.14: Hot spring flowing into the river at Manikaran (May 2019). A Hindu temple and a Sikh Gurudwara (Manikaran Sahib) belonging to the Hindu and the Sikh communities respectively have been constructed on the sites of geothermal manifestation.

Figure 1.15: Statue of God Shiva erected on the spot of hot spring source. The hot spring is considered as Prasad (gracious gift) of Lord Shiva.

1.1.5 Ganeshpuri, Maharashtra

Ganeshpuri is 1,377 kms from Delhi in the state of Maharashtra. It is famous for the temple of Bhagwan Nityanand (Figure 1.16). Figure 1.17 shows the hot spring in the premises of the temple where people take bath and drink the water from the tap. Figure 1.19 shows the map prepared by Geological Survey of India of the hot springs in Ganeshpuri. Ganeshpuri has sixteen thermal springs located in the riverbed as well as terraces on both sides of Tansa river. The surface temperature ranges from 48°C to 58°. Pilgrims from various places come here to take bath in the hot springs and carry back the water with them as Prasad. There are no proper bathing areas and no privacy, hence people (especially women) take baths with their clothes on.

Figure 1.16: Bhagwan Nityanand Samadhi Mandir in Ganeshpuri, Maharashtra.

Figure 1.17: Hot spring in the premises of a Bhagwan Nityanand Samadhi Mandir in Ganeshpuri, Maharashtra. People drink the water from this tap because they believe it is Prashad (gracious gift). They also take a bath in the same pool.

Figure 1.18: Temple can be seen in the background of the hot spring in Ganeshpuri, Maharashtra (May 2019). Despite the unhygienic conditions of the hot spring, people still come to take bath here due to their beliefs.

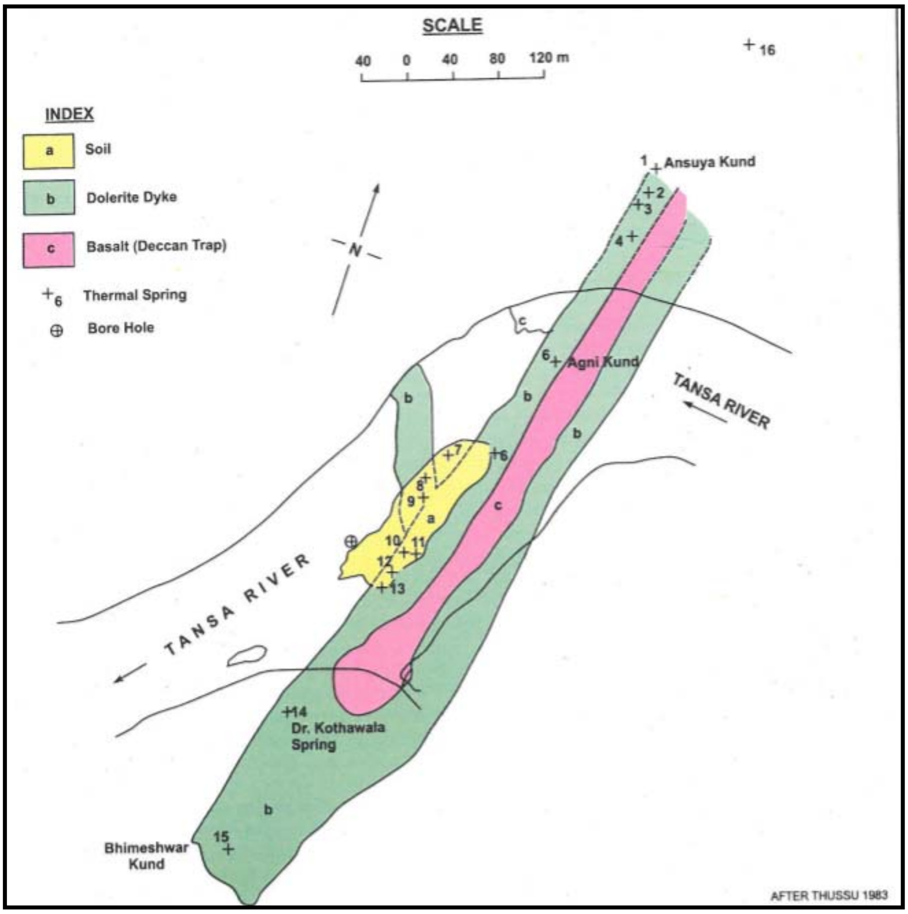

Figure 1.19: Thermal springs of Ganeshpuri, Thane, Maharashtra (Geological Survey of India, 2002)

1.1.6 Rajgir, Bihar

Rajgir is an ancient city in the Nalanda district in Bihar at a distance of 1 196 kms from Delhi. It was the first capital of the kingdom of Magadha which evolved into the Mauryan empire. This place is famous for Hindu, Jain and Buddhist pilgrims due to the religious historical sites like the Vulture's Peak (Gridhra kuta parbat) where the Buddha spent several months meditating and preaching.

The hotsprings in this area have either temple or mosque built around them and thus people of different faith come here for pilgrimage. The belief that these hotsprings are gift of Shiv or Allah is so strong that people are not concerned about the unhygenic conditions of the pools while taking bath. Figure 1.20 and Figure 1.21 shows people taking a bath in the hot springs in Rajgir, Bihar.

Figure 1.20: People taking a bath in the Surya Kund in Laxminarayan temple, Rajgir, Bihar. Kund stands for pool. The belief that the water cures skin diseases makes people take a dip despite the unhygienic conditions.

Figure 1.21: People struggling for their turn to take a dip under the hot spring flowing out of the tap in Rajgir, Bihar.

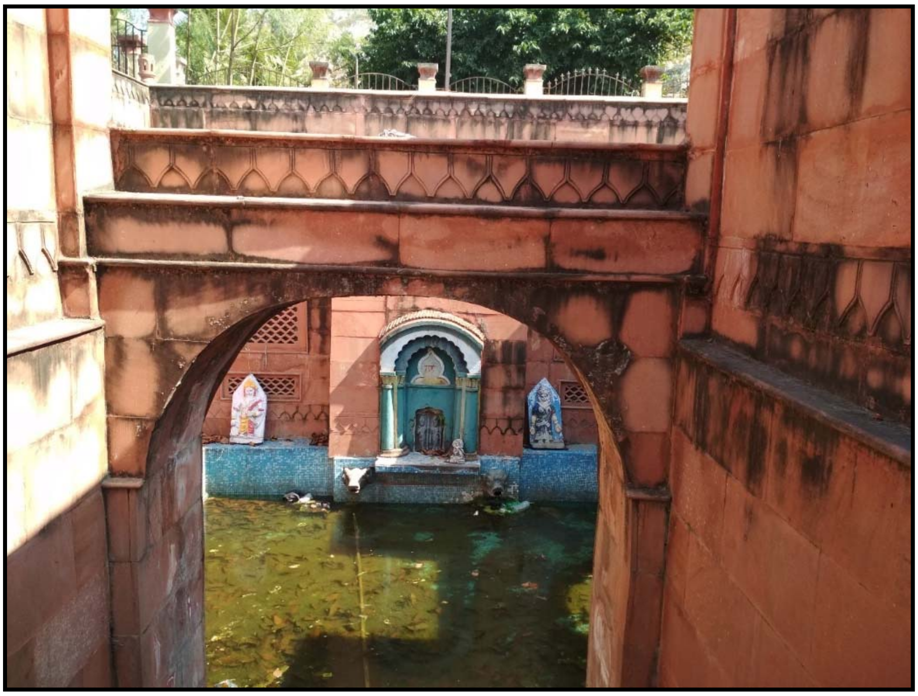

Figure 1.22: Abandoned bathing arena once used for medicinal bathing. Sita Kund, Makhdum Kund, Brahma Kund and Chandra Kund are some of the other pools in this area.

1.1.7 Sohna, Haryana

Sohna is a town 63 kms from Delhi with a population of 53,962 (Wikipedia, 2020). It is the main site where the temple of Shiv is located and the spring is covered by the dome structure and people take bath in the pool outside. The pilgrims and patients who were visiting the site praised about the miracle of their skin disease being cured. The priest incharge of the temple said they stay there for week taking dip in the water considered holy by them. He further mentioned that this hot spring is related to Hindu God Lord Shiva and so it is called Shiv Kund by the locals.

According to GSI, this hot spring is a dug well and not a spring, from which the water is accumulated in a man-made cemented basin enclosed in a dome shaped masonry (Figure 1.23). This main kund (pool) is called Shiv Kund and the water has temperature of 46°C.

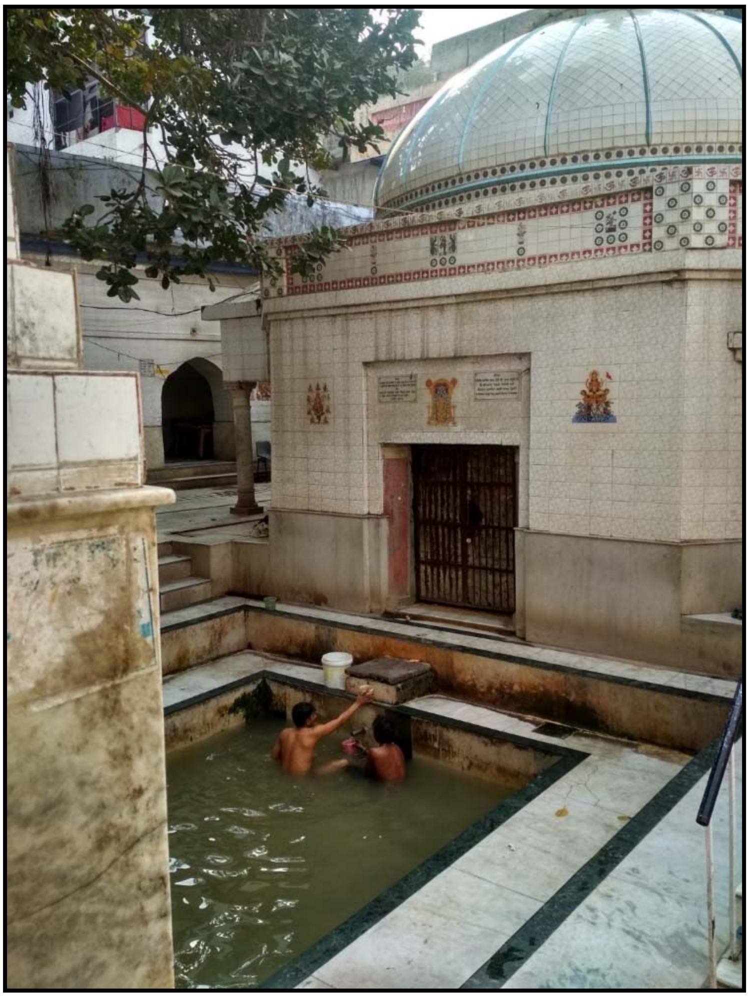

Figure 1.23: The hot spring in Sohna, Haryana where a Hindu temple is constructed at present. As per the Pandit (head priest), people from many states come here and stay for a week to get treated for skin problems by bathing in the pool.

Figure 1.24: The temple at Sohna hot spring.

Figure 1.25: Wells drilled at the Sohna hot spring area and the water is used for gardening and in the bathrooms of the restaurant adjacent to this park.

Figure 1.26: Restaurant near Sohna hot spring. This park is used as an escapade by people from the metro cities like Delhi, Gurgaon as the place is cool and situated on a hillside.

1.1.8 Chumathang hot springs

Chumathang is 170 km from Leh and has several hot springs with surface manifestations as can be seen in Figure 1.27. The hot spring site is a transit point for vehicles going towards Nyoma, Hanley, Tsomoriri, etc.

Figure 1.27: Vapors from surface manifestations at Chumathang.

There are several rooms where people take a bath using geothermal water. There is a traditional Amchi (traditional medicine practitioner) building where patients are treated using geothermal water under the guidance of Amchi. A space heating demonstration project (Figure 1.28) was also done by Norwegian funding with technical expertise from Iceland GeoSurvey (ISOR). This heating system is still used by the restaurant owner who is getting used to this clean energy heating system and wants more such heating system for his hotel. This indicates that the utilization of the geothermal resource can bring positive change in the living condition of people.

Figure 1.28: Radiators installed in the guest room in Chumathang as part of demonstration project.

More technical information on the Chumathang system is given in Chapter 3.

1.2 Discussion and Conclusion

The field visits enabled a description of the conditions and use of the geothermal resources in India. It was found that the current use of geothermal was strongly linked to religious beliefs and the healing properties. Pilgrimage to these sites are made by people of different faith like Hinduism, Islam, Buddhism and Sikhism due to the stories linked to the hotsprings and due to the healing properties for diseases like skin diseases and arthritis.

At present these sites are used for balneology, religious pilgrimage sites and in Chumathang for pilot projects on heating. During the visit it was seen that people come to these sites because of religious reasons which are unshakable. Their faith is so strong that they will drink or take bath in the pools of hotsprings which do not appear to be hygenic.

During the interview with locals and pilgrims it was found that any activity which will lead to a change in the existing religious building structure will harm the sentiments of the people. Many of this sites had small economic zones developed around them like guest houses, shops, street food vendors, restaurants which provided income to many families. On asking the people about the potential utilisation of geothermal energy for space heating cooling, electrification, drying etc, it was found that they had no knowledge. In fact some pilgrims and local residents seem startled when they came to know that geothermal energy can be used for space cooling etc. They were curious to know about the utilisation of geothermal energy when the author was telling them about the potential uses. They are ready to experiment but without any destruction to the existing religious structures. It was humid with scorching temperature of 45°C while the author was travelling to these sites, so most of the head priests were happy to know that they can have space cooling for 24 hours as many of these sites had load shedding for hours.

The main reason for choosing Chumathang as site for case study is that the site is free of religious buildings unlike the others. There is also an urgent need for energy and fresh food. Hence there will not be much resistance from people while carrying out developmental activities in this area like drilling or construction of power plant. Electricity provided currently is for five to six hours in the evening with the help of diesel generator. Power generation will solve the energy problem of remote areas like Chumathang which is otherwise dependent either on diesel generators or off-grid solar photovoltaic providing them with electricity for five to six hours. The compact Organic Rankine Cycle Binary power plants can be used which are capable of producing electricity from 70°C geothermal fluid. The electricity thus produced will be sustainable, reliable and available 24 hours a day adding to the energy security.

Food produced in the greenhouses in the area using geothermal heating could meet some part of the vegetable demand of Ladakh region which is otherwise dependent on the import from other states. The job opportunities due to the development of this site will control the migration of people to other cities to some extent. Hence the overall social impact of utilising geothermal resource was seen to be much greater in Chumathanag which led me to the selection of this area for case study.

The surface temperature of geothermal sites of India which have temperatures ranging from 40°C to 90°C can be used for many direct applications. Some of the applications based on the Lindal diagram (Figure 1.29) that are possible in the above-mentioned sites are greenhouses, binary power plant for electricity generation, aquaculture, space cooling and heating, swimming spas, food drying, cold storage.

In order to develop the geothermal fields with the confidence of people, it is important that at first the local people are given adequate knowledge which was found to be missing during the field visit. Once the people are aware of the benefits of geothermal energy other than balneology, they can voice for the developments of these sites to the politicians which will be much more effective than the same message from an outsider.

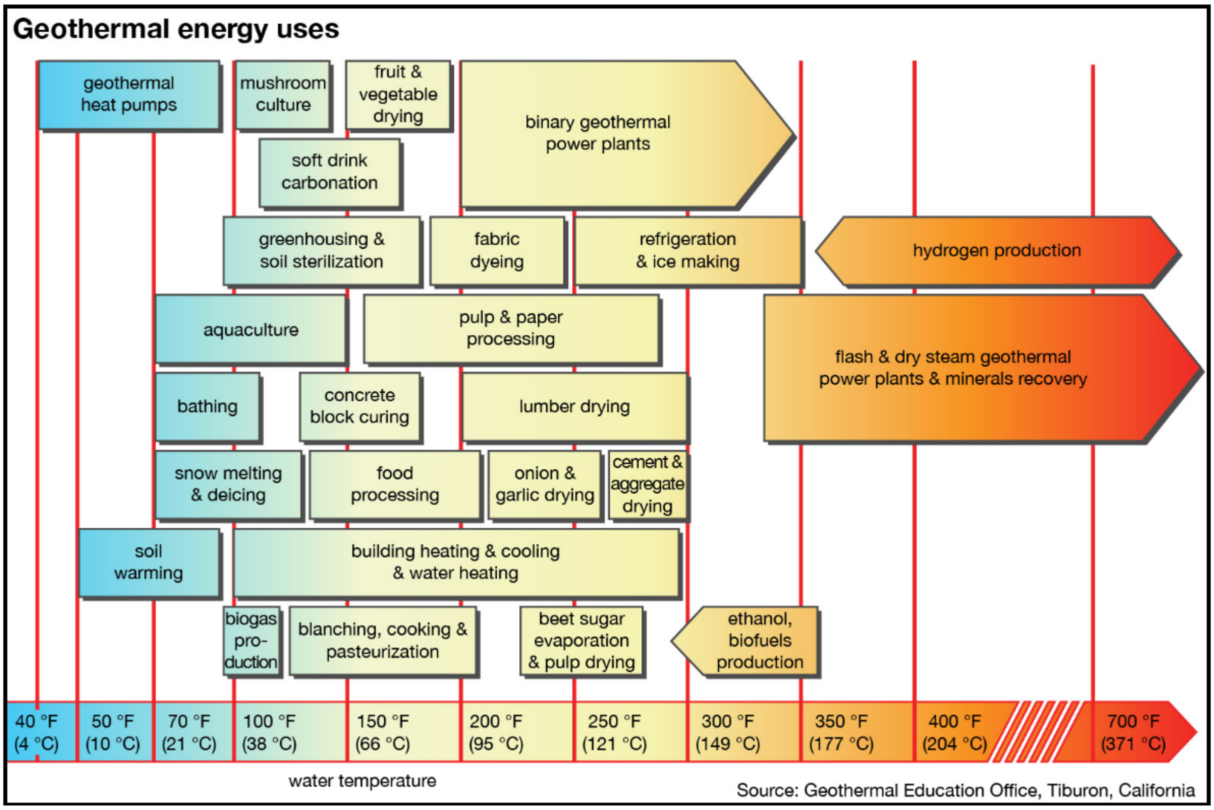

Figure 1.29: The Lindal diagram shows the wide range of possible uses of the geothermal fluid at different temperatures.

Chapter 2

Resources in Ladakh

This chapter gives details on the food and energy resources available in Ladakh. The vast solar, hydro, and geothermal energy resources if utilized sustainably will make Ladakh an energy exporter compared to the present energy-poor region.

2.1 Demography of Ladakh

Ladakh is one of the coldest and most elevated inhabited regions of the world, ranging from 2,300 masl to 5,000 masl. Ladakh has a population of 370,000 of which 75.57% population residing in the rural area. Buddhists consist of 77.30% of the population followed by Muslims with 13.78% and Hindus with 8.16%. The main working force accounts for 33.07% of the total population whereas marginal workers account for 16.50 % and non-workers 49.58%. The main occupation engaging the work force is cultivation (37.92%), agriculture labor (4.28%), household industry (1.24%) and other work (56.56%) (District statistics and Evaluation office, Leh, 2017-18).

Ladakh was made a Union Territory (A union territory is a type of administrative division in the Republic of India. Unlike the states of India, which have their own governments, union territories are federal territories governed directly by the Central Government of India) on 31st October 2019 prior to which it was under the administration of the state of Jammu and Kashmir. The discussion on the advantages and disadvantages of this separation are going on with respect to the actual powers of the local administration regarding job recruitments, project sanctions and implementation. The Union Territory (UT) of Ladakh shares international borders with China on the east and Pakistan on the West and national borders with the state of Jammu and Kashmir and Himachal Pradesh. UT of Ladakh consists of two districts namely Kargil and Leh (Figure 2.1). It is connected to the rest of India via Leh-Srinagar Highway and Leh-Manali highway. The other way one can reach Ladakh is by flying from Delhi, Chandigarh, Jammu or Srinagar. The national highways connecting Ladakh to rest of India are officially closed from October to May.

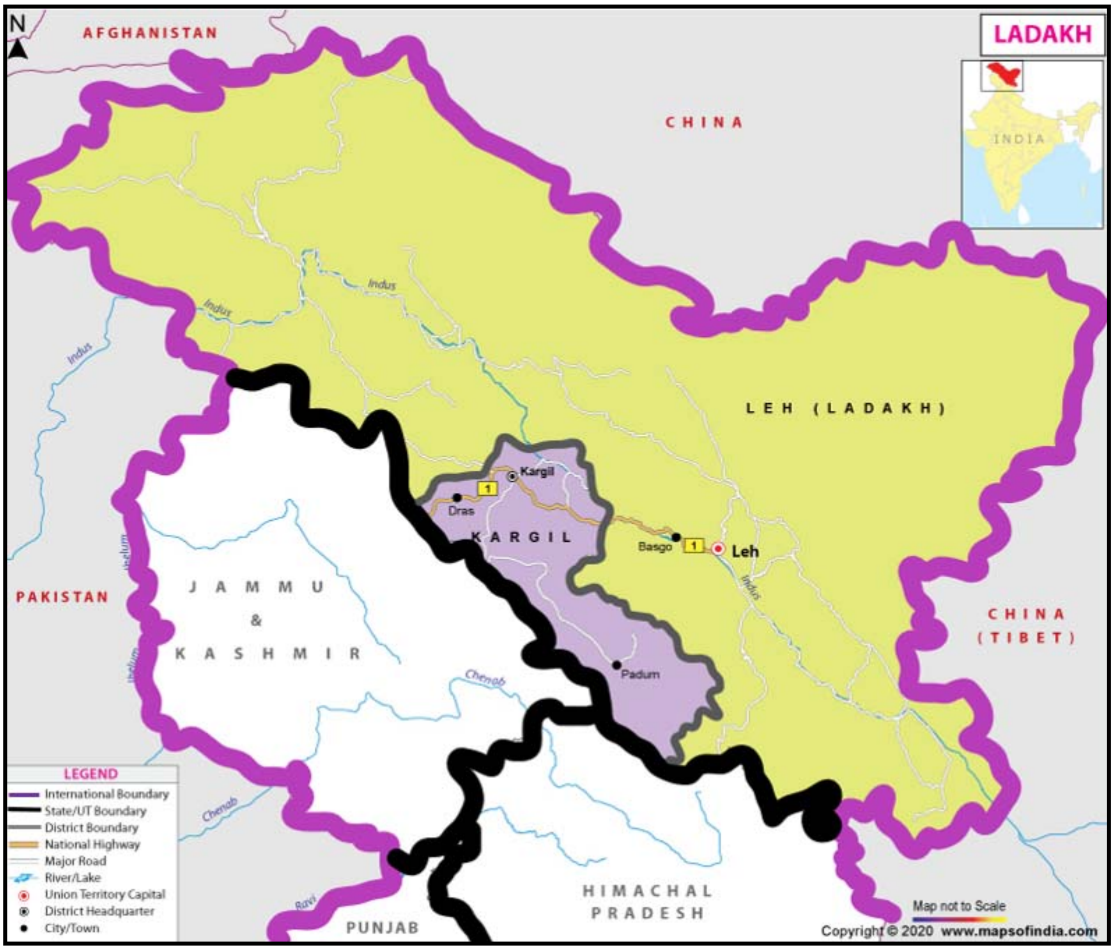

Figure 2.1: Map of Ladakh as 8th Union Territory of India (source: Maps of India). The purple color shows the international boundary of UT of Ladakh, the black line shows the national boundary with other states and the grey line shows the district boundary for Ladakh namely Kargil and Leh.

In terms of an educational institution, there are no professional colleges. This is the main reason for most of the students leaving Ladakh to study in bigger cities such as Delhi, Jammu, Chandigarh, Bangalore, thus draining the economy of the region. Lack of employment opportunities is another reason for migration to other states of the country.

2.2 Food Access/Security

2.2.1 Definition of Food security

Food security started as a concept in the mid-1970s at a time of global food crisis. The initial focus was only on food supply problems of ascertaining the availability and price stability of basic foodstuffs at the national and international levels. The definition of food security has since changed, recognizing that the behavior of potentially vulnerable and affected people was a critical aspect, the Food and Agricultural Organization of the United Nations (FAO, 2003) defined food security as:

"Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life".

2.2.2 Food security and Ladakh

Over the past two decades, the eating habits of Ladakhi people have changed tremendously due to the increase in disposable income and an increase in the tourism industry. More and more agricultural land has given way to hotel buildings making people rely on the import of food. Earlier people grew their food and were the most sustainable society and agriculture was the main source of income.

Apple, apricot, grapes, pear are some of the fruits grown in Ladakh. Barley, wheat, buckwheat are the different grains that are grown here. Now farming is done mostly in the villages only. This has also seen a decline as the people especially the younger generation move to the town and big cities in search of jobs. The region completely depends on the import of food be it the staple like rice, flour or be it fruits and vegetables. These are transported thousands of kilometers from the plains like Delhi and Jammu via Leh. This not only increases the cost triple times but also adds to the increased addition in the CO_2 emissions.

Figure 2.2: A typical vegetable shop in Ladakh. Note that all fruits and vegetables in this shop are imported from the plains of India in trucks. Image source Shutterstock.

During the winter period when the highway is closed there is no access to the fresh food supply. Essential commodities like fossil fuel, rice, and packaged food products, etc. are stocked before the closure of the road. There have been times when the whole region runs out of stock of commodities like packaged milk, sugar, etc. due to uncertainty in the closure of the highway. There has been an initiation from the Consumer Affairs and Public Distribution department of Ladakh for few years to airlift vegetables for the period when the highway is blocked. For this air cargo services of commercial airlines are used and many time People must stand in a queue for hours in order to purchase just 3 kg of vegetables (Figure 2.2).

Figure 2.3: People rushing to get their precious bounty of vegetables in winter.

The ongoing Coronavirus December 2019 (COVID-19) pandemic has shown us how crucial is food security. The closure of both airways and roadways to contain the spread of the pandemic has led to a crisis in the availability of food in Ladakh. People were already suffering from no availability of fresh vegetables and fruits for the long winter period and now the extended closure of the road has only added to the stress. If we compare the situation of Ladakh to the food insecurity severity levels measured by the Food Insecurity Experience Scale (FIES), we find that it lies in the Moderate Food Insecurity level as shown in Figure 2.4

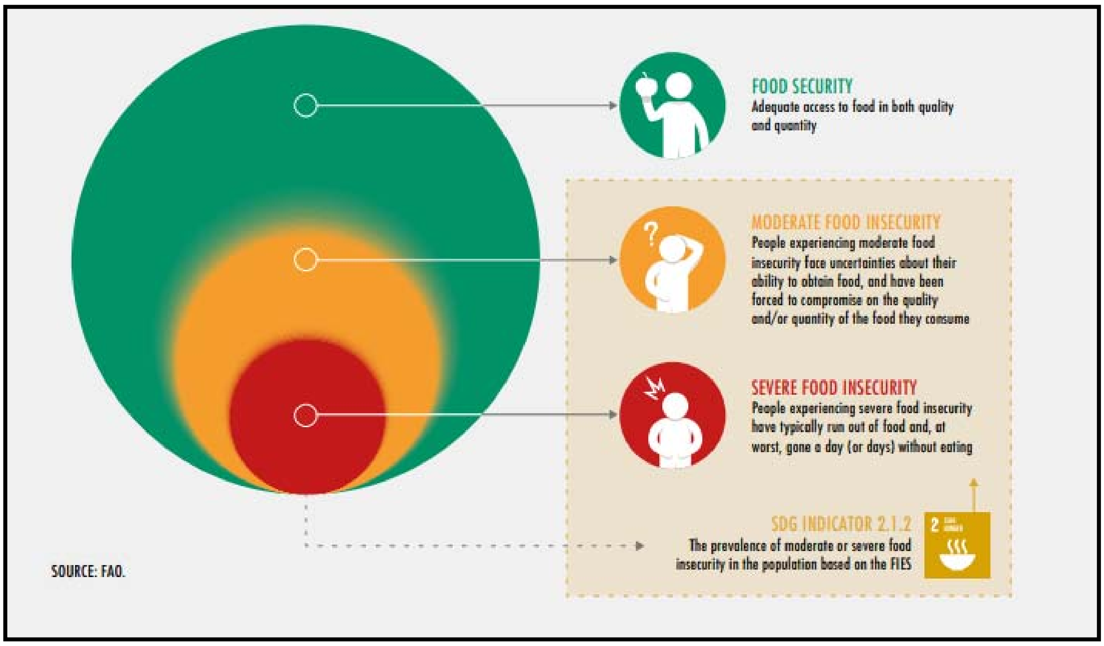

Figure 2.4: Explanation of food-insecurity severity levels measured by the Food Insecurity Experience Scale (FIES) in SDG indicator 2.1.2 (Food and Agriculture Organization of the United Nations, 2019, pp. 5)

2.2.3 Lack of cold storage systems

The fruits and vegetables produced in the short summer season must be either consumed immediately else it gets wasted due to unavailability of cold storage facilities. In recent years we have seen wholesalers from Himachal Pradesh, Srinagar, etc. buying peas, onion at a very low price, and then selling them back in their states. This is due to the absence of cold storage facilities which makes it impossible to store fresh vegetables and fruits produced in Ladakh to store for long term use. Running a cold storage facility becomes expensive due to its dependency on diesel for energy as there is no reliable source of electricity available. Access to reliable energy source will lead to setting up of cold storage systems which can then be used for fresh food stocking to be consumed in the winter months.

2.3 Food market report

An investigation was done to see the demand and supply of fresh vegetables in the winter period when the road is closed, and these supplies must be airlifted.

Figure 2.5: Some vegetables like cabbage, turnip, potato, onion is stored underground in autumn and then sold in the peak winter by the women (PC: Nurzin Angmo, 2020).

The fresh vegetable supply in the area is transported 140 km from Leh after being bought to Leh in trucks from Kashmir or further. Tons of vegetable are imported every month to meet the demands of Leh. In the winter period from October to May, there is no production of vegetables from the local people, and hence there is total dependence on fresh produce from outside the region. In winter, the Leh-Manali highway and the Leh-Srinagar highway are also closed. The only fresh vegetables and fruit supply are airlifted from Jammu and Chandigarh. Due to this, the prices double in winter (Table 2.1). Having commercial greenhouses with a year-round supply of various kinds of vegetables can thus be the only solution to food security.

The quantity of vegetables imported in 2019 after closure of highway in December in Ladakh from the plains of India is given in Table 2.1 (Personal communication, Ruth Mary, Assistant Director, Consumer Affairs and Public Distribution, Leh, February 2020).

Table 2.1: Quantity and cost of imported vegetables in Ladakh.

	Vegetable imported in Ladakh	
	summer	winter
Quantity (kg)	150,000	35,000
The average cost per kilo (USD)	0.9	2
Total amount	**0.135 MUSD**	**0.070 MUSD**

The purpose of showing the cost of vegetables here is to show how expansive it is in comparison to some of the developed countries. For this comparison we can have a look at the per capita income of some different income group countries in Table 2.2. The data for comparison was obtained from The World Bank, 2020a and The World Bank, 2020b.

Table 2.2: Gross national income per capita (GNIPC) of India in USD comparison to the neighboring countries and some developed countries. Data used from World Bank GNIPC 2019 and World Bank list of economies June 2020.

Country	**Income group (World Bank, June2020)**	**Gross national income per capita (GNIPC), World Bank, 2019 (USD)**	**GNIPC world ranking (World Bank, 2019)**
Switzerland	High income	85,500	1
Iceland	High income	72,850	6
United States of America	High income	65,760	7
Germany	High income	48,520	18
Canada	High income	46,370	21
New Zealand	High income	42,670	24
Russia	Upper middle income	11,260	67
China	Upper middle income	10,410	71
India	Lower middle income	2,130	145
Kenya	Lower middle income	1,750	153
Pakistan	Lower middle income	1,530	156
Nepal	Lower middle income	1,090	167
Ethiopia	Low income	850	173
Burundi	Low income	280	192

For example, a kilo of vegetable in Iceland on average cost 4 USD where as in Ladakh it cost 2 USD. The per capita income of Iceland is 34 times more than that of India and as such the expensive vegetables imported in Ladakh are beyond reach for many families. One solution to this problem is having commercial greenhouses.

2.4 The energy situation in the Union Territory of Ladakh (Leh and Kargil district)

2.4.1 Wood and Fossil fuels

Research was done to see the consumption of fossil fuel (only wood) used for burning to keep houses warm during six months of wintertime. Many people also use cow dung along with wood but that is not taken into consideration here. The data was collected for ten households in Chumathang, Panamik and Temisgam villages and twenty households each from the Kargil and Leh town. They were asked about their daily consumption of wood for heating in the winter. Many households use wood and animal dung for cooking purpose throughout the year but that is not considered in this report. The daily consumption of wood for heating ranged from 5 kg to 9 kg per day. Some factors for this variation was the use of liquid petroleum gas (LPG) based heating. An average of the wood consumption is used for this report (Table 2.3).

Table 2.3: Wood used by household in Ladakh for building heating

S. No	Particular	Quantity
1	Wood used for heating	7 kg/day/household
2	Wood consumption in seven months of winter	1,410 kg
3	Cost per quintal (100 kg) firewood	17 USD
4	Expenditure by one household on firewood in winter	240 USD
5	Per capita income	2,130 USD

It was seen that most of the households had to buy wood for their consumption and this wood are mostly transported from Kashmir in trucks. From Table 2.3, we can see that 11.25% of the per capita income goes only for heating in winters.

Ladakh imports all the fossil fuel through Public Sector Undertaking companies like Hindustan Petroleum Corporation Limited (HPCL), Indian Oil Corporation Limited (IOCL) (Personal communication, Rigzin Wangtak, Sr Manager, Institutional Business, IOCL, Ladakh, September 2019). Around 65,000 MUSD worth of oil coming to Ladakh through IOCL which comprises 80% of the requirement of Ladakh. The rest of the 20% of fossil fuel is supplied from other oil companies like Hindustan Petroleum Limited (HPCL) and Bharat Petroleum Corporation Limited (BPCL). So, the total fuel consumption of Ladakh supplied by IOCL is worth 110 MUSD per year (Table 2.4).

Table 2.4: Import of fossil fuel for civil and defense consumption by Indian Oil Corporation Limited (IOCL) in the year 2019

S. No	Particular	Quantity (kiloliters)
1	Petrol, Kerosene, Diesel, Aviation turbine fuel	109,892
2	The average cost per KL (USD)	1,000
3	**Total Cost per year (USD)**	**109,891,350**

This imported fossil fuel is used both by the civilian and the defense population for running vehicles, electrification and heating in winter. Local sources suggest that 95% of the energy used in defense is from fossil fuel in Ladakh. This heavy dependence on the imported fossil fuel is a major threat for national security especially in the remote areas where having electricity grid is not possible now due to terrain. Hence having a reliable local energy source is not only important for the civil population but also necessary for national security.

2.4.2 Energy resources available in Ladakh

Ladakh has a great potential for renewable energy sources like solar, hydro and geothermal. The main agencies responsible for implementing renewable energy projects are Kargil Renewable Energy Development Agency (KREDA) in Kargil, Ladakh Renewable Energy Development Agency (LREDA) in Leh and Jammu and Kashmir State Power Development Corporation (JKSPDC).

There is a local rumor about possible formation of a Ladakh Power Corporation Limited for the newly created UT of Ladakh (Personal communication, Rigzin Samphael, Commissioner Secretary, UT Ladakh, January 2020). This will be a big step as the UT Ladakh will be able to make its own regulations and policies regarding power development projects.

2.4.2.1 Hydropower resource

Ladakh has three major rivers namely Indus, Shayok and Suru with estimated hydropower potential of 960 MW. The current installed capacity of Hydro power is 110 MW with 45 MW Nimoo-Bazgo as the largest one in Leh (Personal Communication, Shiv Kumar, Executive Engineer, Jammu Kashmir Power Development Corporation, Leh, July 2019).

Figure 2.6: Aerial view of Nimoo-Bazgo 45 MW Hydro Project commissioned in 2013 (Wikimedia commons, 2013)

2.4.2.2 Geothermal resource

Ladakh is considered to have the best potential geothermal resource in India with a temperature in the range of 60°C to 90°C. Sections 1.1.8, 1.1.1, 1.1.2, and 1.1.3 gives more detail about the Ladakh geothermal systems.

Ladakh has hot springs with temperatures ranging from 60 to 85°C (Figure 2.7). The first records of the hot springs of Ladakh can be found in the book by Alexander Cunningham, a British engineer. He mentions hot springs of Panamik in Nubra, Chumathang, Demchok and Puga in Changthang in his book (Cunningham, 1854). He mentions that the volcanic neighbourhood of Puga is something like that of the Tuscan lagoons near Monte Cerbole.

Details about these geothermal sites have been discussed in Chapter 1.

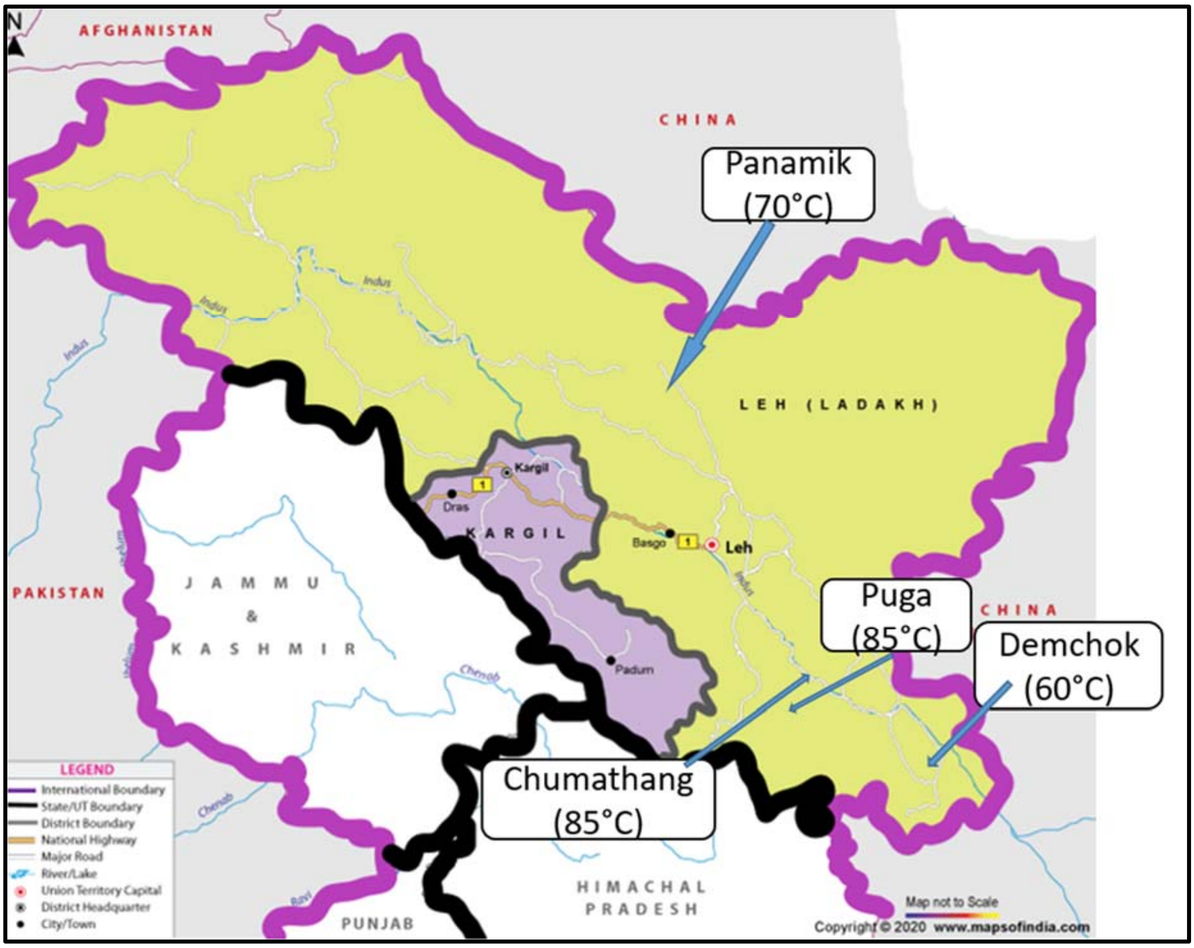

Figure 2.7: Map showing Ladakh with geothermal sites and its border with international countries (adapted from maps of India).

2.4.2.3 Solar resource

The solar energy potential of Ladakh is 23,000 MW and the Government of India through the Solar Energy Corporation of India (SECI) aims to install 7,500 MW of solar in Ladakh by 2023 for 60,806 MUSD (Aiyar, 2019).

2.4.2.4 Wind resource

According to the National Institute of Wind Energy (NIWE), Ladakh has a wind power potential of 5,311 MW at a hub height of 50 m and 100,000 MW at a hub height of 120 m (Joshi, 2019).

2.5 Conclusion

The lack of access to reliable energy and fresh food supply is a threat to food security, energy security and national security in case of Ladakh. The market research done on the chosen case study has revealed the problem faced by the consumers as well as the shopkeepers. The shopkeepers had problem in supplying food in the winter months when the region is disconnected and on the other had the consumers suffered due to unavailability of fresh vegetable and due to the exorbitant prices charged in winter. Having energy supply in order to grow vegetables throughout the year is the solution to achieving food security.

Ladakh has a huge potential for renewable energy which is untapped till now. Despite this richness in energy sources, people of Ladakh still do not have access to a 24-hour reliable electricity supply. For heating of homes, they depend on fossil fuel which is transported from the plains of India in tankers. Ladakh shares international borders with China on the east and Pakistan on the west. This strategic location makes it more important to have a reliable energy supply in the region. It is not only a matter of energy security but a matter of national security.

The current installed capacity of hydropower is not able to meet the electricity demand let alone heating of thousands of houses. The upcoming Gigawatt Solar project is a positive step towards a better energy supply but due to its intermittency it will not be able to provide a 24-hour reliable energy supply.

The geothermal sites of Ladakh have the best potential in India. This is the only source that will be able to provide a reliable energy supply even in the coldest months of the year when the temperature dips below -20°C. This is the reason that hydropower generation either decreases by half or zero in the peak winter.

The development of the geothermal sites for power generation and direct uses will increase the employment opportunities in the region. This will further improve the living condition of the people in these remote areas and reduce migration to cities in search of jobs.

Chapter 3

Chumathang

Chumathang is the case study area of this thesis. This chapter describes the geology and the geothermal resource potential of the area.

3.1 The Demographics

Chumathang village is 140 km south-east of Leh at an altitude of 3,950 masl with ambient temperature ranging from -25 to +25°C. There are 127 households with a population of 641 people (District statistics and Evaluation office, Leh, 2017-18). Chumathang geothermal field is about 40 km north of the Puga field. The nearest highway which connects it to the rest of India is Leh-Manali highway open from June to October. The nearest airport is in Leh.

The village has a government Anganwari center (playschool), veterinary dispensary/animal husbandry center, a sheep husbandry center and a block office. Most of the families have women who do all the household chores as well as farming activities. The health of women is affected the most due to the absence of energy and proper nourishment. Anemia is common in many women (Personal communication, Dr Tashi Thinlas, Physician, SNM Hospital, Leh-Ladakh, July 2019).

The nearest agriculture/fruit market is 138 km from Chumathang. For education, there is a Government-funded Primary school, Middle school, and High school. There is an absence of a hospital, private school, and college. The nearest hospital is 138 km in Leh. Most of the families send their children to Leh or other major cities of India like Delhi, Jammu or Chandigarh for better education. For higher studies in professional courses like engineering or medical one must go outside Ladakh due to the absence of such institutions in Ladakh. This puts a lot of financial burden on the parents.

The electricity requirement of Chumathang village is met by a diesel generator of 20 kW that supplies power for five to six hours in the evening. The requirement of space heating is high in the region and is met by burning fossil fuel like wood, kerosene. Women suffer the most from lack of access to clean and reliable energy. Women do most of the domestic chores, including collection of wood for the fire to cook or to warm houses. This means they have no time to build financial security or further skill development.

3.2 Regional geology

Puga – Chumathang hot spring is located along the convergent junction of two crustal plates, which were involved in the Himalayan Orogeny (Figure 3.1). Geological mapping in the upper Indus valley area identifies three major tectonic belts. These are:

- Northern belt,
- Central belt and
- Southern belt.

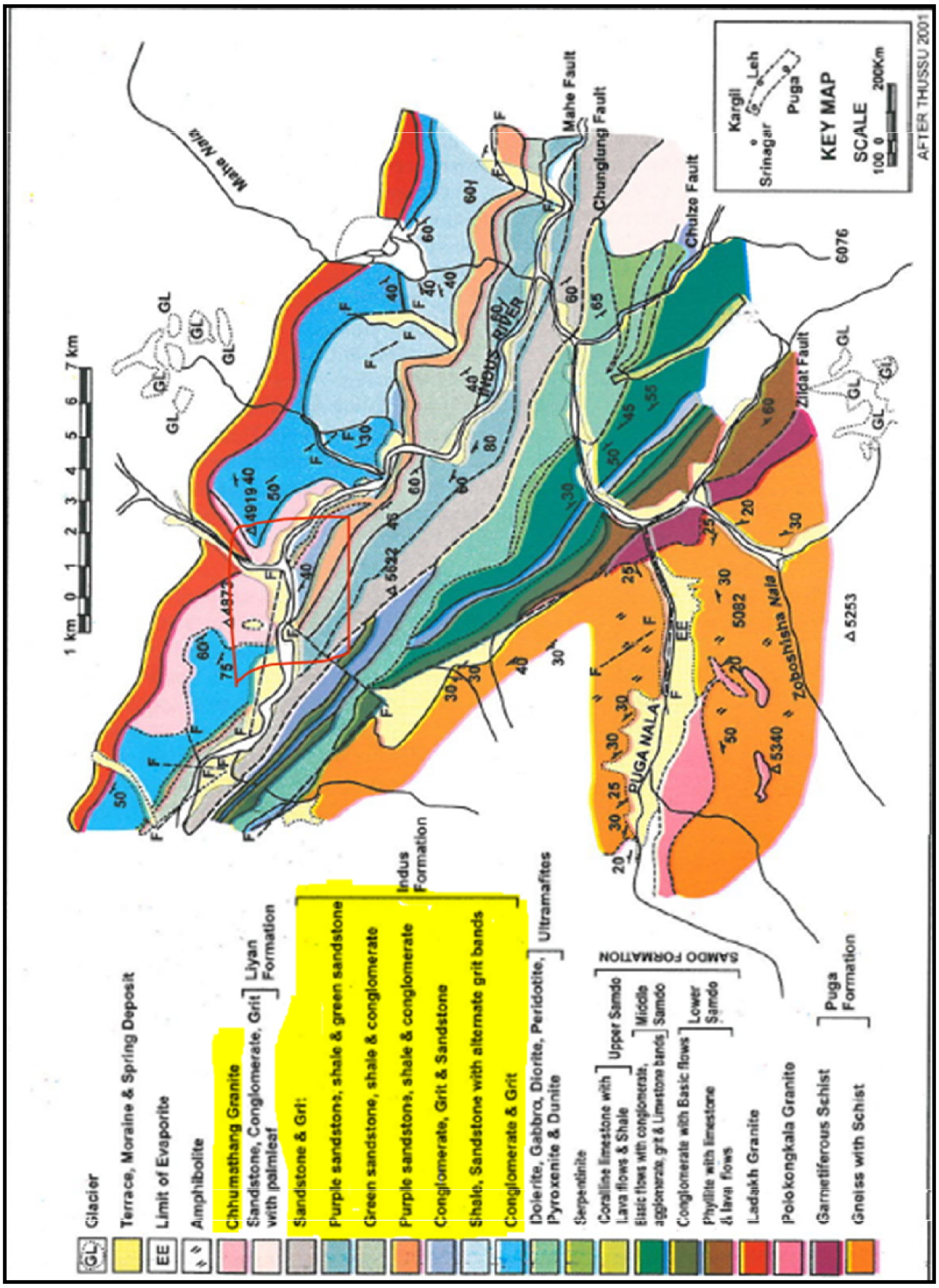

Figure 3.1: Lithology of Chumathang(Geological Survey of India, 1991). Chumathang is the area selected in the figure.

The Chumathang geothermal field is located in the Northern belt. This belt consists of thick sequence of sediments of shallow marine to fluvial origin (the Indus Formation) deposited over the older granite basement (Figure 3.1). These consist of a thick pile of coarse clastic sediments of continental deposits between the Ladakh granite range in the north and Ophiolite suits of rocks (Sumdo Formation) in the south. The sedimentary sequence is intruded by Chumathang granite. This is exposed near Chumathang and extends westwards into Ladakh granite.

3.3 Subsurface temperature

Six boreholes were drilled by GSI in the area for assessing the geothermal gradient, to delineate up-flow zones and deep reservoir conditions. The boreholes were drilled in the depth range of 20 m to 221 m. Artesian conditions were struck in four boreholes. The maximum temperature of the thermal water was 109°C. No measurements were made on the quality of thermal fluids. All the boreholes were completed in the overburden material and bedrock was not reached in any of the boreholes.

The geothermometry shows that Chumathang has a resource temperature ranging from 140°C to 170°C (Geological Survey of India, 2002). The Chumathang system is likely to be deep convection through faults. It is difficult to extrapolate temperature data to estimate the depth of the 140°C isotherm. An estimate based on expert opinion (Personal communication, Bjarni Richter, Director Geothermal, ISOR, Sep 2019) 1,000 m is the minimum depth to reach the minimum temperature for a binary power plant.

3.4 Geothermal Resource Assessment

To set up any geothermal project it is important to know whether there is a good resource for which Volumetric Resource Assessment is done. A volumetric resource assessment was done for the Chumathang geothermal field to know the power generation potential.

3.4.1 Theoretical background

Geothermal resource evaluation (resource assessment) is a process of evaluating surface discharge and downhole data and integrating it with other geoscientific information obtained from geological, geophysical and geochemical measurements. The main focus of geothermal resource evaluation or resource assessment is to confirm that there exists a geothermal resource that could be exploited at a certain capacity for a certain period with well-defined fluid characteristics and resource management strategies to ensure production sustainability over a long term period (Sarmiento, Z. F., Steingrímsson, B., & Axelsson, G., 2013). There is a lot of information on Chumathang, but this is a first attempt at addressing geothermal utilization in the area; however, this initial feasibility assessment will provide a methodology and indicate requirements for future data collection.

3.4.2 Thermal energy calculation

The volumetric assessment is a method to calculate the thermal energy in the rock and the fluid which could be extracted based on specified reservoir volume, reservoir temperature, and reference or final temperature technique refers to the calculation of warm vitality in-the stone and the liquid which could be separated dependent on indicated store volume, repository temperature, and reference or last temperature. This method is based on the work applied by the USGS to the Assessment of Geothermal Resources of the United States. In their work, the last or reference temperature is based on the ambient temperature, following the exhaust pressure of the turbines (for electricity generation). In many cases, a reference temperature equivalent to the minimum or abandonment temperature of the geothermal fluids for the intended utilization of the geothermal reservoir pick is also chosen

(Sarmiento et. al, 2013). The abandonment temperature for space warming is typically 30-40°C however for electricity generation the reference temperature is normally ~180°C (the seperation temperature) for regular force plants and 130°C for binary power plants. It is imperative to remember, in any case, that the efficiency used for the particular energy generation process be based on the same reference temperature, whatever reference temperature is selected.

The volumetric resource assessment method involves estimating the total energy content in a geothermal system and how much of that can be extracted over a given period, based on the volume and temperature of the reservoir. It is usually employed when the data available is sparse and more detailed modeling (e.g. lumped parameters or numerical modeling) cannot be done, however, it does not consider the dynamic response of the reservoir and its geometry. Such responses are e.g. pressure change, recharge, permeability, etc. This accounts for the uncertainty in many of the parameters used in volumetric calculations. The volumetric method is usually a first stage assessment method for geothermal resource assessment. The Monte Carlo method is usually applied to volumetric calculations to consider the overall uncertainty in the results obtained. Probability distributions, P90, P50 and P10 for 90%, 50% and 10% probability of a given outcome, respectively, are assigned to different parameters of the governing equations (Tulinius, 2019).

The governing equations for total thermal energy in a liquid dominated geothermal reservoir is given by

$$Q_T = Q_r + Q_w$$

where

$$Q_r = A \cdot h \cdot [\rho_r \cdot C_r \cdot (1 - \theta) \cdot (T_i - T_f)]$$

and

$$Q_w = A \cdot h \cdot [\rho_w \cdot C_w \cdot \theta \cdot (T_i - T_f)]$$

If the reservoir has two-phase zone existing at the top of the liquid zone then the following set of equations is used to separately account fot the liquid and steam components in the reservoir:

$$Q_T = Q_r + Q_s + Q_w$$

where

$$\mathrm{Q_r} = \mathrm{A} \cdot \mathrm{h} \cdot [\rho_\mathrm{r} \cdot \mathrm{C_r} \cdot (1 - \Theta) \cdot (\mathrm{T_i} - \mathrm{T_f})]$$

$$\mathrm{Q}_s = \mathrm{A} \cdot \mathrm{h} \cdot [\rho_{si} \cdot \Theta \cdot (1 - S_w) \cdot (H_{\mathrm{si}} - H_{li})]$$

$$\mathrm{Q}_w = \mathrm{A} \cdot \mathrm{h} \cdot [\rho_{li} \cdot \Theta \cdot S_w \cdot (H_{\mathrm{li}} - H_{li})]$$

Where,

Q_T	= Total thermal energy (kJ)
$\mathrm{Q_r}$	= Heat in rock (kJ)
Q_s	= Heat in steam (kJ)

A	= Area of the reservoir (m^2)
H	= Average thickness of the reservoir (m)
C_r	= Specific heat of rock at reservoir condition (kJ/kgK)
C_s	= Specific heat of steam at reservoir condition (kJ/kgK)
C_l	= Specific heat of liquid at reservoir condition (kJ/kgK)
T_i	= Average temperature of the reservoir (°C)
T_f	= Final or abandonment temperature (°C)
θ	= Porosity (%)
S_w	= Water saturation
ρ_{si}	= Steam density (kg/m^3)
ρ_w	= Water initial density (kg/m^3)
H_{li}	= Initial water enthalpy (kJ/kg) and
H_{fi}	= Final water enthalpy (kJ/kg)

The above equations provide the total thermal energy of the reservoir. To size the power plant that could be supported by the resource, the following equation is further used.

$$P = \frac{(Q_t \cdot R_f \cdot C_e)}{P_f \cdot t}$$

where

P	= Power potential (MWe)
R_f	= Recovery factor
C_e	= Conversion efficiency
P_f	= Plant factor and
t	= Utilization time period in years (economic life)

- Recovery factor: Recovery factor is the fraction of the stored heat in the reservoir which could be extracted to the surface. It is dependent on the fraction of the reservoir that is considered permeable and on the efficiency by which heat could be swept from these permeable channels.

- Conversion efficiency: The conversion efficiency takes into account the conversion of the recoverable thermal energy into electricity. More accurately the conversion can be estimated in two stages, first the conversion of the thermal energy into mechanical energy and later the conversion of the mechanical energy into electrical energy. This is not considered necessary, in view of all the uncertainties involved in the volumetric assessment method, so applying a single thermal-mechanical-electrical efficiency is considered sufficiently accurate.

- Economic life: The economic life of the project is the period it takes the whole investment to be recovered within its target internal rate of return. This is usually 25-30 years.

- Plant factor: The plant factor refers to the plant availability throughout the year taking into consideration the period when the plant is scheduled for maintenance, or whether the plant is operated as a base-load or peaking plant. The good performance of many geothermal plants around the world places the availability factor to be from 90-97%.

3.4.3 Monte Carlo Volumetric calculations

The Monte Carlo Software developed at ÍSOR (Iceland Geosurvey) was used for the volumetric calculations. The input parameters used for the calculations are given below.

a) Area: The suitable geothermal manifestation/reservoir area in Chumathang is spread over 3 km^2 (Personal communication, Dr Ahsan Absar, Director, GSI). Values of 2.0 km^2, 2.5 km^2, and 3.0 km^2 were used for the pessimistic, optimistic and most likely areas.

b) Thickness: The thickness of the reservoir layer of sandstones ranges from 15 m to 100 m. Therefore, values of 15 m, 100 m, and 80 m were used for the pessimistic, optimistic and most likely thickness, respectively.

c) Reservoir temperature: Temperature value considered for the minimum temperature is the minimum temperature at the surface of the reservoir layer 75°C) and the maximum temperature is the temperature at the bottom of the reservoir layer (170°C). Therefore, values of 110°C, 170°C, and 140°C were used for the pessimistic, optimistic and most likely values, respectively.

d) Porosity: Based on the compaction curve of Limberger et al. (2018) for sand sediments, at a depth of 3 km, the porosity is approximately 0.14. Therefore, values of 0.10 (pessimistic), 0.18 (optimistic) and 0.14 (most likely) were used.

e) Specific heat capacity of rock: Based on Engineering Toolbox (2019a), specific heat capacity of sandstone is about 830 J/kg°C. For this study, the following values were used; 800 J/kg°C (pessimistic), 880 J/kg°C (optimistic) and 830 J/kg°C (most likely)

f) The density of rock: Based on the Engineering Toolbox (2019b), sandstones have a density ranging from 2,100 – 2,400 kg/m^3. Therefore, values of 2,100 kg/m^3, 2,400 kg/m^3 and 2,250 kg/m^3 were used for pessimistic, optimistic and most likely density, respectively.

g) Specific heat capacity of water: This will be calculated by the volumetric software based on the input temperature of the reservoir.

h) The density of water: This will be calculated by the volumetric software based on the input temperature of the reservoir.

i) Recovery factor: Recovery factor values of 5% (pessimistic), 20% (optimistic) and 12.5% (most likely) were used (Gudni Axelsson, ÍSOR, personal communication, 20th October 2019)

j) Cut-off temperature: Cut off temperature of 75°C was used, assuming a binary power generation mode for the geothermal resource.

k) Efficiency: Estimated efficiency values of 11%, 16%, and 13.5% were used for pessimistic, optimistic and most likely values, respectively.

l) Load Factor: Estimated load factor values of 95% was used.

An energy utilization period of 30 years was used for the simulation which was done with 1,000,000 Monte Carlo runs. Table 3.1.shows the input values and parameters used for the volumetric calculation and

Table 3.1: Input parameters for the Monte Carlo volumetric assessment of Chumathang geothermal field.

Monte Carlo Volumetric

File

Rock Type:	Sandstone	Number of Monte Carlo runs	10000
Display output distribution in:	MegaWatts	Number of bins in Histograms	100
Show pop-up plots?	No	Time of energy usages [years]	30

	Min	Best Value	Max	Distribution type
Area [km²]	2.0	2.5	5	Triangular distribution
Thickness [m]	1000	N/A	2000	Triangular distribution
Temperature [C°]	110	140	170	Triangular distribution
Porosity [%]	10	14	18	Triangular distribution
Specific heat of rock [J/(Kg C°)]	800	830	880	Triangular distribution
Density of rock [Kg/m³]	2100	2250	2400	Triangular distribution
Specific heat of water [J/(Kg C°)]	N/A	N/A	N/A	From temperature
Density of water [Kg/m³]	N/A	N/A	N/A	From temperature
Recovery factor [%]	5	12.5	20	Triangular distribution
Cut-off temperature [C°]	N/A	70	N/A	Fixed value
Efficiency [%]	11	13.5	16	Triangular distribution
Load factor [%]	N/A	95	N/A	Fixed value

Table 3.2: Results of Monte Carlo volumetric assessment.

Results	
Most likely value	7.1 MWe
Start of 90% acceptance range	4.1 MWe
End of 90% acceptance range	16.8 MWe
Highest Value	33.3 MWe
Lowest Value	1.5 MWe
Mean	9.2 MWe
Median	8.5 MWe
Standard deviation	4.0 MWe
Skewness	1.1 MWe^-2

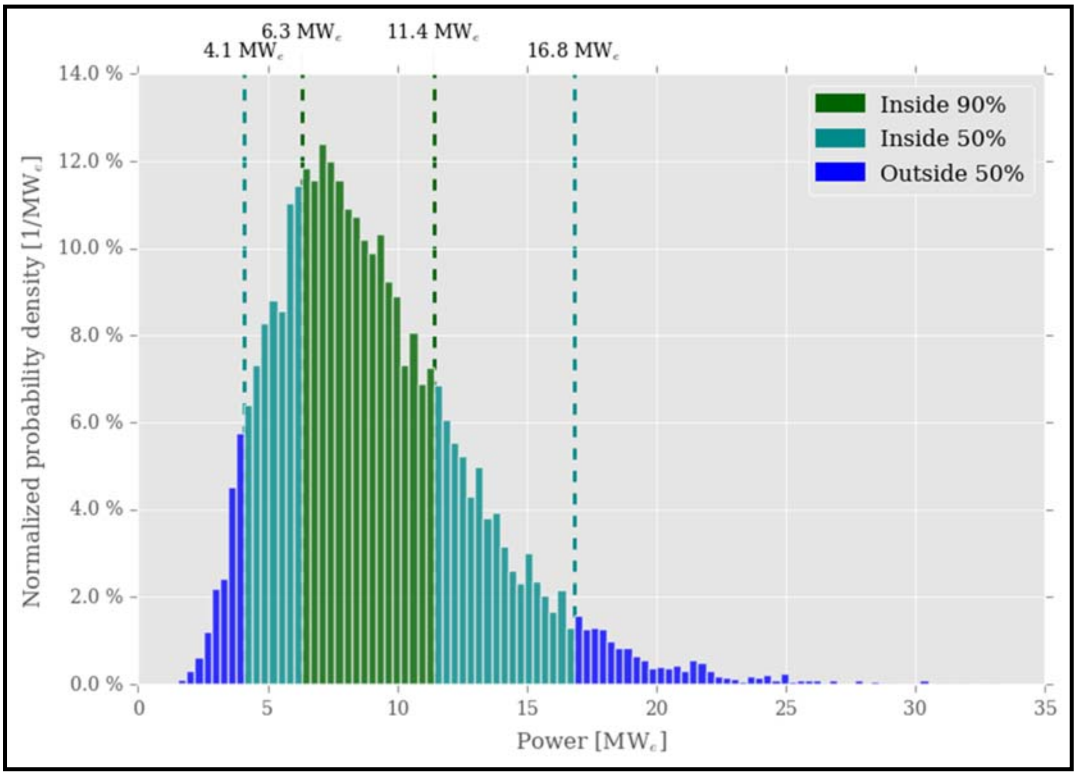

Figure 3.2: Probability distribution for Monte Carlo volumetric assessment of the Chumathang geothermal reservoir

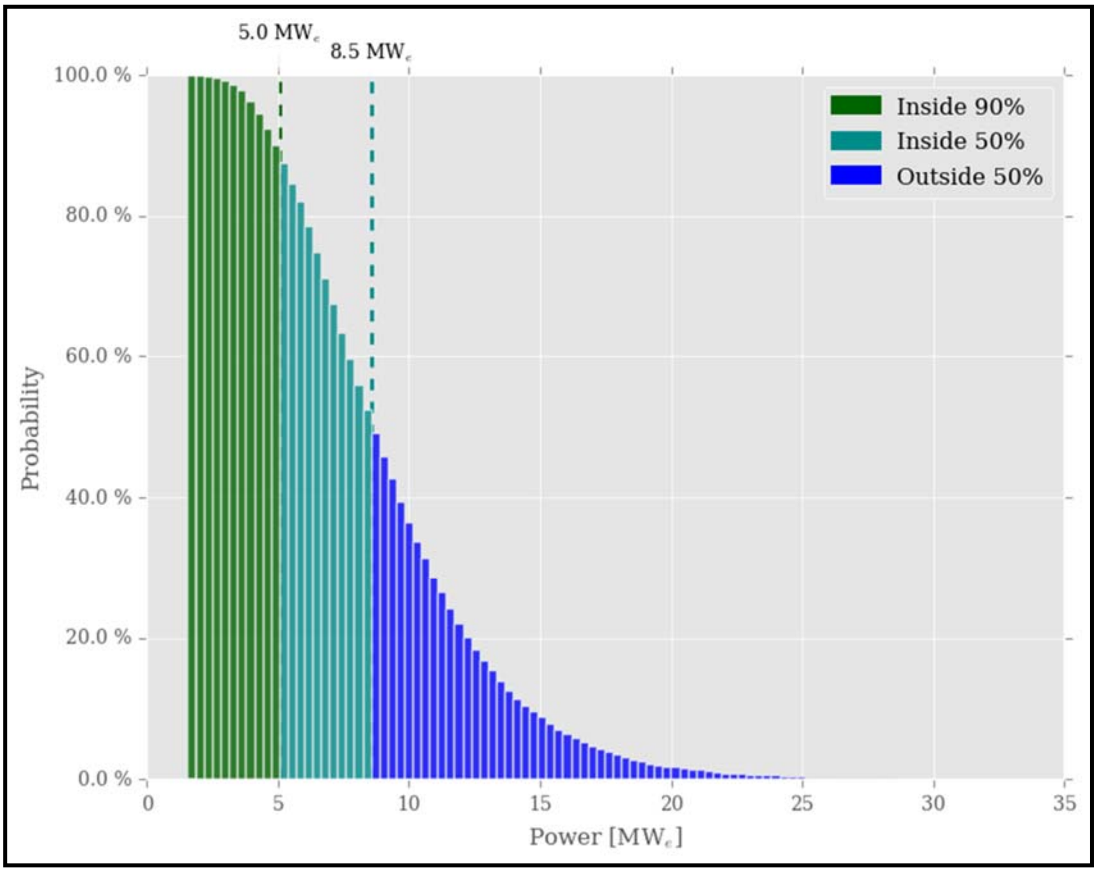

Figure 3.3 Cumulative probability distribution for Monte Carlo volumetric assessment of the Chumathang geothermal reservoir.

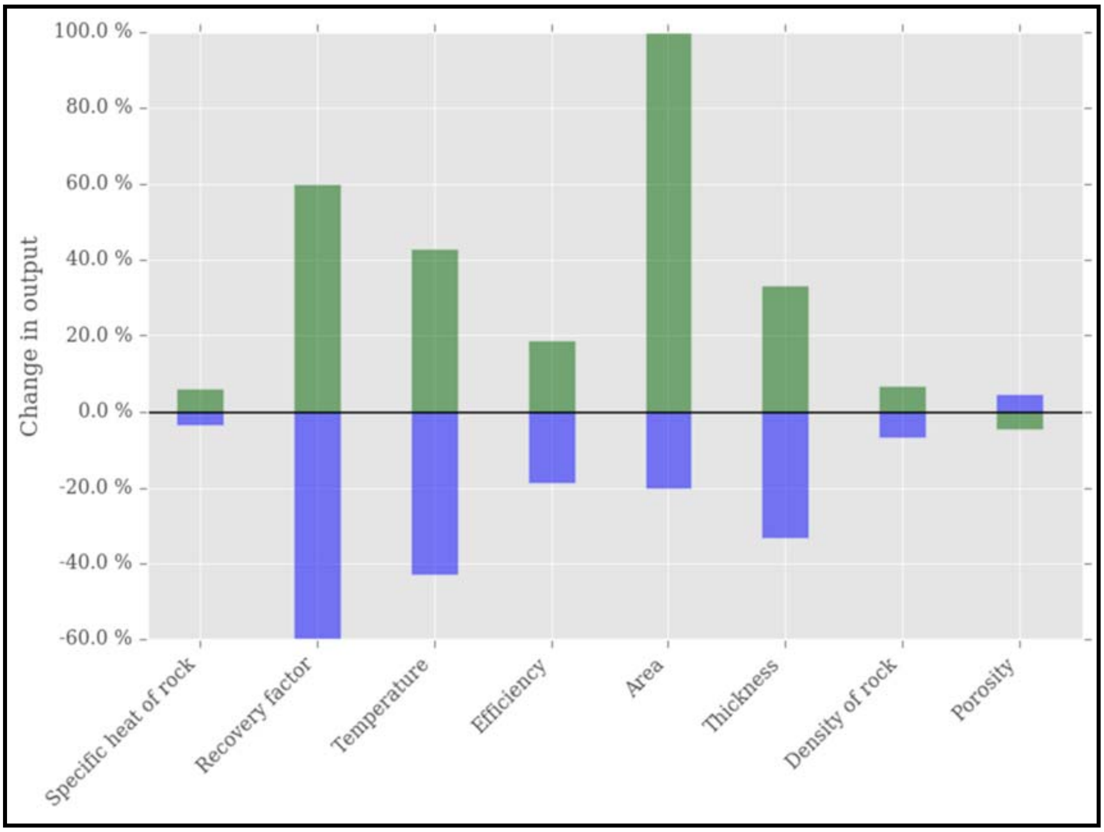

Figure 3.4: Sensitivity of the volumetric assessment results in the input parameters.

Table 3.3 shows the cumulative probability thresholds.

Table 3.3: Cumulative probability thresholds.

Cumulative Probability Thresholds:		
P95%	4,1	MWe
P90%	5	MWe
P85%	5,4	MWe
P80%	6	MWe
P75%	6,3	MWe
P70%	7	MWe
P65%	7,3	MWe
P60%	7,6	MWe
P55%	8,2	MWe
P50%	8,5	MWe
P45%	9,2	MWe
P40%	9,5	MWe
P35%	10,1	MWe
P30%	10,8	MWe
P25%	11,4	MWe
P20%	12,4	MWe
P15%	13,3	MWe
P10%	14,6	MWe
P5%	16,8	MWe

Most likely value	7,1	MWe
Highest Value	33,3	MWe
Lowest Value	1,5	MWe
Mean	9,2	MWe
Median	8,5	MWe
Standard deviation	4	MWe
Skewness	1,1	MWe^-2

An 8½"open hole well with 9 5/8” production casing can accommodate a pump that can deliver at least 40-50 kg/s or even more. Mass flow of about 180 kg/s of 120°C temperature would be required for 4 MWe gross. If the temperature is 140°C, then the mass flow of geothermal fluid needed would be about 100 kg/s.

For this report we have designed the plant capacity to 5 MWe which will suffice the energy requirement of Chumathang considering that at present only 20 kW diesel generator is providing electricity to the village. For an estimation of the sustainability for 25 years, drilling and flow test will be required.

2-3 production wells will probably be needed with a depth of 1,000 m and 1-2 reinjection wells to have 5 MWe output. In general, the production wells should be sited within the fracture zone (with the hot water) as close to the mountainside as possible. The reinjection wells, if needed, could be either in another fracture zone or the same but close to the Indus river (downstream from the up/outflow).

3.5 Conclusion

The Monte Carlo Volumetric assessment was done to calculate the geothermal resource availability of the Chumathang site. There is not much data available on the geology of the region so certain assumptions were made in consultation with Guðni Axelsson, Chief Geophysicist, Icelandic Geosurvey (ISOR) and Bjarni Richter, Director, Geothermal, ISOR.

The most likely potential of the Chumathang site is 7.1 MWe and the highest potential value is 33 MWe. At present the village is electrified by a diesel generator of 20 kW. The power plant is designed for 5 MWe which will suffice the electricity needs of the village with resource temperature of 140°C in the next chapter and a greenhouse is designed to cater to the food security issue in chapter 6. The extra electricity produced will be transferred to the local grid for supply to the nearby villages.

Chapter 4

Binary Power Plant

The type of power plant considered is binary power plant due to the low temperature of the geothermal field. The closed cycle loop of the binary plant will further help in low maintenance of the plant during operation. This section gives an overview of the main components of geothermal binary power plants and the design parameters used in this case study. The process of a binary power plant is shown in Figure 4.1 and Figure 4.2 shows the 48 MW binary power plant at Cerro Pabellon in north of Chile.

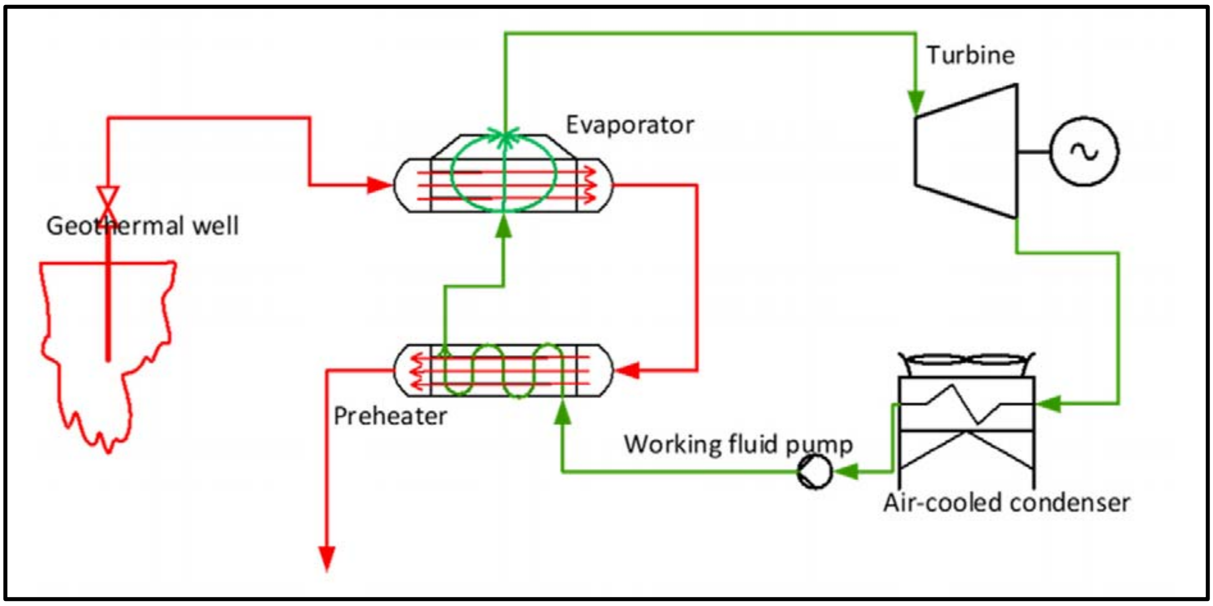

Figure 4.1: Schematic of Binary cycle power plant with shell and tube heat exchanger.

Figure 4.2: 48 MW Binary power plant, Cerro Pabellón, Chile. This plant is in the Atacama Desert in the Antofagasta region at an altitude of 4,500 masl (source: ThinkGeoEnergy).

4.1 Power Plant Components

4.1.1 Preheater and Vaporizer

In a binary power cycle, preheater and the evaporator are closed, heat exchangers. There is no contact between the geothermal fluid and the working fluid. They can either be shell & tube or plate heat exchangers. Due to the ease of operation, shell and tube heat exchangers are preferred over plate heat exchangers (Verkis, 2014). The pressure at the shell and tube heat exchangers is easier to control, an important property to control to avoid the escape of gases from the geothermal fluid and precipitation. They are furthermore easier to clean. Shell and tube heat exchangers are however more expensive and take up more space than the plate type and are difficult to clean.

4.1.2 Heat exchanger Pinch

The minimum temperature difference that can be attained between the geothermal fluid and the working fluid in the heat exchanger is called the Pinch temperature/pinch-point. Low pinch values contribute to higher plant efficiency but then it contributes to higher capital costs. The lower the pinch value the higher the price of the heat exchangers. Low pinch value implies a larger heat exchanger area and eventually selection of more expensive material. The pinch-point temperature difference is generally known from the manufacturer's specifications.

In actual practice, the choice of pinch temperature is an optimization exercise between cost and efficiency and the final choice is in the hands of plant vendors.

4.1.3 Turbine

The binary cycle turbine is responsible for converting the vapor thermodynamic energy of the working fluid to mechanical work on the turbine shaft which is coupled with the generator (Valdimarsson, 2011).

Most binary plants are nowadays supplied as turn-key plants, i.e. one company supplies the equipment: heat exchangers, turbine(s), generator, cooling system, control, and instrumentation although buying and installing individual equipment is an option. The choice of material depends on the working fluid used in the loop. Standard turbines are available on the market for small plants ranging from 250 to 10,000 kW and it is common to have a single or a double-flow turbine, the single/double-flow corresponding to the number of inlets. Single flow is usually considered sufficient for smaller power plants. Double flow turbines are often used for larger plants and have the advantage of allowing for the shutdown of one inlet without a complete production shutdown. It is common to have two turbines to drive one generator installed on one shaft between the turbines for binary plants larger than 5 MW (Verkis, 2014).

The isentropic efficiency of the turbines is up to 85 %. The gross work output of the real turbine is this enthalpy change multiplied by the working fluid mass flow and its isentropic efficiency. It is possible to calculate the gross electrical output by multiplying the gross work the output of the turbine by the efficiency of the generator.

4.1.4 Working fluid/media

A binary power plant makes use of geothermal fluid to heat a secondary working fluid that runs in a closed system. The figure shows the process flow diagram (PFD) and the principal components of the binary power plant. The geothermal fluid is passed through a heat exchanger and after the transfer of heat to the working fluid it is often pumped back to the ground or use for cascade applications. In the heat exchanger, heat gets transferred to the working fluid. When the working fluid exits the heat exchanger, it has a vapor quality of near to 100%. At this stage, the vapor is sent to the turbine where the thermal energy is converted to mechanical energy. In the turbine, the vapor loses some of the thermal energy it possesses and exits the turbine normally as two-phase flow. At this stage, the working fluid needs to regain the pressure it had before the turbine. To do that it is sent to a condenser to condense the working fluid and after that, it can be pumped back up to the correct pressure.

The selection of the working fluid has great implications for the performance of a binary power plant. There are many choices available for working fluids but at the same time, there are many constraints on the selection related to the thermodynamic properties of the fluids, health, safety, and environmental impact.

Table 4.1 shows the thermodynamic properties of some candidate working fluids for binary plants. We can see from the table that all the working fluids have critical temperatures and pressures far lower than water.

Table 4.1: The thermodynamic properties of some candidate working fluids for binary

plants.

Fluid	Formula	T_c °C	T_c °F	P_c MPa	P_c lbf/in^2	P_s@300 K MPa	P_s@400 K MPa
Propane	C_3H_8	96.95	206.5	4.236	614.4	0.9935	n. a
i-Butane	i-C_4H_{10}	135.92	276.7	3.685	534.4	0.3727	3.204
n-Butane	C_4H_{10}	150.8	303.4	3.718	539.2	0.2559	2.488
i-Pentane	i-C_5H_{12}	187.8	370.1	3.409	494.4	0.09759	1.238
n-Pentane	C_5H_{12}	193.9	380.9	3.240	469.9	0.07376	1.036
Ammonia	NH_3	133.65	272.57	11.627	1686.3	1.061	10.3
Water	H_2O	374.14	705.45	22.089	3203.6	0.003536	0.24559

4.1.5 Pumps

For the wells, we will use vertical pumps that are submerged into the well. This brings the pressure up to 5 bar absolute. For the Rankine cycle, we will use horizontal pumps that will be located near to the ACC and heat exchanger.

4.1.6 Cooling technologies

Steam is condensed and cooled before re-injection in closed-loop steam systems. The heat gained in the working fluid in the Binary cycle must be rejected to make continuous power. Following are the typical methods of heat rejection used in Binary Power Plants.

4.1.6.1 Water cooling

Water is used to cool the vapor back into a liquid so it can be used again in the generation process.

4.1.6.2 Air-cooled condenser

Air cooling is defined as rejecting heat from an object by flowing air over the surface of the object through convection. The air must be cooler than the object or surface from which it is expected to remove heat. This follows the second law of thermodynamics which states that heat will only move spontaneously from a hot reservoir (the sink) to a cold reservoir (the air) (National Renewable Energy Laboratory, 2018).

The region is at a location of 4,300 masl and the average annual temperature is 2°C. This condition makes it logical to select an air-cooled condenser (ACC). The ACC is a type of a surface condenser where the working fluid flows through a bank of finned pipes and is cooled down with ambient air. The air draft is created with fans.

A brief of the list of types of equipment used in Binary ORC Power Plants is given in Table 4.2

Table 4.2: The list of types of equipment for basic binary power plants

S. No	Components	Types of equipment
1	Down hole pumps and motors	Multistage centrifugal pumps, line shaft – driven from surface-mounted electric motors or submersible electric pumps
2	Brine supply system	Sand removal system, solids knock-out drum.
3	Brine/working fluid heat exchangers	Preheater: Horizontal cylinder, liquid-liquid, shell and tube type with brine on tube side and working fluid on the shell side, or vertical, corrugated plate type. Evaporator: Horizontal cylinder or kettle-type boiler, Superheater section (optional), Brine on the tube side, working fluid on the shell side.
4	Turbine-generator and controls	Working fluid turbine (axial or radial flow), generator, and accessories.
5	Working fluid condenser, accumulator and storage system	Condenser Dump tank and accumulator: holding tank large enough to store full capacity of working fluid charge Evacuation pumps to remove working fluid to storage during maintenance.
6	Working fluid feed pump system	Condensate pumps Booster pumps (as needed)
7	Heat rejection system	Wet cooling system: water cooling tower with an external source of make-up water, cooling water pumps and motors, cooling water treatment system (as needed) Dry cooling system (if a source of make-up water is not available): Air-cooled condensers with manifolds and accumulator, Induced draft fans and motors.
8	Back-up systems	Standby power supply
9	Brine disposal system	Brine return pumps and piping: Horizontal, variable-speed, motor-driven units High-head, high-volume flow design.
10	Fire protection system (if working fluid is flammable)	High-pressure sprinkler system Flare stack

4.2 Conceptual design

The general arrangement of any power plant is site-specific. Chumathang is very well connected to the rest of Ladakh and is a transit point for people traveling from Nyoma to Leh. Figure 4.3 shows the approximate location of the power plant which is near the source.

Figure 4.3: Location of the Binary Power Plant in Chumathang, Ladakh

The heat exchangers, turbine and generator are located next to ACC to minimize pipe lengths. The well location is shown by the red dot and the main pipeline by the red line. A buffer tank for the working fluid is located near to the ACC and set up in such a way that if it would explode than there is nothing located in the axial direction of the tank. A fire water tank is located next to the control room. The geothermal fluid available in Chumathang will be having a temperature of 140°C so a binary power plant will be installed to generate power. The geothermal fluid coming out of the heat exchanger can be used for cascade utilization like greenhouse heating, space heating, and recreation. A detailed assessment of cascade uses other than the greenhouse is beyond the scope of this report.

4.2.1 Power plant modeling

For the modeling of the power plant, the following parameters were chosen.

The temperature of geofluid = 140°C.

Pressure from well pumps = 5 bar absolute.

To make sure that the geothermal fluid has no steam, the wellhead pressure is increased to 5 bar using vertical pumps. This also makes the fluid more suitable for reinjection into the ground without the use of a separate injection pump. To avoid scaling due to the geothermal fluid phase change reinjection temperature of 50°C is selected.

The monthly average ambient temperature of Chumathang over a period of ten years from 2009 to 2019 can be seen in Figure 4.4.

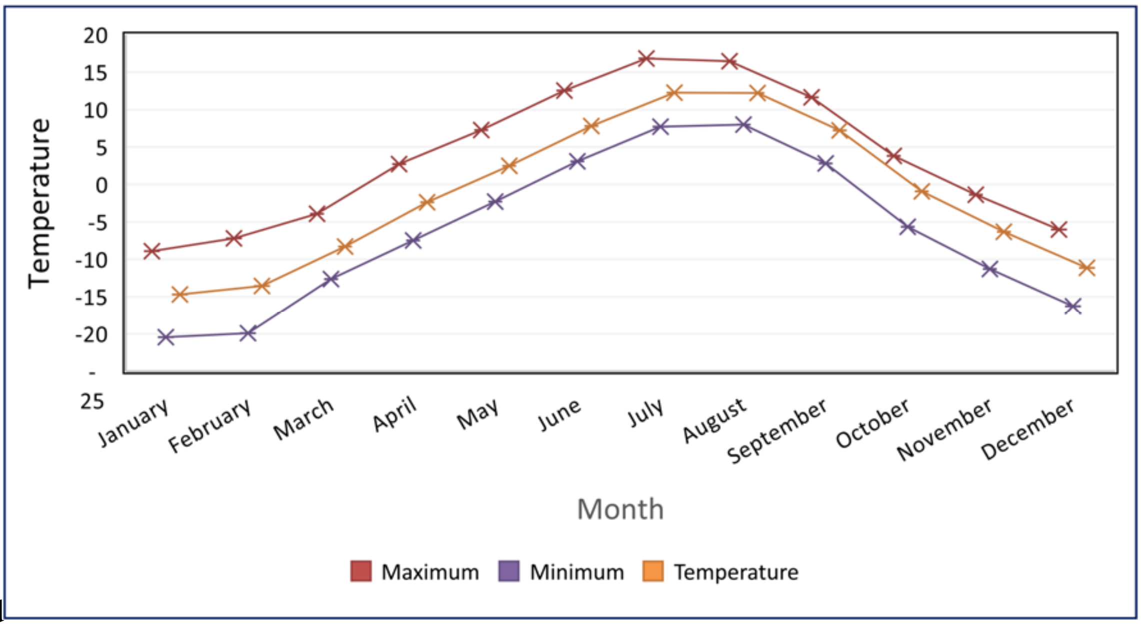

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Figure 4.4: Annual monthly temperature in Chumathang, Union Territory of Ladakh (adapted from world weather online, 2020).

The different design parameters considered for the Binary power plant are shown in Table 4.3.

Table 4.3: Parameters for the Binary power plant.

Inputs		Units
Well mass flow	100	Kg/s
Downhole temperature	140	°C
Re-injection temperature	50	°C
Heat exchanger TTD	45	°C
Air-cooled condenser air temperature	2	°C
ACC TTD	5	°C
Range	10	°C
Subcooling	3	°C

4.2.2 Working fluid selection

The properties of the working fluid affect the design of the turbine and the heat exchanger and therefore the costs. The choice of the working fluid is characterized by several factors such as the thermodynamic characteristics of the system, the environmental impact, the flammability and the toxicity of the organic compound. In general, the working fluid should guarantee the highest possible efficiency, hence, the maximum output power. The main thermodynamic properties are listed below:

- High Conductivity: The conductivity affects the coefficient of conduction in the heat exchangers.

- Low Viscosity: Low viscosity, either in the liquid phase or in the steam phase, means low friction losses in the exchanger and a high coefficient of thermal transmission.

- Evaporating pressure: This is the maximum pressure achievable. Working with a low evaporating pressure means reducing the costs and complexity of the system.

- Molecular weight: In some cases, the molecular weight of an organic fluid can be higher than the one of the waters. Working with a fluid with a high molecular weight means having a fluid with high critical temperature, therefore it is possible to work with high-temperature sources achieving higher efficiency. Moreover, molecular weight means high density and low specific volume with benefits regarding the space occupied by the system and the design of the turbine.

- Security Level: Flammability and toxicity are two factors that must be considered to guarantee a high-security level, reducing the leakage risk.

Table 4.4 shows a comparison between different low-temperature binary geothermal power plans and their fluids.

Table 4.4: Comparison of Binary Power Plants using low geothermal fluid temperature, T_{geo}.

Plant and location	T_{geo}(°C)	Cycle	Working fluid	Gross capacity (kW)	Cooling tower
Nigorikawa, Japan	140	Rankine	R114	1,000	Wet
Otake, Japan	130	Rankine	Isobutane	1,000	Wet/dry
Husavik, Iceland	124	Kalina	NH_3-H_2O	1,700	Wet
Nagqu, China	110	Rankine	Isopentane	1,000	Dry
Altheim, Austria	106	Rankine	C_5F_{12}	1,000	Dry
Wabuska, CA, USA	104	Rankine	Isopentane	1,750	Wet
Chena hot Spring, Alaska, USA	74	Rankine	R134a	400	Wet/dry
Kutahya-Simav, Turkey	145	Rankine with superheat	R124	2,900	Wet

4.3 Analysis and efficiencies

4.3.1 Turbine analysis

When we calculate the work produced by the turbine, we assume that there is no heat loss from the turbine.

$$W_{turb} = \dot{m}_{R134a} \cdot (h_3 - h_4)$$

The enthalpy in position 5 is found by using the formula for turbine efficiency.

$$\eta_{turb} = \frac{(h_3 - h_4)}{(h_3 - h_{4s})}$$

4.3.2 Air-cooled condenser analysis

Using the energy balance for a heat exchanger we calculate the mass flow of air in ACC. We assume that the pressure difference between the inlet and outlet of the fan is 0.15 kPa and use the following formula to calculate the power consumption of the fan:

$$W_{acc} = \frac{\dot{m}_{air} \cdot \nu \cdot \Delta P}{\eta_{fan} \cdot \eta_{motor}}$$

A big design factor is finding the optimum temperature range with regards to the power consumption of the fans. As the range goes down the output from the turbine increases as the condensing temperature and pressure get lower. On the other hand, as the temperature range decreases the mass flow of air in fans increases and the power consumption gets high relatively fast compared to the output increase from the turbine.

4.3.3 Pump analysis

To calculate the power consumption of the pump we use the following formula:

$$W_p = \frac{\dot{m}_{R134a} \cdot \nu \cdot \Delta P}{\eta_{pump} \cdot \eta_{motor}}$$

Knowing that the work input to the pump also equals the mass flow multiplied by the difference in enthalpy over the pump, we can re-arrange the formulas to calculate the enthalpy in position 6.

$$W_{acc} = h_5 + \frac{\nu \cdot \Delta P}{\eta_{pump} \cdot \eta_{motor}}$$

For the lift pumps, we estimated total MW consumption based on prior calculation for a reinjection pump that operates at 5 bars.

4.3.4 Thermal efficiency

To calculate the thermal efficiency, we first calculate the heat inserted to our system in the heat exchanger.

$$Q_{in} = \dot{m}_{water} \cdot (h_1 - h_2)$$

Knowing Qin and Wnet we get the thermal efficiency as a ratio of the two.

$$\eta_{Thermal} = \frac{W_{net}}{Q_{in}}$$

4.3.5 Specific power output

We calculate the specific power output by dividing the net output by the mass flow of geothermal fluid.

$$SPO = \frac{W_{net}}{\dot{m}_{water}}$$

4.4 Results

Having specified these inputs and methods we can calculate the output of the power plant (Figure 4.5).

With geothermal fluid temperature of 140°C the gross power output is 5.2 MW. The parasitic load is 1.9 MW and the net power output is 3.3 MW which is enough to cater to the energy needs of the defense and civil population in Chumathang which currently satisfies its electricity need through a 20 kW diesel generator.

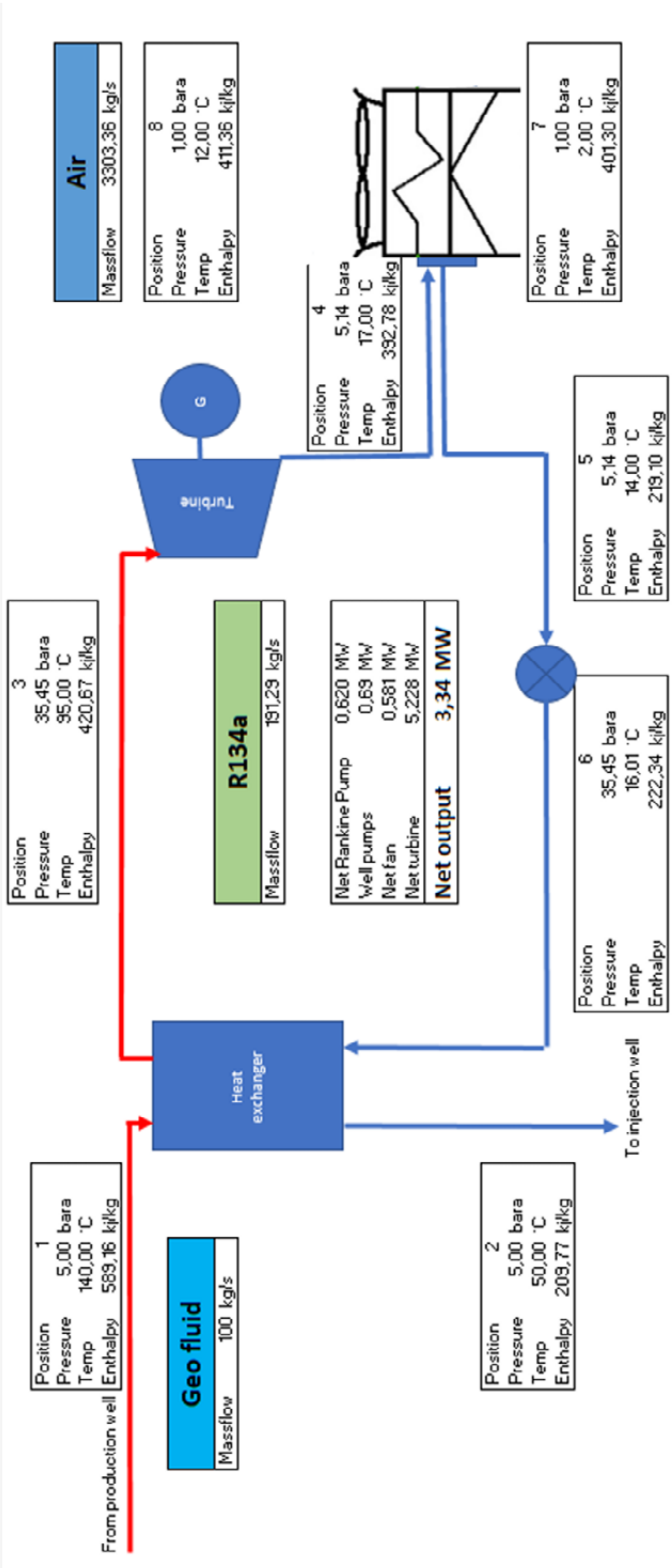


Figure 4.5: Results of the Binary Power Plant model.

Chapter 5

Greenhouse

This chapter describes the importance of greenhouse vegetation or protected crop cultivation for the Ladakh region and gives the main results of the energy analysis of the suggested greenhouse design. Greenhouses are used in Ladakh only in the winter months from October to April but in peak winter production decreases due to the freezing ambient temperatures. The absence of fresh vegetables for 8 months of the year makes Greenhouse vegetation or Protected crop cultivation an important part of agriculture.

5.1 Greenhouse vegetation (Protected crop cultivation)

The national highway connecting Ladakh to the rest of India gets blocked from October to May due to snowfall in the high passes. Ladakh has a cold and arid climate with low precipitation (100 mm). Due to the high altitude, only some fruit and vegetables are produced in the region in the summer season. In winter when the temperature goes below -20°C, it becomes impossible to grow anything in the open air and hence there is no access to fresh fruits and vegetables. According to Dr. Tashi Thinlas, Physician at the Public Hospital, Leh, the absence of fresh fruits and vegetables is one of the reasons for nutrition deficiencies, especially among girls.

Greenhouses have been in use in Ladakh since the 1980s with many Non-Governmental Organizations (NGOs) pioneering in introducing the greenhouse vegetation culture. Some of these are the Ladakh Ecological and Development Group (LEDeG), Ladakh Environmental and Health organization (LEHO) (Personal communication, Ishey Tundup, Director, LEDeG, July 2019). Apart from these Government of India provided incentives for the promotion of greenhouse vegetable cultivation through the Department of Horticulture, Ladakh Renewable Energy Development Agency (LREDA).

Many schemes were introduced like distributing the polyethylene sheet (silpaulin) for subsidized amount, providing 50% grants for constructing a greenhouse, providing frames and silpaulin, etc. to the farmers (Personal communication, Dr. Tsewang Thinglas, Director, LREDA, July 2019).

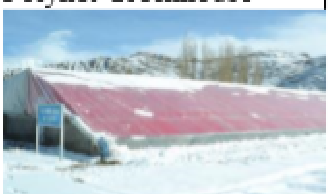
5.2 Types of greenhouses in Ladakh

There are various types of greenhouses being used in Ladakh provided by different organizations for vegetable production in the winter months as shown in Table 5.1. Prototypes of all these greenhouses can be seen at the Defense Institute of High-Altitude

Research (DIHAR), Leh (Personal communication, Dr. Tsering Stobdan, Senior scientist, DIHAR, June 2019).

DIHAR is an institute under the Defense Research and Development Organization (DRDO), Ministry of Defense, Government of India. DIHAR is researching on cold arid ago-animal technologies and greenhouse technologies for high altitude and cold desert areas. The greenhouses are heated by solar radiation and no external source of heating is used. Hence the temperature drops down below freezing point in January and February due to which there is no growth in the vegetables. Since no external heating is used it becomes difficult to maintain a constant temperature inside the greenhouse due to which only vegetables with low-temperature requirements can be grown. The sowing in the greenhouses is done in the month of mid-October and harvested in the month or early March. The vegetables that are grown are coriander, spinach (Mongol).

Table 5.1: Different types of greenhouses in Leh (Personal communication, Dr. Tsering Stobdan, Senior scientist, DIHAR, June 2019).

S.No	Type of greenhouse	Structure	Glazing	Orientation
1	Ladakhi Greenhouse 	Mud brick wall, wooden door on the east wall, manually operated ventillators either on roof or west wall, slope wooden roof on north side wall.	UV-stabilised polyethylene sheet	east-west orientation
2	Trench Greenhouse 	underground rectangular trench (30'×10'×3'; L×W×D), stone wall on four sides, Five cylindrical galvanised iron pipes (5 cm diameter, 13' long) are placed horizontally in east-west direction at 6 feet gap on top of the trench at ground level to hold the cladding material.	UV stabilised 120 GSM translucent polyethylene sheet	north-south orientation
3	Polytrench Greenhouse 	improvised Trench greenhouse (30'×10'×3'; L×W×D), unnel shaped galvanised steel frame over the trench on which the cladding material (polyethylene) is fixed		north-south direction
4	Polyench Greenhouse 	semi-underground (1 m below ground level) passive solar greenhouse (75'×25'×10'; L×W×H)	UV stabilised 120 GSM translucent polyethylene	east-west orientation
5	Polynet Greenhouse 	greenhouse (90'×27'×9'; L×W×H), wall are made of concrete material (stone and cement), and the east and west walls are half opened (i.e. at 3-4 feet height.), The north wall is 8' height and 2' thick, and the east and west wall are 1' 6'' thick. The wooden roof is 6' width covered with soil on top of it.	UV stabilised 120 GSM translucent polyethylene sheet.	east-west orientation.

6	Polycarbonate Greenhouse 	passive solar greenhouse (120'×30'×10'; L×W×H), The polycarbonate sheet is fixed on galvanised steel frame on 2' concrete wall above ground level on all four sides. The roof has slope on north and south sides.	triple layer 8 mm thick polycarbonate sheet	
7	FRP Greenhouse 	passive solar greenhouse (100'×30'×11'; L×W×H)	fiber-reinforced polymer (FRP) sheet	east-west orientation

5.3 Design of greenhouse in Ladakh

The most successful commercially available greenhouse has been the one provided by LREDA. Figure 5.1 shows the sections of the greenhouse. The greenhouse is constructed using mud-brick for the walls, talbu (willow twigs), and mud for the roof, husk, or wood chips for insulation between walls. The glazing material is polyethylene sheet of 150 GSM.

The greenhouse is oriented in the east-west direction to have maximum sun gain during winters. It has walls on the north, east, and west sides to protect from the wind and heat loss. The location of the door is kept on the east wall as the wind direction is west to east.

Ventilators are provided at the west wall and on the roof to get rid of excess heat during daytime (Figure 5.2).

For this project, we assume that the size of the greenhouse is 1,000 m^2 with the heating pipes laid under the plants. At design conditions the inside temperature is maintained at 20°C.

5.3.1 Material selection for the greenhouse construction

The materials considered in the analysis of the greenhouse are mostly available locally. This has been selected to reduce the cost of transportation. Also, by using locally available sustainable materials the project becomes more sustainable. The materials for the walls are mud-brick which is a widely used construction material. The insulation between the walls is straw. Only the glazing material which in this case is polyethylene sheet will be transported from the plains of India.

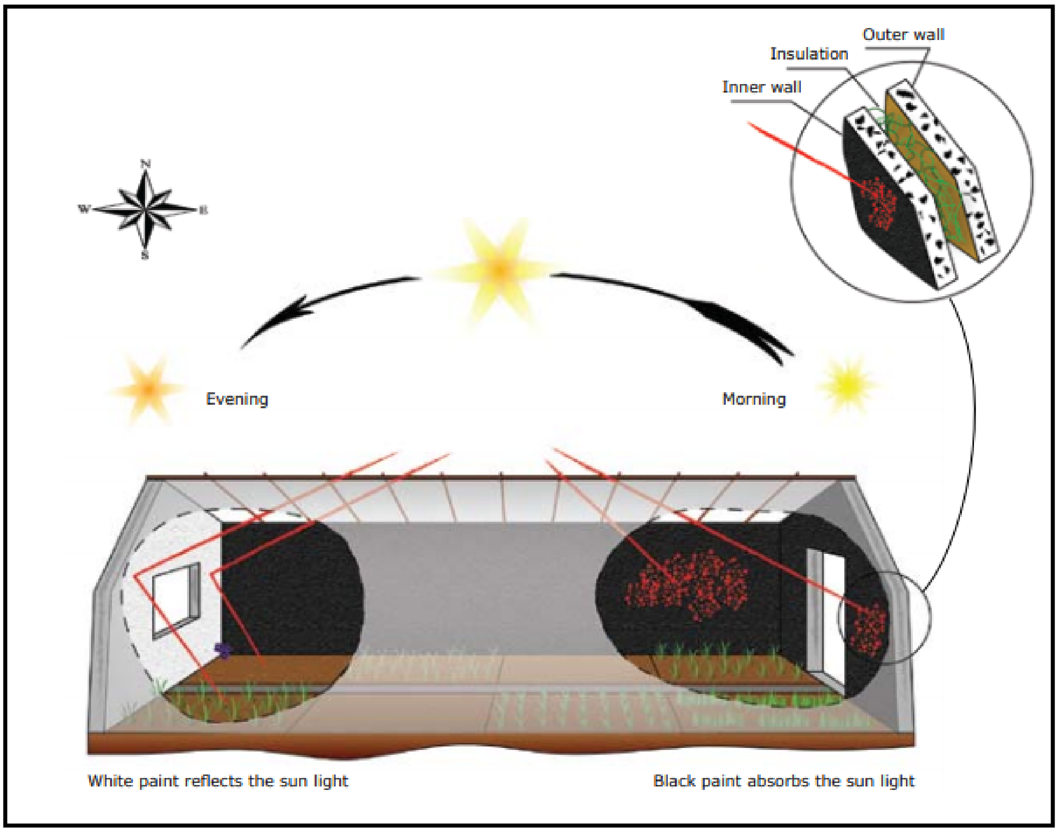


Figure 5.1: Front view of the LREDA commercial greenhouse. The wall is a double-layered mud-brick wall with insulation in between to protect against heat loss. The walls are painted black to absorb the heat during daytime and reflect at nighttime.

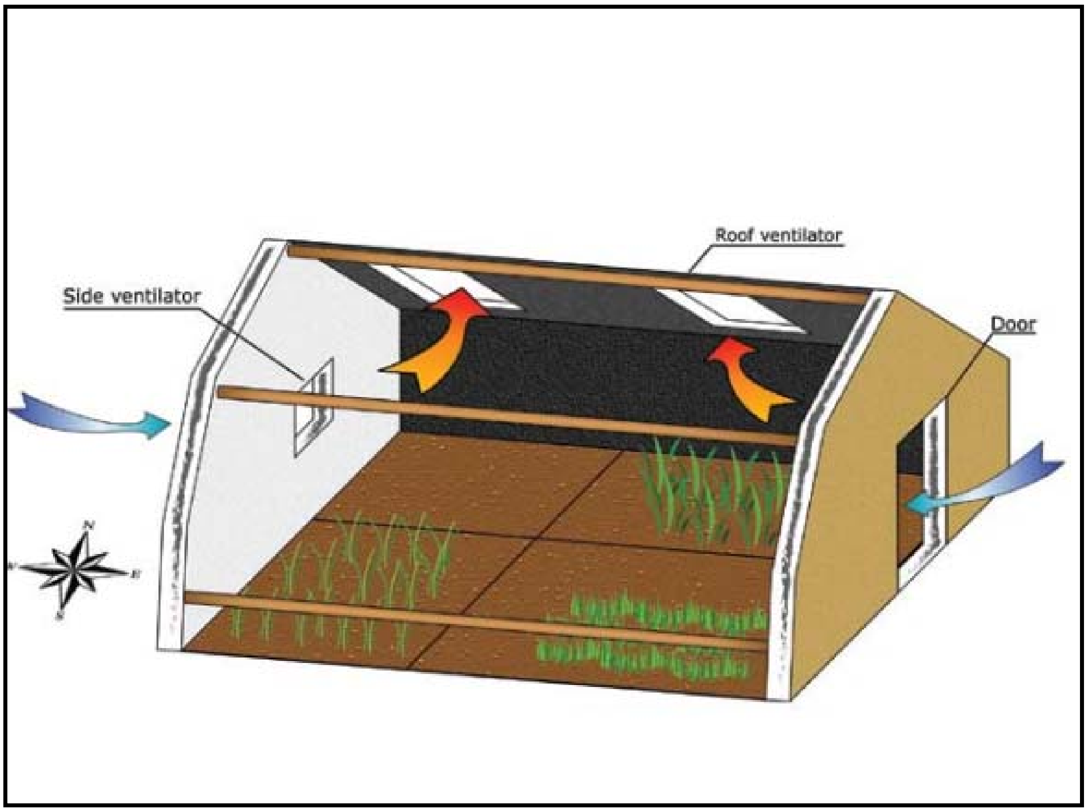


Figure 5.2: Heat convection in the LREDA greenhouse.

5.3.2 Weather data

Ladakh falls under the cold climate zone as shown in Figure 5.3 (Bureau of Energy Efficiency, Ministry of Power, Government of India, 2017).

Weather data is an important factor while calculating heat losses. It was not possible to get the weather data from the Indian metrological department due to privacy issues. The ten-year weather data from World weather online is used which shows the data collected from their station in Hanle which is 80 km from Chumathang. The monthly maximum, minimum, and average temperatures for ten years from 2009 to 2019 are shown in Figure 4.4. The average minimum temperature is -20°C and the average maximum temperature is 15°C.

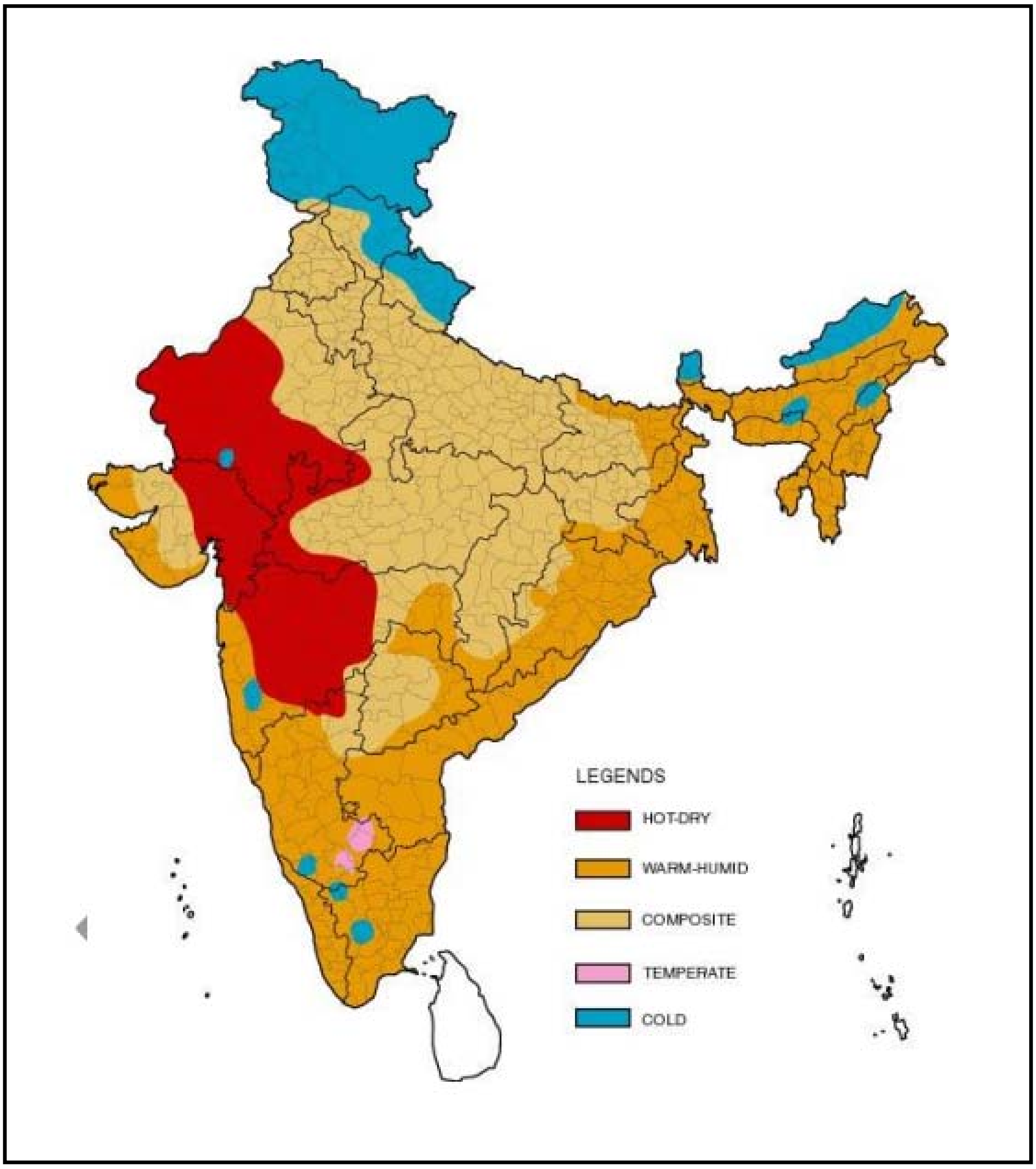


Figure 5.3: Climate zones of India (Bureau of Energy Efficiency, Ministry of Power, Government of India, 2017).

5.4 Heat load calculations

The various parameters that characterize the greenhouse and the operating conditions are shown in .
Table 5.2.

Table 5.2: Design parameters for greenhouse.

Length	125 m
Width	8 m
Height	2.4 m
Floor surface area	1,000 m^2
Volume	2,400 m^3
Greenhouse indoor design temperature	18°C
Outdoor design temperature	-20°C

Figure 5.4 shows the transfer mechanism of energy in a greenhouse.

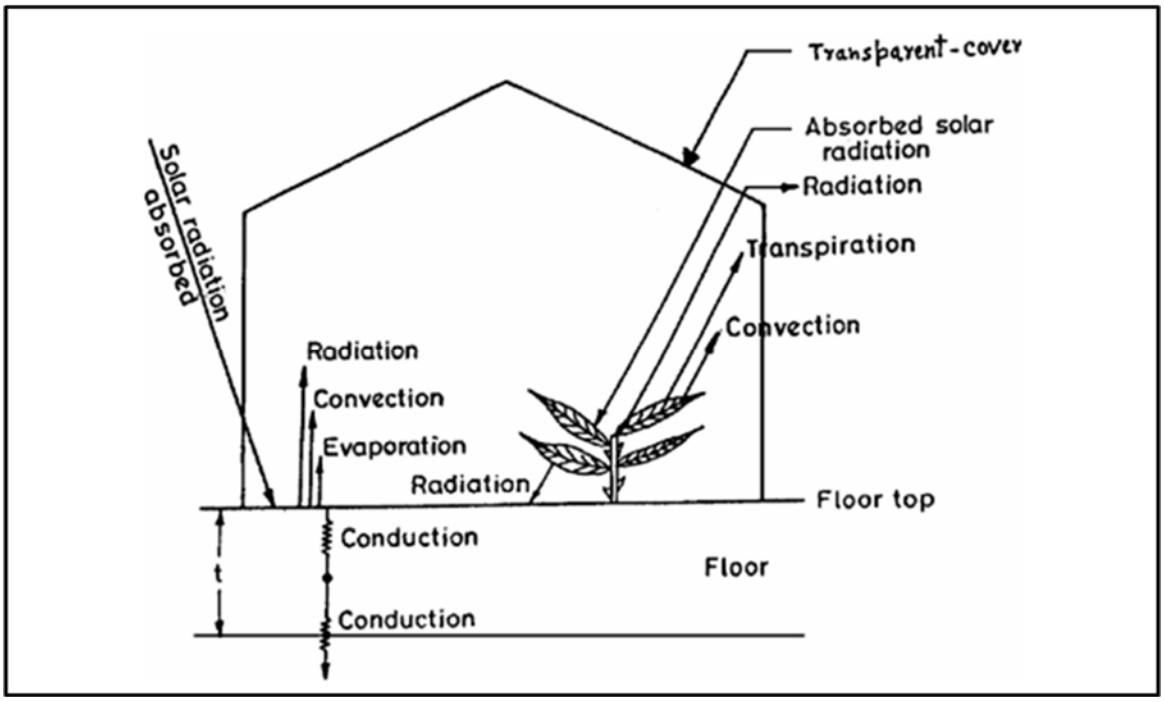


Figure 5.4: Energy transfer mechanism in a greenhouse (Taki et al., 2018).

In the static method, heat loss for a greenhouse is composed of two components:

- Transmission losses through the walls and roof,
- Infiltration and ventilation losses caused by cold outside air.

In the greenhouse that is considered here, there are walls on the north, east and west side of the greenhouse. Each of these walls has three layers. The inner layer wall is made of 0.3 m thick mud-brick, in the middle there is 0.15 m thick straw insulation and then the outermost layer is 0.3 m mud-brick wall. The glazing material, which covers the south side of the greenhouse and for a large part the “roof”, is polythene.

5.4.1 Transmission Heat Losses

5.4.1.1 Calculation of U-Values

U-value stands for the thermal transmittance or overall heat transfer coefficient. U-value of a building component such as a wall, glazing or roof describes how well or badly that component transmits heat from the inside to the outside. The lower the U-value, the better it is for heat retention from escaping heat to the outside (Greenspec, 2020). We can say that the U-value measures the amount of energy (heat) lost through a square metre of that material for every degree (K) difference in temperature between the inside and the outside. Thermal resistance (R) is defined as the reciprocal of the thermal transmittance. The U-value is commonly determined by computation from the thermal resistances of the different building materials between inside and outside (the wall) as well as the convective heat transfer coefficients between the wall surface and the surrounding air on both sides of the wall. Given that the wall consists of three layers of materials the U-value can be calculates from the following equation:

$$U_{wall} = \frac{1}{(\frac{1}{h_i} + R_1 + R_2 + R_3 + \frac{1}{h_0})}$$

Where

U_{wall}	= Thermal transmittance, W/m^2K
h_i	= Heat transfer coefficient at inside of the wall, W/m^2K
h_o	= Heat transfer coefficient at outside of the wall, W/m^2K
R_1, R_2, R_3	= Thermal resistance of the wall layers, m^2K/W

The U-value of the mud-brick wall is calculated using the above equation while the U-value for the polythene glazing is taken from Lund, (1996).

The thermal Resistance is the fight the material puts up against the heat passing through it for a given thickness and area. For a solid layer, the R-value can be calculated using the following equation:

$$R = \frac{t}{\lambda}$$

Where

t	= Thickness of the material, m
λ	= Thermal conductivity, W/(mK)

The λ -value or the thermal conductivity indicates how well a material conducts heat. It is the quantity of heat (W), conducted through 1 m^2 wall, in a thickness of 1 m, when the difference in temperature between the opposite surfaces of this wall equals 1 K. The lower the λ-value, the better the insulation property of the material.

Table 5.3 gives the thermal conductivity of some of the common building materials used as per Energy Conservation Building Code 2017 by Bureau of Energy Efficiency, Ministry of Power, Government of India.

Table 5.3: Building and Insulating materials and their thermal conductivity (Bureau

of Energy Efficiency, Ministry of Power, Government of India, 2017)

Material	Thermal conductivity (λ)(W/(mK))
Asbestos Cement Board	0.4709
Cement Plaster	1.208
Ceramic Frit Glass	0.6882
Clay Tile	0.6323
Float Glass/ Clear Glass	1.0522
Extruded Polystyrene XPS	0.0321
Fibre Reinforced Plastic (FRP)/Fiberglass	0.2252
Fire Brick	1.2729
Glass wool	0.0351
Plastic Polymer	0.5027
Polyurethane Foam (PUF)	0.0372
Rigid Polyurethane (25 kg/m^3)	0.0384
Tempered Glass	1.0493
Wood	0.2652

The insulation used between the walls is straw, as can be seen in Figure 5.5. Straw is an agricultural by-product, the dry stalks of cereal plants after the grain and chaff have been removed. Straw makes up about half of the yield of cereal crops such as barley, oats, rice, rye, and wheat. The thermal conductivity (λ) of straw is 0.08 W/mK (Greenspec, 2020).

Figure 5.5: Straw insulation used between the walls at North, East, and West of Greenhouse.

Since the mud-brick walls are insulated the convective thermal resistance at the inside and outside of the wall is relatively small and can be neglected. However, it is important to include the thermal convective resistance in the calculations of the heat loss through the polythene glazing, both because it is a relatively large part of the thermal resistance per unit area for this part of the construction and also because the polythene covers a dominating part of the total surface area of the greenhouse. The convective thermal resistance depends strongly on the wind speed.

Table 5.4 shows the thickness and thermal conductivity of the main materials that are used in greenhouse construction.

Table 5.4: Thickness and thermal conductivity of materials used in greenhouse

construction.

Material	Thickness (m)	λ-value (W/mK)
Mud-brick	0.3 x 2 layers	1.28
Straw (insulation)	0.15	0.08
Polythene	0.006	0.5

Table 5.5 shows the thickness, total surface area, and the thermal transmittance of the two types of walls/glazing used in greenhouse construction.

Table 5.5 also shows the results of the heat loss calculations based on the following equation:

$$Q_t = U \cdot A \cdot (T_i - T_o)$$

where
Q_t = Total heat transmission losses through walls and roof (W)
U = Overall heat transfer coefficient or thermal transmittance (W/m2 °C)
A = Surface area of the greenhouse (walls and glazing material) (m^2)
T_i = Indoor design temperature (°C)
T_o = Outdoor design temperature (°C)

As shown in Table 5.5 the total heat loss is estimated to be 317 kW at design conditions when the outdoor temperature is -20°C.

Table 5.5: Heat loss from different construction components of the greenhouse.

Construction part	Thickness (m)	Surface area (m)	U-value (W/m^2K	Heat loss (kW)
Mud-brick wall	0.75	338.4	0.43	5.5
Polythene glazing	0.006	1,175	6.98	311.5
Total		1,513		317

5.4.2 Infiltration Heat Losses

The air change method is the general method for the calculation of infiltration heat losses. The method is based upon the number of times per hour (ACH) that the air in the greenhouse is replaced by cold air leaking from outside. The number of air changes, which occur, is a function of wind speed, greenhouse construction, and inside and outside temperatures. Table 5.6 outlines general ACH values for different types of greenhouse constructions, which can be used by the designers.

Table 5.6: Air Change per Hour (ACH) values for glazing/ cover materials (Lund, (1996))

Greenhouse cover material	Air Change per Hour (ACH)
Single glass	2.5-3.5
Double Glass	1.0-1.5
Fiberglass	2.1-3.1
Single Polythene	0.5-1.0
Double Polythene	0.0-1.0

After selecting the appropriate number from Table 2, the following equation is used to calculate the infiltration heat losses.

$$Q_i = V \cdot ACH \cdot c_p \cdot \rho \cdot (T_i - T_o)/3600$$

where

Q_i	= Infiltration heat loss (W)
V	= Volume of greenhouse (m^3)
ACH	= Air change per hour
c_p	= Specific heat capacity of air (J/kg °C)
P	= Density of air (kg/m^3)

The Infiltration heat loss for the greenhouse is calculated as 30 kW.

The total heat load, Q, for the greenhouse can be calculated as the sum of the transmission heat losses and the infiltration heat losses as follows:

$$Q = Q_t + Q_i$$

The total heating load for the greenhouse is calculated as 347 kW.

The mass flow of geothermal water required to heat the greenhouse is given by the following equation

$$\dot{m} = \frac{Q}{C_p \cdot (T_i - T_o)}$$

For this greenhouse, the mass flow of geothermal fluid required at the design conditions is 2.2 kg/s.

The monthly heating requirement for the greenhouse is shown in Figure 5.6.

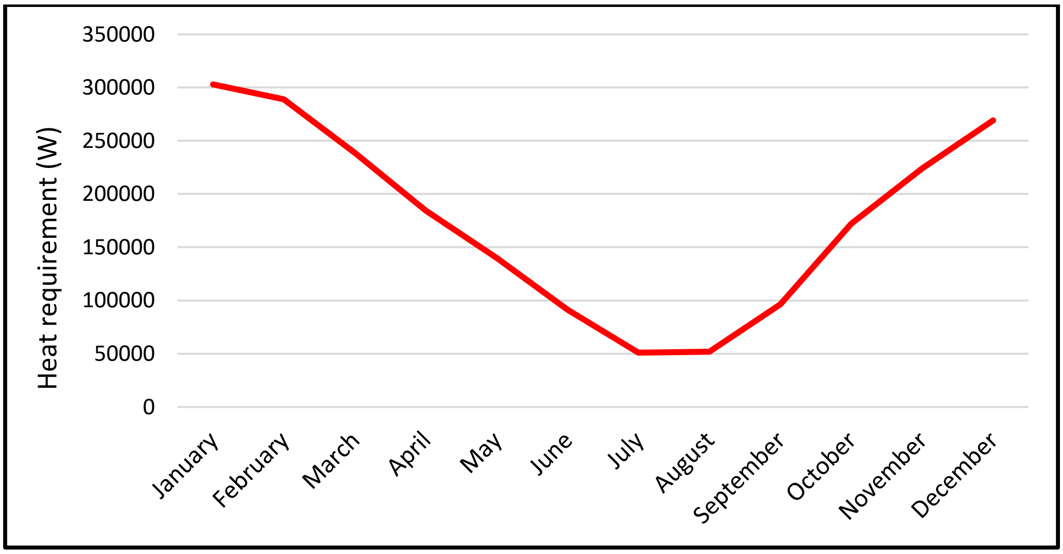


Figure 5.6: Monthly heating requirement for the greenhouse.

5.5 Heating systems

The heating systems can be classified according to the position of the heating installation as shown in Figure 5.7. The categories are the following:

- Heating systems in the soil.
- Heating systems laid on the soil surface or the benches.
- Aerial heating systems.
- Cascading.
- Combinations of the above

For the heating of this greenhouse pipes will be laid at the bottom of the bench, on the side walls and above the plant table like shown in Figure 5.7.

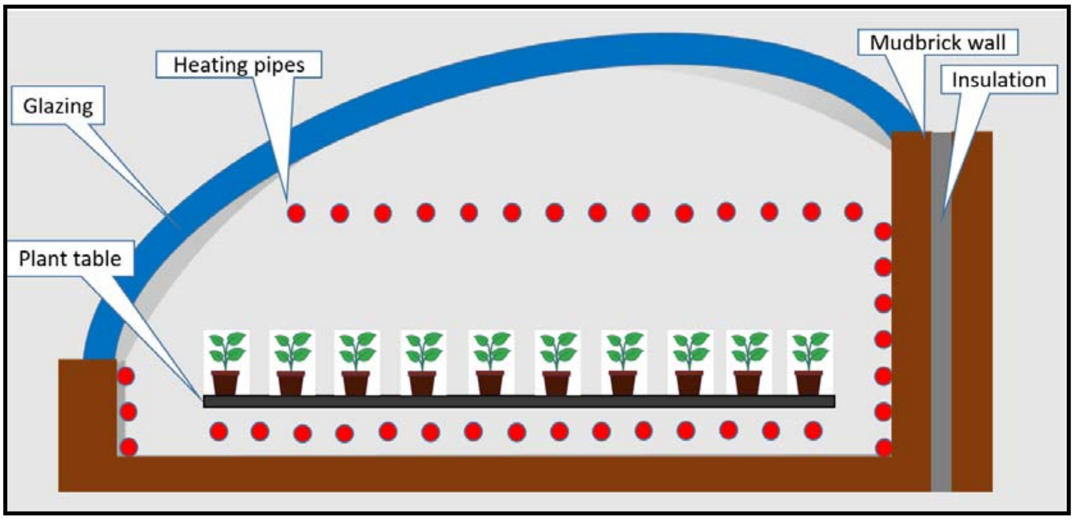


Figure 5.7: Heating pipes layout in the greenhouse.

Pipes will be of steel and 0.05 m diameter. This is selected due to its easy availability in the local market. This size of pipe is also used widely in the greenhouses in Iceland as found during the site visits, see Figure 5.8

Figure 5.8: Heating pipes under the plant benches, on the side of walls in an Icelandic greenhouse.

The length of the heating pipes required is calculated using equation from Lund, 1996, given by the following equation:

$$L = \frac{3.6 \cdot Q}{\left[4.422 \cdot \left(\frac{1}{D}\right)^{0.2} \cdot \left(\frac{1}{1.8 \cdot T_{ave} + 32}\right)^{0.181} \cdot (\Delta T)^{1.266} + 15.7 \cdot 10^{-10}\left[(1.8 \cdot T_1 + 32)^4 - (1.8 \cdot T_2 + 32)^4\right]\right] \cdot 11.345 \cdot A}$$

Where:

L	= Pipe Length (m)
Q	= Total Heating Load (W)
D	= Outside pipe diameter (mm)
T_{ave}	= 255.6 + (AWT + T_{air})/2 (°C)
AWT	= T_{wi} - ΔT/2 (°C)
T_{wi}	= Heating water supply temperature (°C)
T_{air}	= Greenhouse design inside air temperature (°C)
T_1	= 255.6 + AWT (°C)
T_2	= 255.6 + T_3 (°C)
T_3	= (AUST + T_{air})/2 (°C)
AUST	= Average temperature of unheated surfaces in the greenhouse (°C)
A	= Outside surface area of pipe /unit length (m^2/m)

Based on the above equation, the total length of pipe required to heat the greenhouse of 1,000 m^2 is 5,235 m.

5.6 Conclusion

Heat load analysis was done on greenhouse of size 1,000 m^2. It was assumed that the construction materials used will be available locally to make it more sustainable as well as economical. Table 5.7 Gives the summary of results of the greenhouse calculation.

Table 5.7: Summary of the results of greenhouse.

Greenhouse parameters	Symbol	Values	Unit
T inside,	T_i	18	°C
T outside,	T_o	-20	°C
Length, m	L	125	m
Width, m	W	8	m
Height, m	H	2,4	m
Area,	A	1,000	m^2
Volume, m3	V	2,400	m^3
Transmission heat loss	Q_t	313,825	W
Infiltration heat loss	Q_i	30,266	W
Total heat load	Q	344,091	W
Mass flow of geofluid	$\dot{m}$	2,163,168	kg/s
Length of pipe for heating	L	5,235	m

Chapter 6

Financial analysis

This chapter presents the results of the financial analysis of the power plant and greenhouse project with different scenarios. The best available costs of equipment and construction materials are used for the analysis.

6.1 Financial assumption

For the assessment of the financial model, it was necessary to introduce some assumptions shown in Table 6.1. Investors would normally require a percentage from the project owner for assurance of continued commitment. For this report, it has been assumed an equity share of 30% and a debt share of 70% with and interest of 6% over a period of 25 years.

The price of electricity is the current tariff in the region.

Table 6.1: Financial assumptions for Chumathang Binary power plant.

Financial Assumptions	
Downhole temperature	140°C
Power Plant type	Binary plant
Plant capacity	5 MW
Plant availability	85%
Power plant cost per kW	3,000 USD (Verkis, 2014)
Construction Time	2 years
Planning Horizon	25 years
Equity share	30%
Debt share	70%
Interest rate	6%
O and M	7%
Price of the electricity as per PPA	0.07 USD/kWh

The cost of the LREDA commercial greenhouse is 60.6 USD/m^2 (Personal communication, Dr. Tsewang Thinglas, Director, LREDA, June 2019). The assumptions used in the financial analysis are given in Table 6.2. The cost of vegetables is based on the market survey done by the author in 2019-20. For the Icelandic greenhouse, cost from Lambagi farmer was used for the analysis. The cost per m^2 for LREDA greenhouse is 60.6 USD/m^2 and for the Icelandic greenhouse is 1,246 USD/m^2.

Table 6.2: Assumptions for financial analysis for greenhouse.

CAPEX	construction cost per m^2	30.30	USD
	size considered here	1,000	m^2
	cost	30,303	USD
Revenue	average cost	1.5	USD
	production in 1000 m^2	20,455	kg
	total revenue each year	30,682	USD

6.2 Scenario 1: Power plant only

The economic viability of a geothermal binary power plant needs the knowledge of several values: the exploration costs, the depth of resources, the size of the reservoir, the power plant size, the transmission availability and capacity, the market factors and the energy selling price. Figure 6.1 shows the cost distribution for air-cooled Binary Power Plant used in the GETEM tool by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

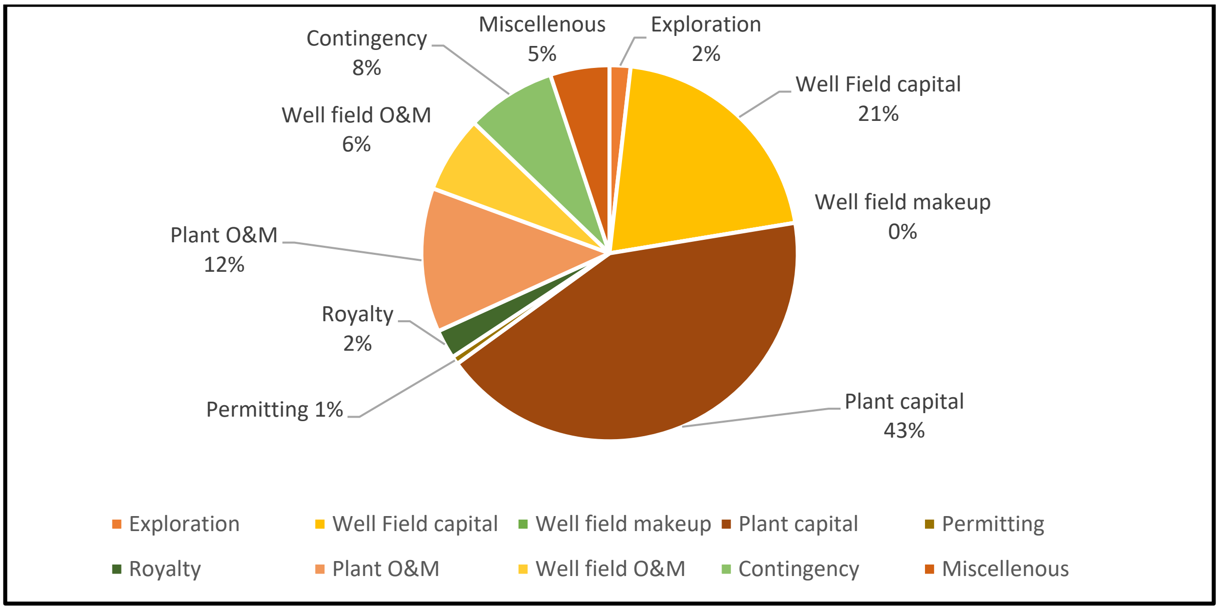


Figure 6.1: Cost distribution for air-cooled binary power plant (adapted from GETEM tool by U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2016).

Normally, the first estimate is the least accurate since it does not consider the risk of failure to access the resources, but it is useful to evaluate the feasibility of the project.

6.2.1 Capital expenditure (CAPEX)

To evaluate and calculate the costs of the project, the costs have been divided into different activities. The project components have been divided into five main categories to evaluate the contribution of different components to the final cost:

- Preparation works: access road, well pad site preparation, water pipeline system, water pump station, and storage.

- Drilling: production wells and injections wells.

- Power plant: this section was divided into more different categories, mechanical, electrical and control, civil works. other permitting costs: generation license, feasibility study, resettlements, detailed surface studies, ESIA licenses.

- Capacity building: training of engineers, technicians, operation, and maintenance staff, etc.

The CAPEX in case of scenario 1 is 15 MUSD.

6.2.2 Operational and maintenance costs (OPEX)

Operation costs include all the expenditures linked to the operation of the binary plant, steam gathering, and transmission line. The maintenance costs include the expenses related to the operation of the components of the equipment, such as a turbine, pumps, motors, buildings, etc. The Operational & Maintenance costs group together all these figures; hence, they include all the factors to keep the power plant in a safe condition in terms of good working requirements

During the first years of operation, the O&M cost is expected to be relatively low, but it is estimated to go up after some years of activity. Considering the data available from the Verkis, 2014 for a binary plant, it has been possible to calculate the O &M expenses.

The OPEX is case of scenario 1 is 7% which is 1.05 MUSD.

6.2.3 Net present valuation

The project will achieve a break-even point after 10 years of service (Figure 6.2).

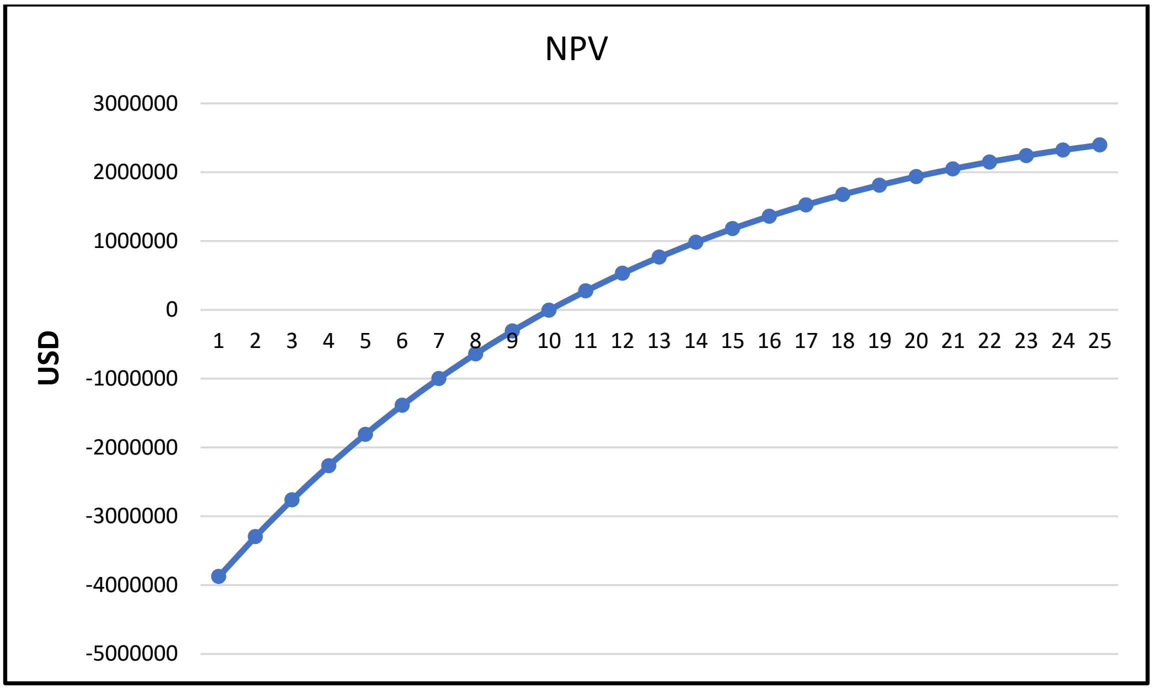


Figure 6.2: Development of NPV during the operation period.

6.2.4 Revenue

The sales of electricity determine the revenue generated each year. Figure 6.3 shows the inflow and outflow of cash during the first year of the plant operation.

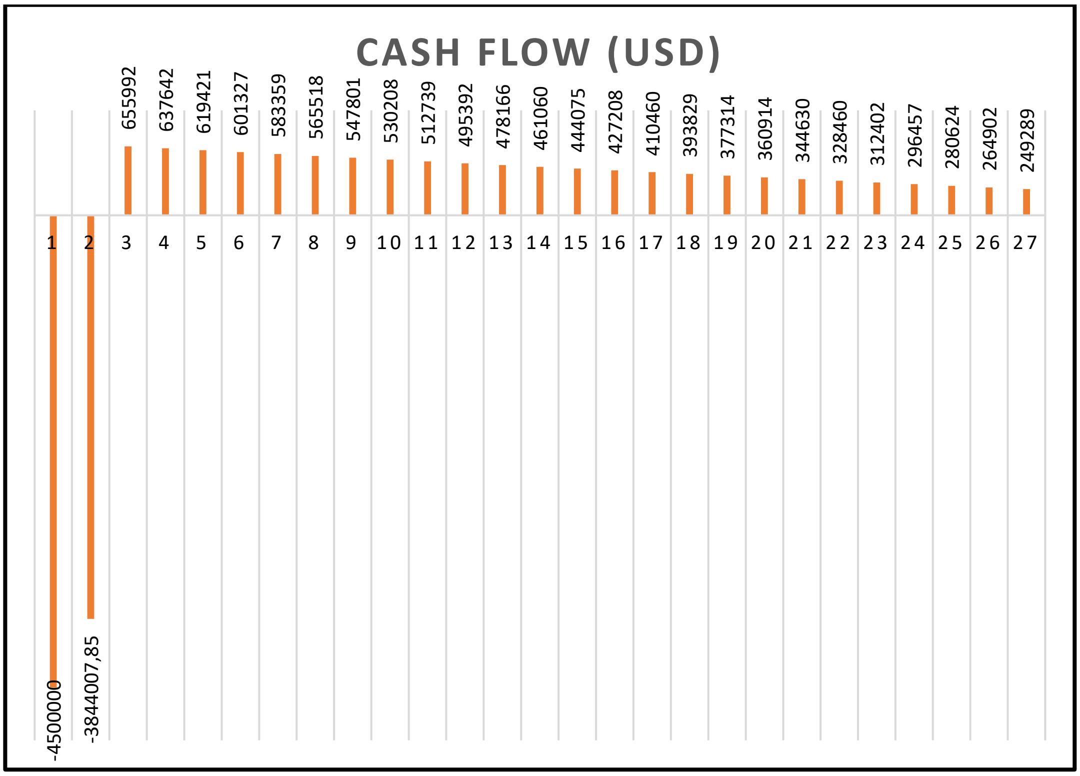


Figure 6.3: Cash Outflow and Inflow (in USD).

6.2.5 Comparison with other energy generation source

Solar, Hydro, and Diesel generators are the current sources of electricity in the region. Financial analysis was done on a 5 MW Hydro Power plant to compare with geothermal power plant.

For the analysis, the existing cost used by the Jammu and Kashmir Power Development Corporation (JKPDC) was used. JKPDC is the state-owned power company that is authorized to undertake the construction of Hydro Power Projects in Ladakh. During an interview with Shiv Kumar, Executive Engineer, JKPDC, Leh, it was mentioned that the time value of money is not considered by JKPDC during construction of Hydropower projects in Ladakh. As such JKPDC does not earn any profit from the hydro projects in Ladakh. JKPDC considers a cost of 2.29 MUSD per MW for the construction of Hydro Power projects in Ladakh. It was told that this is due to the high transportation costs of materials like civil and electro-mechanical equipment from the plains of India. The operational cost of 15% is considered by JKPDC.

Figure 6.4 shows the development of NPV during the operation period of the Hydro Power Plant of 5 MW.

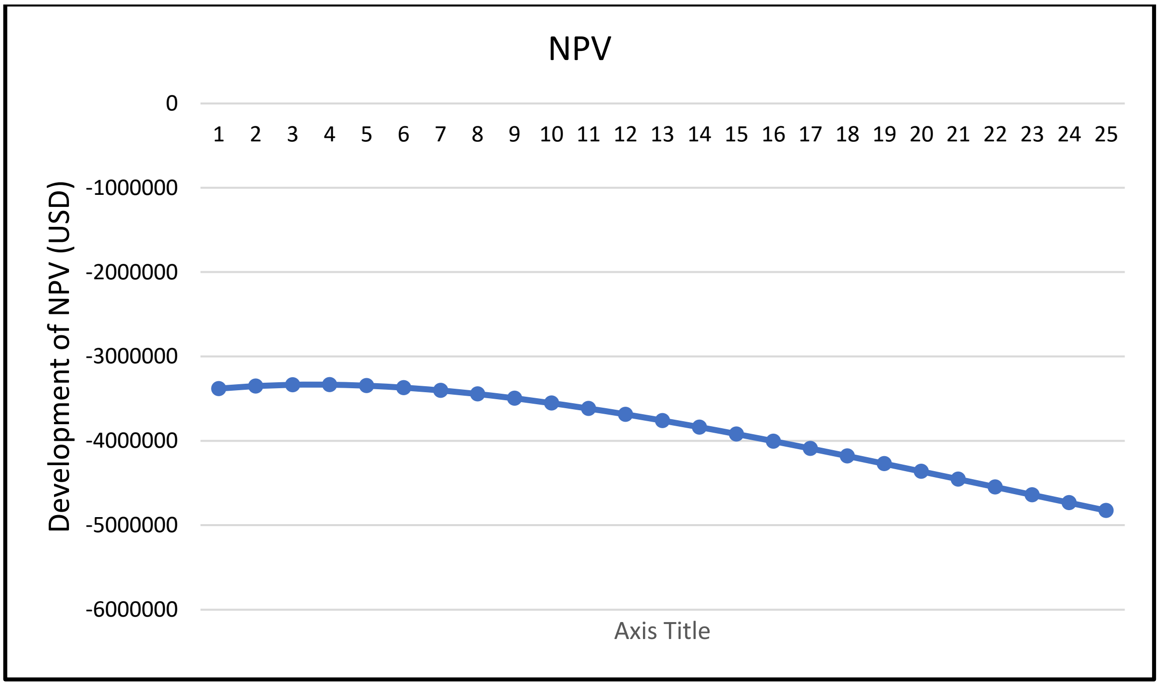


Figure 6.4: Development of NPV during the operation period of the Hydro Power Plant of 5MW.

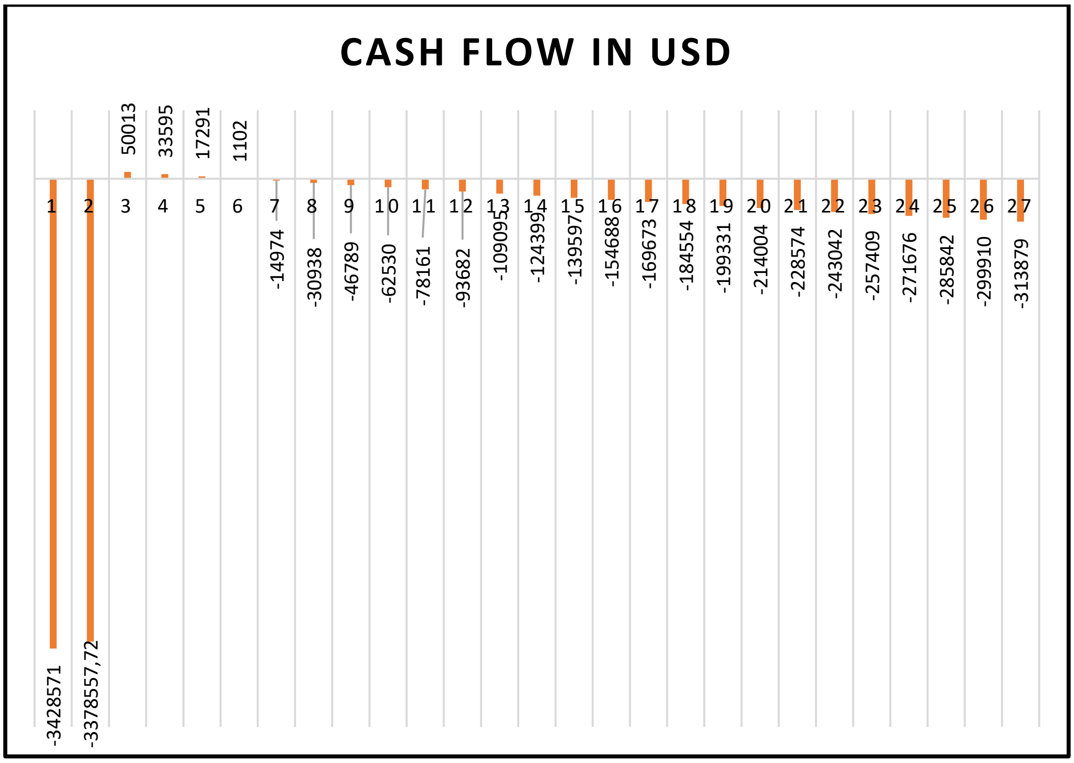


Figure 6.5: Cash Flow during the operation period of the Hydro Power Plant.

6.3 Scenario 2: Greenhouse only

6.3.1 Local greenhouse with heating

The LREDA commercial greenhouse design used in this project gives a positive NPV of 347,276 USD as seen in Figure 6.6. This is mainly since the construction materials used are all locally available except for the glazing material and the piping materials which are transported from the plains of India.

For the revenue, per unit cost of 1.5 USD is used. The breakeven point is achieved in the first year of operation. The CAPEX in this case is 030,300 USD and the OPEX is 2,121 USD per year.

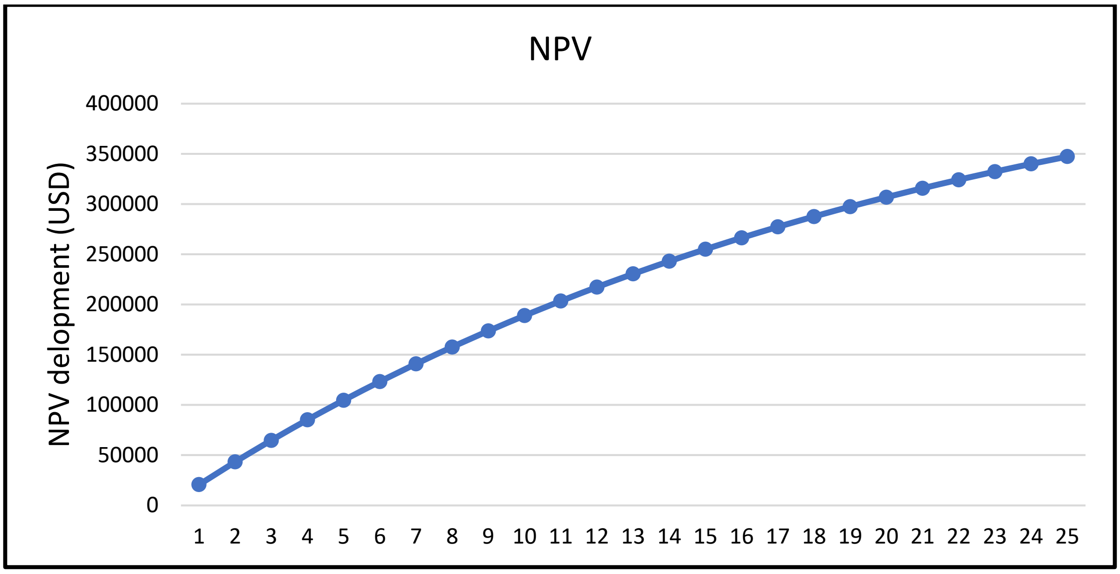


Figure 6.6: Development of NPV during the operation of the greenhouse.

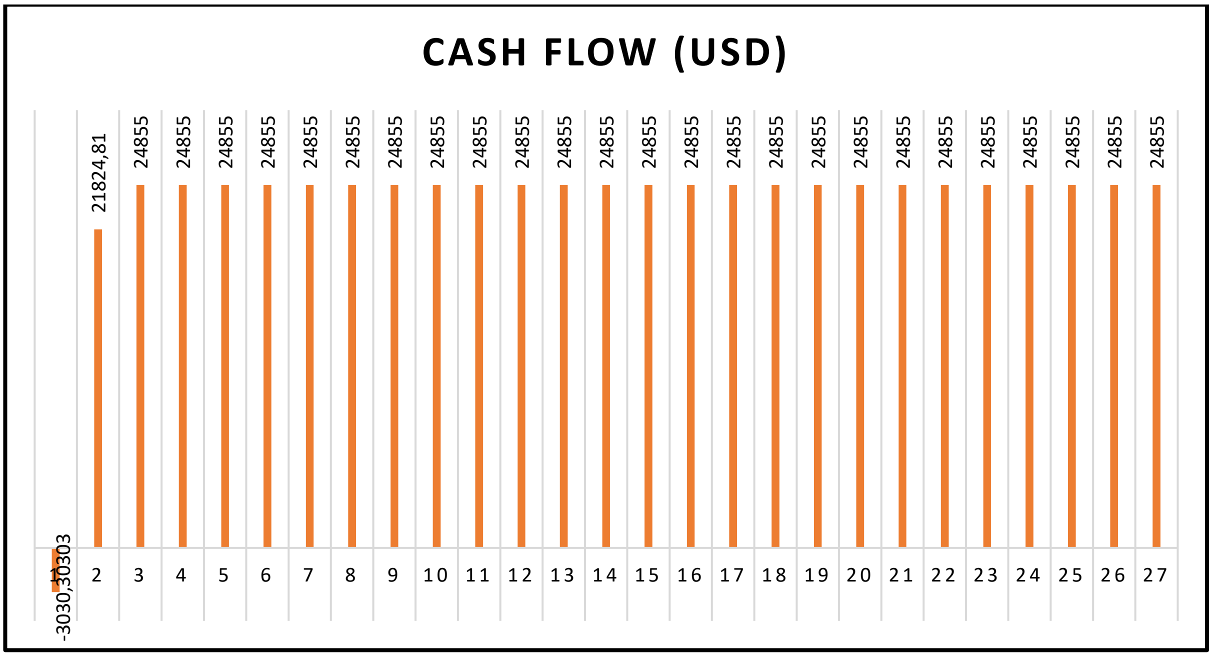


Figure 6.7: Cash flow during the operation of the Greenhouse in USD.

6.3.2 Icelandic greenhouse scenario

Cost analysis was made for the 1,000 m^2 greenhouse in Icelandic style, i.e., fully computerized greenhouse. For this the greenhouse owner Lambhagi, Iceland was interviewed during which it was found that the construction material for the greenhouse was imported from the Netherlands. The farmer was constructing a 7,000 m^2 fully automatic greenhouse for which the cost was 8.72 MUSD i.e. 1,246 USD/m^2. The yield is 90 kg/m^2 per year. For the calculation of the revenue the local cost per kg of vegetables used is 1.5 USD.

The CAPEX in this case is 1.25 MUSD and the OPEX is 0.872 MUSD. The NPV development during the operation of the fully automated greenhouse is shown in Figure 6.8.

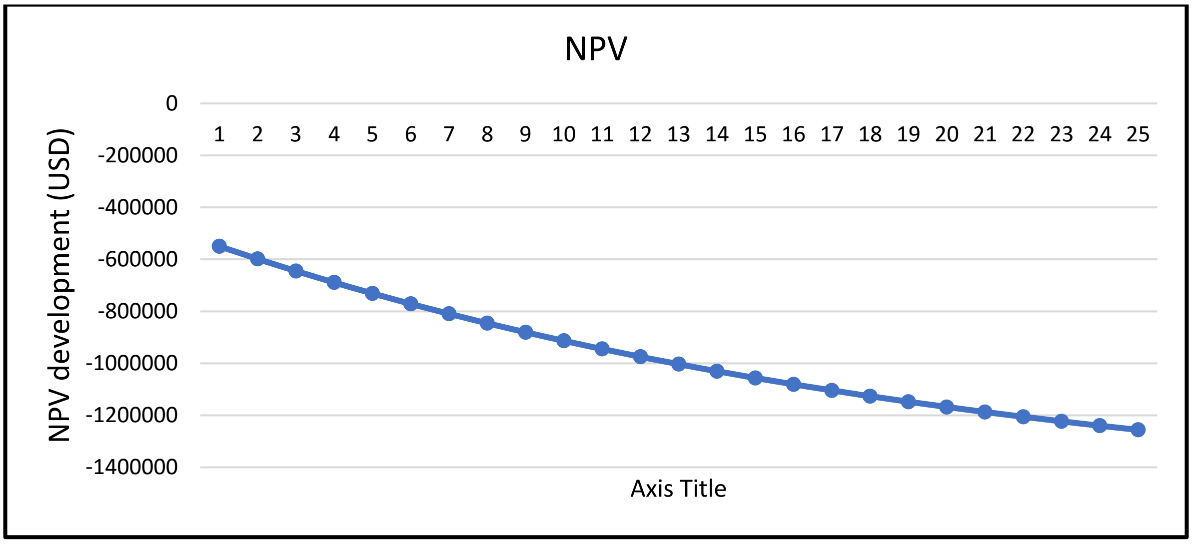


Figure 6.8: Development of NPV during the operation of the fully automated Icelandic style greenhouse when the cost of tomato per kg is 1.5 USD

The NPV is -1,168 MUSD which means that the project is financially not viable. The only factor to have a positive NPV here is to increase the per kg cost of tomato from 1.5 USD to 2.5 USD in which case the project reaches the breakeven point after six years of production. This can be seen in Figure 6.9.

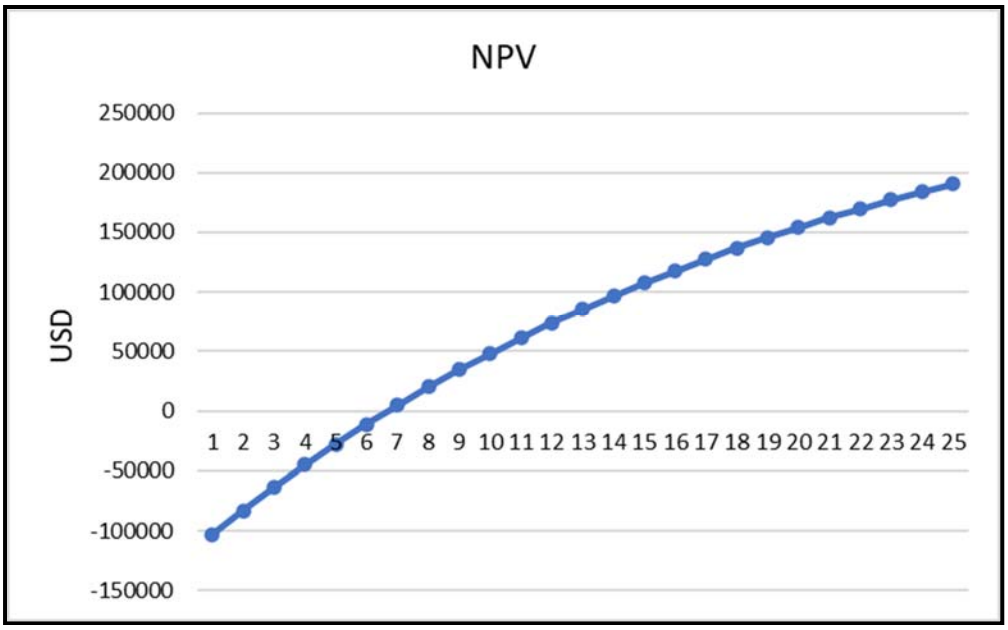


Figure 6.9: Development of NPV during the operation of the fully automated Icelandic style greenhouse when the cost of tomato per kg is 2.5 USD.

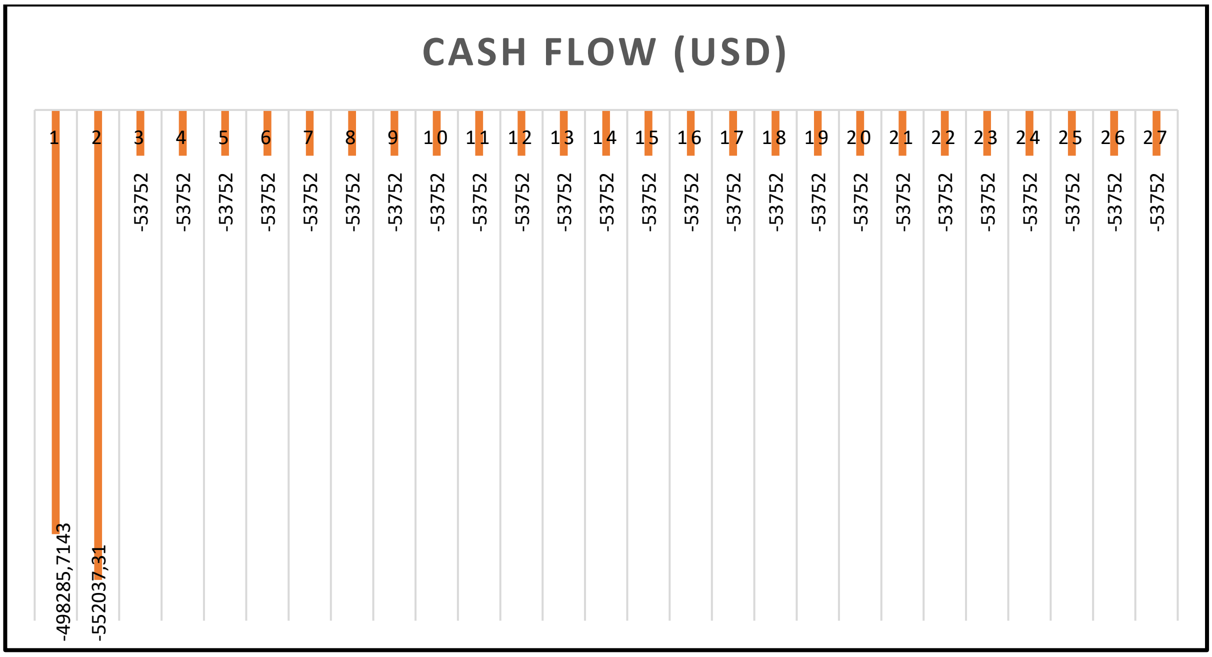


Figure 6.10: Cash Flow during operation of Icelandic style greenhouse.

6.4 Scenario 3: Power plant and greenhouse

For this scenario 5 MW geothermal Binary Power Plant and LREDA commercial greenhouse is considered.

The CAPEX in this case is 15,030,300 USD and the OPEX is 1,052,000 USD. Figure 6.11 and Figure 6.12 shows the NPV and the Cash Flow for this scenario. The NPV is positive with 2,258,000 USD and the breakeven point is at the end of 9 years of project operation.

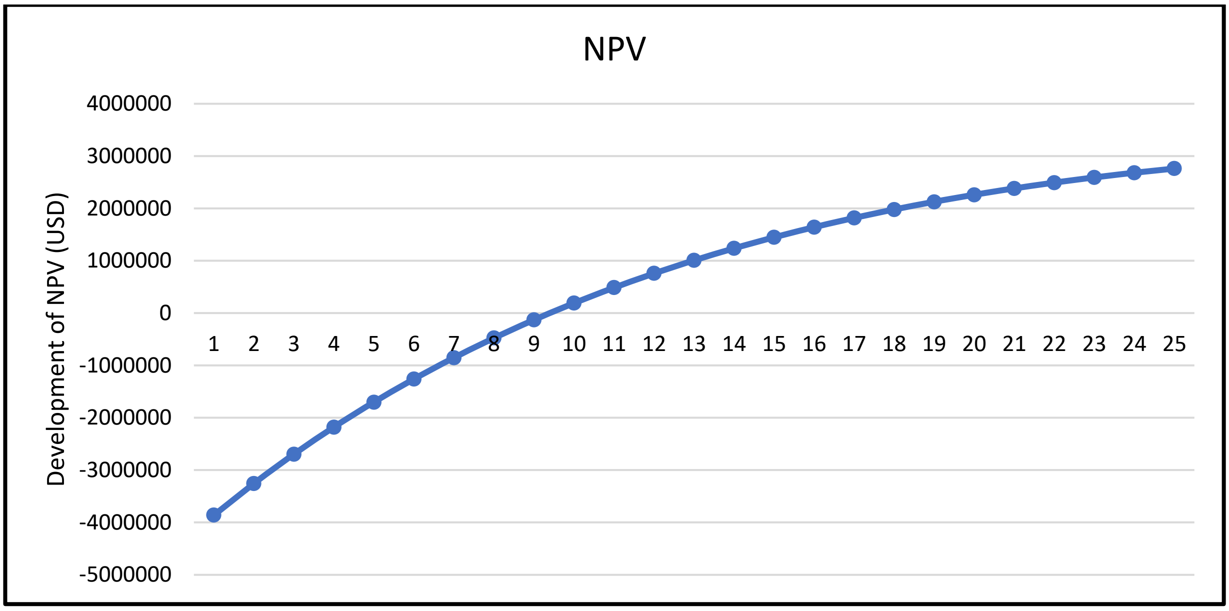


Figure 6.11: Development of NPV during the operation of the combined project of Geothermal Binary Power Plant and Greenhouse.

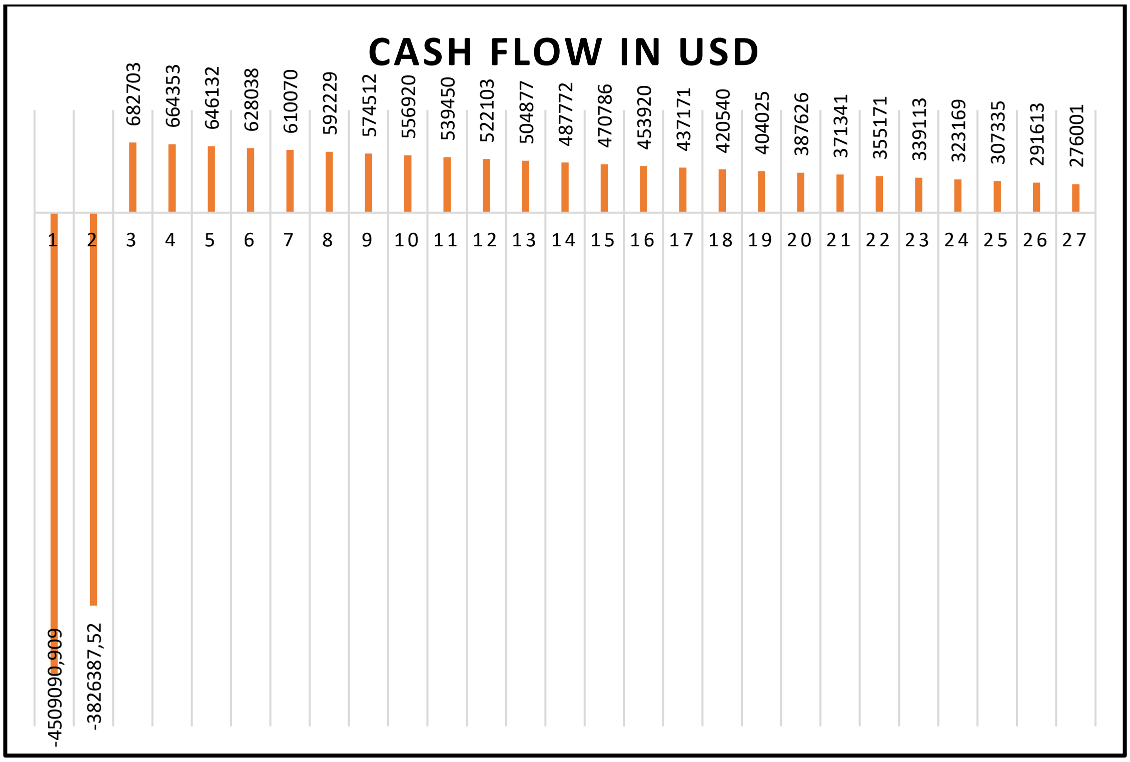


Figure 6.12: Cash Flow during the operation of the combined project of Geothermal Binary Power Plant and Greenhouse in USD.

6.5 Risk mitigation and financing of the project

The most difficult task in geothermal project funding is securing funding for surface exploration and drilling operations. This is the riskiest phase in geothermal development as can be seen in Figure 6.13.

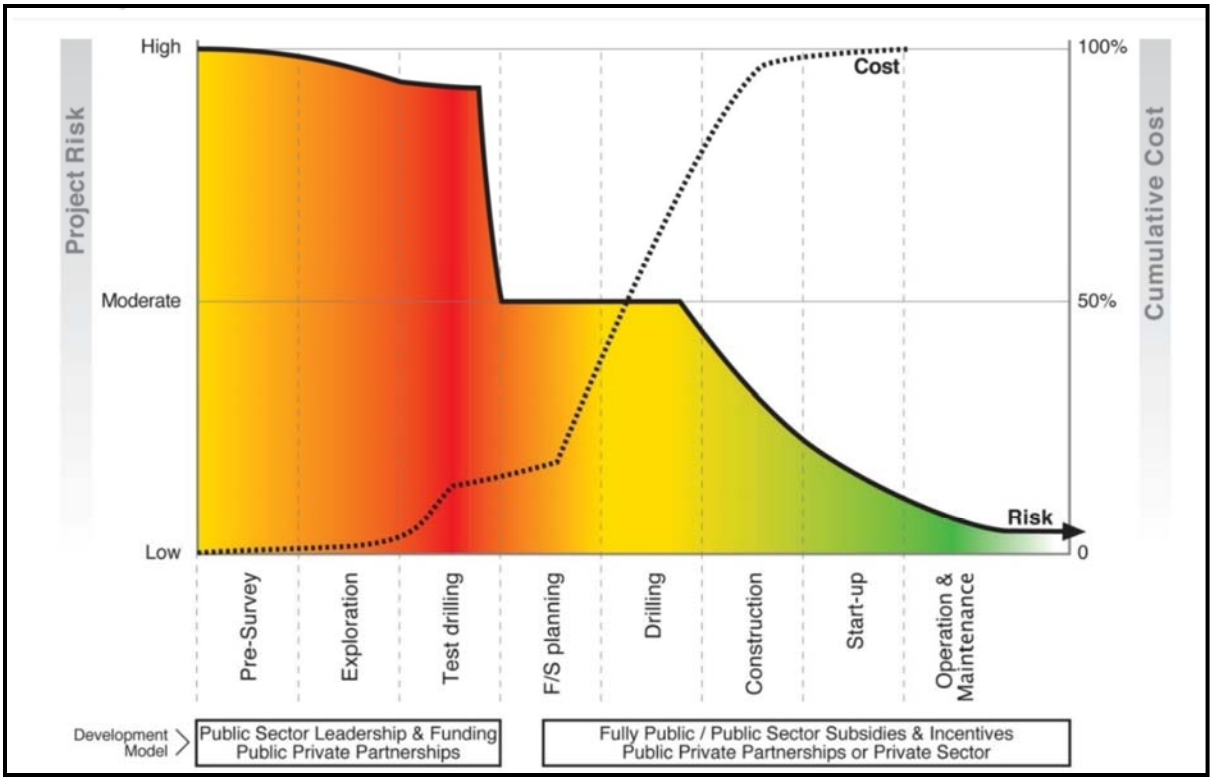


Figure 6.13: Geothermal project financing risk (ESMAP, 2012).

This phase of the financing can be addressed through public financing and the creation of public companies to exploit geothermal resources. Financial institutions like the World Bank, Global Climate Fund also finance projects at this stage. The Green Climate Fund (GCF) contribution aims at reducing the early-stage exploration risk taken by geothermal developers with the uncertainty to find resources. The funding from GCF is a package consisting of a senior concessional loan for public sector projects, a reimbursable grant for private sector projects, and a grant for technical assistance (GCF. 2019). A key innovation in the financing package is the use of convertible bonds that will enable private sector geothermal sponsors to mitigate the exploration risk while providing an adequate upside in case of success. It is estimated that less than 10 percent of the global geothermal capacity has been tapped so far, mainly because early-stage exploration risks in geothermal development are a barrier that needs to be addressed with the right calibration of financing packages. GCF has established six criteria in its Investment Framework to guide its investment decisions namely impact potential, paradigm shift potential, sustainable development potential, needs of the recipient, country ownership and efficiency and effectiveness (Figure 7.2). This project fulfills all the above criteria and thus is suitable for funding from GCF. Funding from GCF can be asked for to cover the high initial exploration cost.

6.6 Conclusion

Financial analysis was done for three different scenarios with a project life duration of 25 years, an equity share of 30% and a debt share of 70% with an interest rate of 6%. In 2017 the range of the cost of geothermal power generation was between 2.25 and 5.50 MUSD/MW (IRENA 2018). For the binary power plant, cost of 3 MUSD/MW is used which is within the acceptable range. Tariff of 0.07 USD/kWh was considered for the revenue generation and NPV calculation.

Financial analysis for greenhouse was done based on the cost of local available materials and a comparison was done for a fully automated Icelandic greenhouse. The size considered was 1,000 m^2 with a cost of 60.6 USD/m^2 for LREDA greenhouse is and 1,246 USD/m^2 for the Icelandic greenhouse.

The development of NPV for the Icelandic greenhouse is negative hence for the third scenario which is power plant and greenhouse, the financial analysis is based on the cost of the LREDA commercial greenhouse design and this scenario is viable and profitable for any investor. With a CAPEX of 15,030,300 USD and the OPEX is 1,052,000 USD.

The production in the greenhouse will be 20 kg/ m^2 and 2,700 kg per year. With an average cost of 1.5 USD/kg for vegetables, and a tariff of 0.07 USD/kWh for the electricity, the NPV is positive with 2,258,000 USD and breakeven point at the end of 9 years of project operation.

Chapter 7

Socio-economic impact

This chapter describes the socio-economic impact of utilizing geothermal resources in Chumathang. The development of this site will have a great impact on decreasing immigration of people to town, increasing employment opportunities, and increase food security. Many of the United Nations Sustainable Development Goals (UNSDGs) are fulfilled by this project.

7.1 Social and economic benefit

Economic development and employment benefits are interrelated. When geothermal power plants are planned and built, expenditures are made for services and equipment, as well as for taxes and royalties. These expenditures stimulate the creation of additional indirect jobs, more economic activity, and increased tax revenues. Ultimately, this reduces the burden on individual taxpayers in the community. The geothermal power industry provides a wide range of employment opportunities from exploration and drilling jobs, to high-tech manufacturing of generator, turbine, and power conditioning components to maintenance jobs at geothermal power plants. Through the economic multiplier effect, wages and salaries earned by industry employees generate additional income and jobs in the local and regional economies.

For this thesis, an assessment was done for the ENVISION checklist. Envision is an objective framework of criteria designed to help identify ways in which sustainable approaches can be used to plan, design, construct, and operate infrastructure projects. Envision not only asks, “Are we doing the project right?” but also, “Are we doing the right project? (Institute for sustainable infrastructure, 2019). The detailed assessment for the checklist is given in annexures. Envision includes 64 sustainability and resilience indicators, called ‘credits’, organized around five categories which are quality of life, leadership, resource allocation, natural world and climate.

The Envision Scoresheet is an online tool that allows project teams to collaboratively assess projects using Envision, upload documentation, describe key features of the project, and register the project for third-party verification. Scores are automatically tallied by credit category and for the whole project. An account is required to access the online scoresheet on ISI’s website.

Figure 7.1 gives the percentage of points earned in the different credit categories. As per the points, this project achieves a Platinum ENVISION rating.

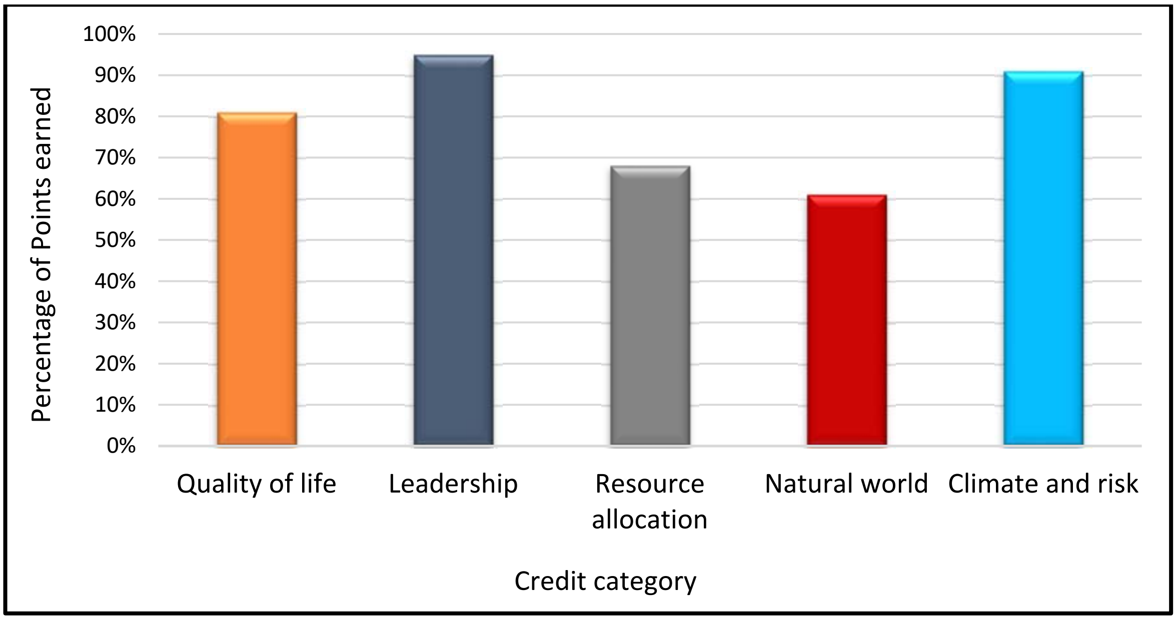


Figure 7.1: Credit points and ratings based on ENVISION (ISI 2019).

As per the ENVISION guidelines, to receive recognition, projects must achieve a minimum percentage of the total applicable Envision points. Projects can be recognized at four award levels:

- Verified: 20%
- Silver: 30%
- Gold: 40%
- Platinum: 50%

The ENVISION ratings show that the project can fulfill the Six Investment Criteria required for the funding from Green Climate Fund (GCF) which is shown in Figure 7.2. Hence the project can receive funding from GCF.

The Green Climate Fund (GCF) set up by the United Nations Framework Convention on Climate Change (UNFCCC) in 2010 is the world's largest dedicated fund helping developing countries reduce their greenhouse gas emissions and enhance their ability to respond to climate change. GCF is the first climate finance mechanism which placed gender as a key element of its programming architecture, and its commitment to gender equality centers on gender-responsive climate action programs and projects that benefit women and men (Green Climate Fund, 2020).

The GCF Governing Instrument states that: "The Fund will strive to maximize the impact of its funding for adaptation and mitigation, promoting environmental, social, economic and development co-benefits and taking a gender-sensitive approach."

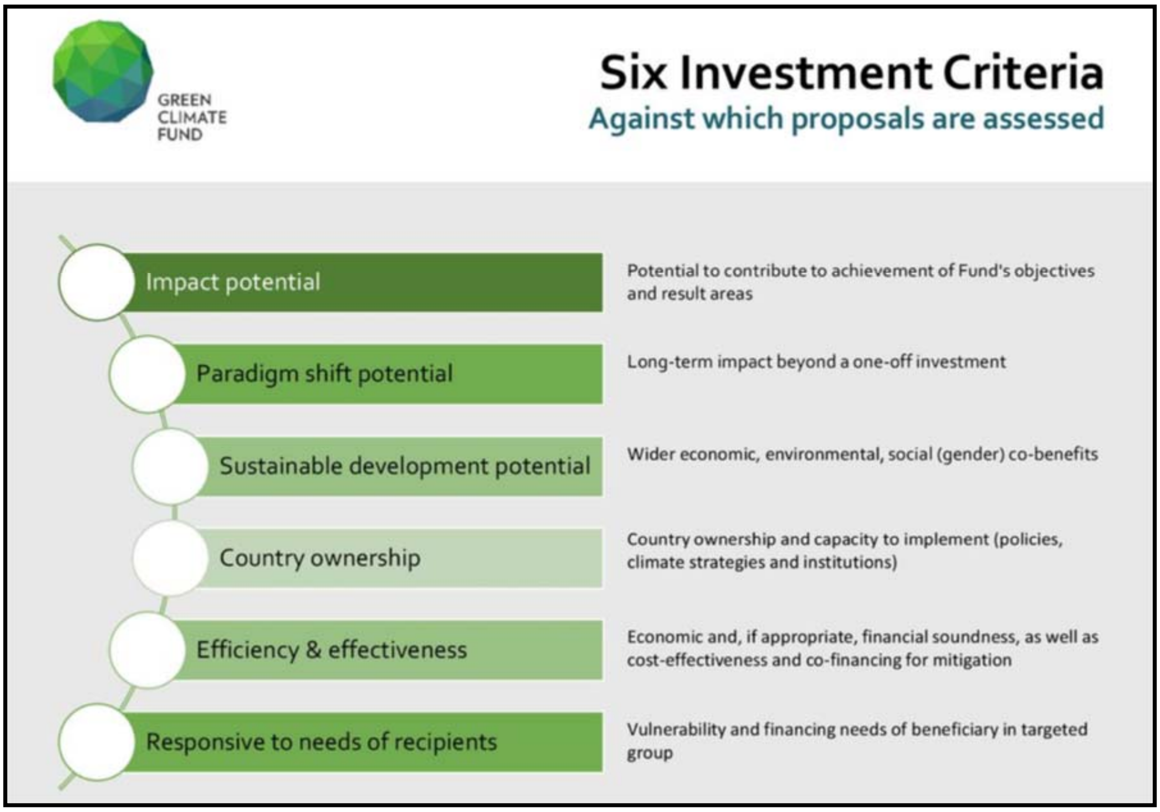


Figure 7.2 The Six Investment Criteria for Green Climate Fund (GCF 2019).

GCF makes investments within 8 strategic result areas, in line with country priorities (Green Climate Fund, 2020b):

- Energy generation and access
- Transport
- Buildings, cities, industries and appliances
- Forests and land use
- Health, food and water security
- Livelihoods of people and communities
- Ecosystems and ecosystem services
- Infrastructure and the built environment

In India, Ministry of Environment, Forests and Climate Change is the National Designated Authority (Green Climate Fund, 2020b). Other Direct access acredited entities are

- Infrastructure Development Finance Company (IDFC) Bank Limited
- Infrastructure Leasing and Financial Services (IL&FS) Environmental Infrastructure and Services Limited (IEISL)
- National Bank for Agriculture and Rural Development (NABARD)
- Small Industries Development Bank of India (SIDBI)
- Yes Bank Limited (Yes Bank)

Through this project some major concerns of the region will be addressed especially the following:

- Upliftment of women: During the research it was found that women did most of the household work be it cooking, laundry by hand, collecting everyday fuel and looking after children. The access to energy makes their work easy as they can use electricity for cooking, laundry and space heating thus reducing the physical labor. Women also do the farming and in cases when they have greenhouses they are able to produce and sell vegetables in winter season. This adds to food security of the region and the financial security of women.

- Economic Impacts: One of the most important economic aspects of geothermal energy is that it is generated using indigenous resources, which reduces a region's dependence on imported energy. The power generated from this plant will serve as baseload for the Ladakh region reducing trade deficits. Reducing trade deficits keeps wealth at home and promotes healthier economies.

- Employment Benefits: Due to lack of industries and private companies there is a lack of job in the region and thus the number of unemployed educated youth has been increasing. Projects like this could bring employment benefits in addition to having more industries due to the availability of power. In general, for every MW of geothermal power plant construction, 26 direct, indirect, and induced jobs are created. Operation and Maintainence jobs are more desirable because they represent full-time jobs for the duration of plant service.

Seeing all these impacts of the project on the community, the project has a possibility of getting funded from GCF.

7.2 Sustainable development goals (SDGs)

With the increasing concern globally about the climate change and environmental impacts, we must make sure that any new project that is to be done fulfills at least one or more of the 17 Sustainable Development Goals (SDGs) of the United Nations. This report is designed in such a way to fulfill SDG 7. SDG 5 and SDG 2 as a priority. The project will further fulfill SDG 9, SDG 13 as shown in Table 7.1.

Table 7.1: United Nations Sustainability Development Goals (UNSDs) met through this project

United Nations Sustainability Development Goals (UNSDGs)	How is it met
SDG 2 (Zero hunger)	By having fresh vegetable supply through the greenhouse
SDG 5 (Gender equality)	Women will get a much better quality of life due to access to clean energy.
SDG 7 (Affordable and clean energy)	By having access to clean energy
SDG 9 (Industry, innovation, and infrastructure)	Having 24-hour access to reliable energy will lead to setting up of industries leading to more employment opportunities
SDG 13 (Climate change)	Geothermal is a clean and reliable source of energy compared to fossil fuels and has much fewer emissions hence helping fight climate change.

7.3 Conclusion

The ENVISION credit rating done shows that that project can get funding from various funding agencies like the Green Climate Fund. The social and economic impacts of the project is positive and as such fulfils many UNSDGs.

When there is access to energy woman's life is improved as she can use the energy to do the above daily chores.

The access to energy can solve food security issues too as can be seen from the case study done in this thesis.

Energy access not only fulfils the UNSDG 7, but many other SDGs related to issues like climate change, unemployment, migration of people, gender equality, food poverty. are fulfilled.

Chapter 8

Discussion

Geothermal energy source can be a solution to meet the energy demands especially in remote areas where the provision of transmission lines is not possible through decentralized systems. The direct use of geothermal can change the lives of people living in remote regions. Cooling, cold storage, decentralized microgrids, recreation, food drying, etc. are some of the options which can be implemented around the geothermal sites in the remote areas to improve the lives of these people.

The thesis gives a brief description of the present condition of some geothermal sites visited during the research. An effort has been made to study how these sources, most of which are in remote areas, could be developed to improve the living condition of the people. It was found that more focus should be made on direct utilization of the geothermal sources for heating, cooling, cold storage, greenhouse, recreation, etc. which will help generate different employment opportunities and stop the migration of people from rural to urban areas. In order to develop the geothermal fields with the confidence of people, it is important that at first the local people are given adequate knowledge which was found to be missing during the field visit. Once the people are aware of the benefits of geothermal energy other than balneology, they can voice for the developments of these sites to the politicians.

The case study of Chumathang village considered for this report shows how a community can benefit from the utilization of geothermal sources. This adds to the energy and food security of the region which otherwise relies completely on imports of fossil fuel and food.

The Monte Carlo Volumetric assessment was done to calculate the geothermal resource availability of the Chumathang site. It was found that the most likely potential of the Chumathang site is 7.1 MW_e and the highest potential value is 33 MW_e.

At present the village is electrified by a diesel generator of 20 kW which provides electricity for 5 to 6 hours daily. The power plant is designed for 5 MW_e which will suffice the electricity needs of the village. The case study was focused on addressing two components, energy and food security, which was found to be the current problem of the area. A 5 MW binary power plant was designed which could replace the current installed 20 kW diesel generator providing reliable and clean energy.

A commercial greenhouse of 1,000 m^2 was designed which would be able to supply year-round fresh vegetables. For this site it is suggested that a combined power plant and greenhouse project could solve the energy and food security issue of the region. With a CAPEX of 15,0303 MUSD and the OPEX of 1,052 MUSD, the NPV is positive with 2,258 MUSD and the breakeven point is at the end of 9 years of project operation.

The ENVISION credit rating done shows that that project can get funding from various funding agencies like the Green Climate Fund. The social and economic impacts of the project is positive and as such fulfils many UNSDGs related to issues like climate change, unemployment, migration of people, gender equality etc. Migration of people to the cities in search of employment is a major issue that can be solved with opportunities due to access to energy. When there is access to energy woman's life is improved as she can use the energy to do the above daily chores.

A more detailed assessment of the geothermal sites in Ladakh like Panamik, Puga, Demchok, Chumathang needs to be done in order to know the actual potential. Exploratory wells need to be drilled in order to know the actual condition of the reservoir. Geothermal can provide the base load for the energy requirements in Ladakh and if the actual potential of these reservoirs is known then the region can change from an energy poor to an energy exporter. This is important not only for the energy security of the region but for the national security of India too.

Having energy access to this remote border area will mean development of these areas and the people living in these areas will not be lured by the development across the border.

References

Aiyar, A. S. S. (2019). View: With time, effort and luck, Ladakh could become north India’s power hub. Retrieved March 8, 2020, from https://economictimes.indiatimes.com/industry/energy/power/view-with-time-effort-and-luck-ladakh-could-become-north-indias-power-hub/articleshow/71495335.cms?from=mdr

Bureau of Energy Efficiency, Ministry of Power, Government of India. (2017). *Energy Conservation Building Code 2017*. Retrieved from https://beeindia.gov.in/sites/default/files/BEE_ECBC%202017.pdf

Cunningham, A. (1854). Ladák, Physical, Statistical and Historical with Notices of the surrounding countries (1st ed., Vol. 1). London, United Kingdom: Wm.H.Allen and Co.

Department of Science and Technology, Government of India. (2020). Survey of India. Retrieved March 12, 2020, from https://dst.gov.in/survey-of-india-zone

Dickson, M. H., & Fanelli, M. (2003). *Geothermal Energy*. Paris, France: United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000133254

DiPippo, R. (2016). Binary cycle power plants (4th ed.). United States of America: Butterworth-Heinemann.

Energy Sector Management Assistance Program (ESMAP). 2012. Geothermal handbook: Planning and financing power generation. The World Bank Group. Washington DC. USA. 150 pp.

Food and Agricultural Organization of the United Nations. (2003). Trade reforms and food security - Conceptualizing the Linkages. Retrieved from http://www.fao.org/3/y4671e/y4671e06.htm

Food and Agriculture Organization of the United Nations. (2019). The State of Food Security and Nutrition in the World 2019. Retrieved from http://www.fao.org/3/ca5162en/ca5162en.pdf

Geological Survey of India. (1991). Geothermal atlas of India. Calcutta: Geological Survey of India.

Geological survey of India. (2002). Geothermal energy resources in India. Lucknow: Geological Survey of India.

Greenspec. (2020). U values in building construction - introduction. Retrieved May 6, 2020, from http://www.greenspec.co.uk/building-design/u-value-introduction/

Green Climate Fund. (2020). Gender. https://www.greenclimate.fund/projects/gender

Green Climate Fund. (2020b, July). GCF at a glance. https://www.greenclimate.fund/sites/default/files/document/gcf-glance_0.pdf

Green Climate Fund. (2020b). India. https://www.greenclimate.fund/countries/india

Hindustan Times. (2007). Uranium in icy Ladakh - India. Retrieved February 20, 2020, from https://www.hindustantimes.com/india/uranium-in-icy-ladakh/story-MvWC5QfG3ghMtFKzaIxCVP.html

International Energy Agency. (2020). India 2020 Energy Policy Review. Paris: International Energy Agency.

IRENA (2018). Renewable Power Generation Costs in 2017. International Renewable Energy Agency. Abu Dhabi. 160 pp.

Institute for sustainable infrastructure. (2019, August 23). Overview. https://sustainableinfrastructure.org/envision/overview-of-envision/

Joshi, A. (2019). Ladakh has wind power potential of 1 lakh Mw: NIWE DG Balaraman. Retrieved March 8, 2020, from https://energy.economictimes.indiatimes.com/news/renewable/ladakh-has-wind-power-potential-of-1-lakh-mw-niwe-dg-balaraman/72842397?redirect=1

Kasapoğlu, H., & Parlaktuna, M. (2005). *A Technical Feasibility Study on the Use of Çavundur Geothermal Field for Greenhouse Heating*. Retrieved from https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/2307.pdf

Lund, J. W. (1996). *LECTURES ON DIRECT UTILIZATION OF GEOTHERMAL ENERGY*. Retrieved from https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-1996-01.pdf

Maps of India. (2020). Ladakh Map - Union Territory Information, Facts and Tourism. Retrieved July 6, 2020, from https://www.mapsofindia.com/maps/ladakh/

Maps of India. (2018). Jammu and Kashmir Map - Union Territory Information, Facts and Tourism. Retrieved July 6, 2020, from https://www.mapsofindia.com/maps/jammuandkashmir/

Ministry of AYUSH, Government of India. (2019). Introduction of SOWA - RIGPA | Ministry of AYUSH | GOI. Retrieved March 18, 2020, from http://ayush.gov.in/about-the-systems/sowa-rigpa/introduction-sowa-rigpa

Ministry of New and Renewable Energy, Government of India. (2020). Annual Report 2019-20. Retrieved from https://mnre.gov.in/img/documents/uploads/file_f-1585710569965.pdf

National Resources Defence Council, Administrative Staff College of India, Council on Energy Environment and Water, Indian Institute of Public Health Gandhinagar, Self-Employed Women´s Association, & The Energy and Resources Institute. (2018). The road from Paris: India´s progress towards its climate pledge. Retrieved from https://seors.unfccc.int/applications/seors/attachments/get_attachment?code=5TTFIGI4HAV24LGCS0WE8SOJW36HGY1R

National Renewable Energy Laboratory. (2018). *Geothermal Power Plants*. Retrieved from https://openei.org/wiki/Geothermal/Power_Plant

Ngugi P.K. 2012: What does geothermal cost? - the Kenya experience. United Nations University Geothermal Training Program. Iceland. 13 pp.

Press Information Bureau, Government of India. (2019). Press release on UT of JK and Ladakh. Retrieved February 15, 2020, from https://www.mha.gov.in/sites/default/files/PressRelease_NoteonUTofJK%26Ladakh_04112019.pdf

Lalit, R., & Kalanki, A. (2019). How India is solving its cooling challenge. Retrieved August 25, 2019, from https://www.weforum.org/agenda/2019/05/india-heat-cooling-challenge-temperature-air-conditioning/.

Ragnarsson, ,Á. 2019. Geothermal heating of greenhouses, UNU-Geothermal Training Program, Geothermal Utilization unpublished lectures.

Richter, A. (2020). Power, energy, electricity, heat and geothermal – the importance of the right terminology. Retrieved March 9, 2020, from https://www.thinkgeoenergy.com/power-energy-electricity-heat-and-geothermal-the-importance-of-the-right-terminology/?fbclid=IwAR086Qire5kr25nGT6NtTcBtlghBdTsG7kZwbZXgdyQNpEgeXyXaNZDJ6kg

Sarmiento, Z. F., Steingrímsson, B., & Axelsson, G. (2013). Volumetric resource assessment [Dataset]. Retrieved from https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-16-34.pdf

Shutterstok. (2020). Photo of vegetable seller https://image.shutterstock.com/image-photo/local-fruit-vegetable-shop-main-260nw-713976850.jpg

STRATA. (2017). *The Footprint of Energy: Land Use of U.S. Electricity Production*. Retrieved from https://www.strata.org/pdf/2017/footprints-full.pdf

Taki, M., Rohani, A., & Rahmati-Joneidabad, M. (2018). Solar thermal simulation and applications in greenhouse. Information Processing in Agriculture, 5(1), 83–113. https://doi.org/10.1016/j.inpa.2017.10.003

The World Bank. (2020a). World Bank Country and Lending Groups – World Bank Data Help Desk. Worldbank. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

The World Bank. (2020b, July). Gross national income per capita 2019, Atlas method and PPP. https://databank.worldbank.org/data/download/GNIPC.pdf

U.S. Energy Information Administration. (2020). EIA - Electricity Data. Retrieved March 19, 2020, from https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a

U.S. Department of Energy. (2019). GeoVision Harnessing the heat beneath our feet. Retrieved from https://www.geothermal.org/PDFs/GeoVision-full-report-opt.pdf

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. (2016).

GETEM -Geothermal Electricity Technology Evaluation Model. Retrieved January 18, 2020, from https://www.energy.gov/eere/geothermal/downloads/getem-geothermal-electricity-technology-evaluation-model-0

Verkis. (2014). geothermal binary power plants, Preliminary study of low temperature utilization, cost estimates and energy cost. Retrieved from https://www.verkis.com/media/pdf/iceida-geothermal-binary-overview.pdf

Wikimedia commons. (2013). *Nimoo-Bazgo Hydro project* [Photograph]. Retrieved from https://commons.wikimedia.org/wiki/File:Nimoo_Bazgo_Project.jpg

Wikipedia contributors. (2020). Geography of India. Retrieved March 13, 2020, from https://en.wikipedia.org/wiki/Geography_of_India

World Energy Council. (2019). World Energy Trilemma Index 2019. Retrieved from https://www.worldenergy.org/assets/downloads/WETrilemma_2019_Full_Report_v4_pages.pdf.

world weather online. (2020). world weather online. Retrieved February 2, 2020, from https://www.worldweatheronline.com/hanle-weather-averages/jammu-and-kashmir/in.aspx