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THESIS NO:

Techno Economic Evaluation of LPG Gas Stove Replacement by Induction Stove in the Households of Kageshwori Manahara Municipality 'Ward No.5'

by

Sanjeev Khadka

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Techno Economic Evaluation of LPG Gas Stove Replacement By Induction Stove in the Households of Kageshwori Manahara Municipality Ward No.5'"** submitted by Sanjeev Khadka, in partial fulfillment of the requirements for the degree of Master of Science in Energy System Planning And Management Engineering.

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ABSTRACT

Nepal's energy sector has a significant share of fossil fuel, 16.5% of the total energy sector is occupied by the fossil fuel. On the one hand, Nepal heavily relies on LPG and petroleum imports from India. Meanwhile, Nepal is continuously striving towards development of hydropower projects. The energy balance of the country must be revisited keeping in mind about the growing production and the improving transmission network for the hydroelectricity.

Most of the Liquefied Petroleum Gas (LPG) imported inside the country is consumed within the Kathmandu Valley alone, out of 10 LPG cylinders that are imported within the country Kathmandu valley alone consumes 6 cylinders. The data published by the Nepal Oil Corporations (NOC) regarding the LPG import also indicates that the prices have been soaring up along with the volume of import. The growth in the production of the hydroelectricity by Nepal creates a favorable environment to increase the consumption and the export of such electricity. The current scenario of LPG import is just adding up the pressure to the economy of the country and apparently the country has to look forward for the better options to address the scenario. The significant growth and development in the hydropower sector can provide a formidable a solution to cut down the LPG import by utilizing the indigenous electricity produced from the hydropower. Currently various cooking technologies are being noticed in the market, among them Induction stoves are also the one. This thesis focuses on techno-economic aspects of replacement of LPG by the induction stove and the impact on the environment that can be achieved from the replacement. So, a clear picture must be presented to the consumers regarding the thermal efficiency, NPV, the payback period and the environmental benefits.

The cooking efficiency of the induction stove is found to be at least 86% whereas the cooking efficiency of the LPG stoves is less than 50%. The comparative NPV for the induction stove and the LPG stove also shows that the induction stove is a better option compared to the LPG stove. The calculation regarding the payback period for the replacement of the LPG stove by the induction stove also shows that the savings in the O&M cost by replacing the LPG stove by the induction stove has more than 90% probability of recovering the initial investment made in the induction stove within thirty one months.

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ABBREVIATIONS

AHA	American Heart Association
AHS	Annual Household Survey
BC	Black Carbon
CB	Crystal Ball
CBS	Central Bureau of Statistics
CES	Center for Energy Studies
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
GWP	Global Warming Potential
IGBT	Insulated Gate Bipolar Transistor
IHD	Ischemic Heart Disease
ICD	Implantable Cardioverter Defibrillators
LPG	Liquefied Petroleum Gas
MCM	Monte Carlo Method
MCS	Monte Carlo Simulation
MJ	Mega Joule
MT	Metric Tons
NEA	Nepal Electricity Authority
NO_2	Nitrogen dioxide
NOC	Nepal Oil Corporation
NPC	National Planning Commission
NPV	Net Present Value
PM	Particulate Matter
SO_2	Sulphur dioxide
T & D	Transmission and Distribution
TJ	Tera Joule
VDC	Village Development Committee
WECS	Water and Energy Commission Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Nepal is a South Asian and a landlocked nation with neighboring countries China towards the north and India towards the southern territory. Nepal covers a territory of 1,47,181 sq.km, the east to west length of the country is around 800km whereas north to south length is 90 to 230 km from. According to the National Population and Housing Census held in 2078 B.S, the total population of Nepal was counted to be 2,91,92,480 which represents a 10.18% growth in the population counted during the census 2068 of Nepal. The average household size of the country is 4.32 person per household, meanwhile the urban household size is 4.25 person per household and the rural household size is 4.55 per household. The population growth per year for the country is 0.93% per year (Central Bureau of Statistics, 2078) .

Energy is associated with the livelihood of the population, it is essential for lighting, cooking, transportation, operating the computer, charging the cellphone and powering up any mechanical, electrical and electronics equipment. Thus, it is evident that energy and livelihood goes together hand on hand. If we look at the various economic sectors, energy consumption can be classified into sectors as such residential, industrial, transportation, commercial, agricultural, construction and mining (WECS, 2014). These economic sectors are the pillar for the growth and development of any nation, furthermore the necessity of energy in these sectors clearly highlights the importance of energy. In simpler terms, if a country can suffice its energy demand, then the country can go forth to conduct activities to achieve its targeted goals.

There must be the balance between the supply and demand of the energy. The supply of energy could be done by either utilizing the indigenous energy resources found inside the country or by importing the required amount of energy. So, it is very important for any country to have an estimate of energy resources that can be found within the country and how the energy can be made available to its citizens in a financially feasible way. In Nepalese context, the significant source of indigenously available energy resource is flowing water and the energy associated with it, hydro-electricity. Besides the energy that could be harnessed from perennial rivers of the country, Nepal does not have its own natural gas reserves and oil mines. Energy always have direct impact upon the social and economic standpoint of the Nepali Society and it will continue in the upcoming future as well (WECS, 2014).

Nepal is home to several perennial rivers; consequently, Nepal has got a huge potential for hydroelectricity that can be derived from the available water resources. There are approximately 6,000 rivers in the country with the water flow length of around 45,000 k.m. Annually the expected water runoff in these rivers are expected to be 220 billion cubic meter. Based upon these facts the theoretical potential for hydroelectricity in the country is expected to be 83 GW. The possible hydropower potential of Nepal could not be fully harnessed and hence around 42 GW is considered to be techno-economically feasible to develop (Gunatilake, Wijayatunga, & Roland-Holst, 2020). Currently, the total installed hydropower capacity of Nepal is 2136.775 MW, a total of 2123.543 MW From 122 projects with individual installed capacity more than 1MW and the total of 13.232 MW from 17 projects with individual installed capacity less than 1MW (Department of Electricity Development, 2022). But due to the seasonal variation of the amount of rainfall, T&D losses, pre-scheduled maintenance of hydropower plants and several other problems linked with the operation and maintenance of the hydropower the production is lesser than the installed capacity. Several hydropower projects are in the construction phase and there are other several hydropower projects which are currently under study. Currently the growth in the hydropower development of Nepal is in a positive note.

Firewood is the most common energy carrier in Nepal, it accounts for more than 60% of the energy consumption. Firewood consumption has always been a threat for the forest and it also contributes to the indoor air pollution and adverse effect on the health of the people. Compared to other nations, Nepal has a very high energy consumption relative to its GDP. So, it becomes evident that the country needs a suitable strategy for the sustainable and efficient energy use. Energy sector can be made sustainable and efficient energy by focusing upon the indigenous energy resources of Nepal such as hydropower, biomass etc. Thus, the energy sector is viewed as the key sector with regard to the economic growth and the realization of development goals as formulated in government’s policy document (WECS, 2022).

Nepal mainly depends upon only one supplier country, India for the net import of the petroleum and gas. Since energy is an important driver of economic activities in the country it becomes quite essential that there should be a secure supply of energy to meet national demand on both the short term and the long term. As a net importer of petroleum products and gas from only one supplier country Nepal should keenly promote policies regarding the energy security to tackle with the supply and demand gap of energy, frequent price fluctuations of petroleum products and poor diversification of primary energy supply (Darlamee & Bajracharya, 2021).

There has been a very good indication regarding the increase in the electricity production with in Nepal in the upcoming years (Vaidya, 2020). Out of the total population of the country 92.51% of the population has access to the grid electricity (Nepal Electricity Authority, 2022) . The increase indicates that the electrification rate may increase further in the future. "Mr. Sagar M. Gyawali, Assistant Manager at NEA, suggested the existing distribution network of the country can support up to 500,000 induction cooktops" (Vaidya, 2020). Induction cook stoves are environment friendly in a sense that in the context of Nepal they are operated from the electricity generated from the hydropower which does not cause any sort of emissions. In the context of Nepal where most of the household rely on the combustion-based cooking technology the transition to induction cook stove will help to reduce the indoor air pollution as well. Other benefits from the induction cook stove is that it helps in the energy security of Nepal by cutting down the LPG import in the country and thus helping to reduce the trade deficit with India by decreasing the import of the fuel.

1.2 Problem Statement

The dependency upon a single country for the fuel import by Nepal will always keep the energy supplying country in the upper hand, the LPG supply cut off during the economic blockade by the India is a clear example. But now a day our market has got various cooking technologies as options which can be energy efficient than LPG and uses hydroelectricity, an indigenous energy of the country. The development in the sector of hydroelectricity also shows that Nepal needs to consume more electricity. And hence the Consumers (citizens of the country) need to visualize the benefits that they can obtain by switching into energy efficient cooking technology.

1.3 Objectives

Main objective of the study is to conduct the techno-economic analysis of Liquefied Petroleum Gas replacement by the Induction cook stove.

Specific objectives of the study are:

- To compute and compare the thermal efficiency of the household LPG gas stove and the induction cook stove
- To perform financial analysis
- To compute reduction in GHGs and $PM_{2.5}$ emission.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 Energy Scenario of Nepal

The classification of energy sources, in the Nepali context, is broadly assessed under three heads, they are traditional, commercial, and alternative energy resources. Biomass, firewood, agricultural residue and animal dung are some examples of Traditional energy resources wherein fuels are directly burnt during the process of combustion. Fossil fuel (Petrol, Diesel, LPG, Kerosene) and electricity that are commercially available in the energy market are classified under the commercial energy sources. Energy from sun, wind, micro hydro, biogas etc. are classified under the alternative sources of energy (WECS, 2017).

Nepal, however, has a long way to materialize the hydro potential. Noticeable demand for energy in the Nepali energy market is fulfilled by the traditional energy resources, especially biomass. Energy balance shows the predominance of biomass in the energy scenario of the country, but nevertheless this huge reliance upon the biomass results in the depletion of the environment (WECS, 2017) .

Table 2.1 Distribution of Energy Consumption by fuel types in the year 2021

S.N.	Fuel Type	Share (%)
1.	Fuel wood	60.38
2.	Agriculture-residue	3.00
3.	Animal Waste	2.87
4.	Kerosene	0.13
5.	Petrol	3.13
6.	Diesel	10.14
7.	ATF	0.35
8.	LPG	3.48
9.	Furnace Oil	0.54
10.	Coal	9.34
11.	Electricity	4.22
12.	Biogas	1.56
13.	Solar	0.759
14.	Wind	0.001
15.	Micro/Pico/Hydro	0.08

(WECS, 2022)

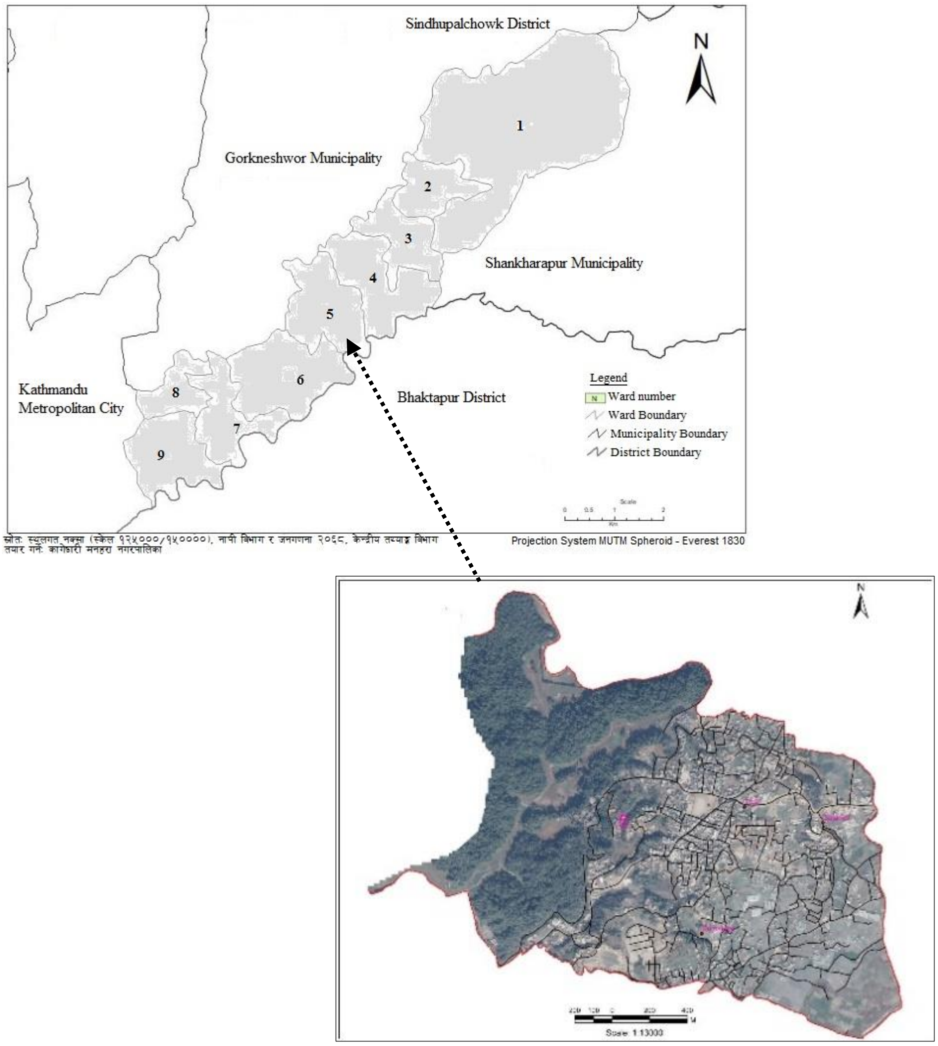
Table 2.1 makes it evident that the fuel wood has the largest percentage share, 60.38% in the energy consumption profile of the country followed by the petroleum's (kerosene, petrol, diesel and ATF) share, 13.75%. Renewable energy and Electricity are among the least contributing fuel in the energy consumption profile of Nepal. According to the Energy Data Sheet 2014 report published by WECS residential sector is the only sector consuming fuel wood with its majority end use as residential cooking, which negatively affects the environment (WECS, 2014).

Combustion product of the fossil fuel and traditional fuel contains hazardous pollutants like Particulate matter ($PM_{2.5}$ and PM_{10}), Black Carbon (BC), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Carbon Monoxide(CO) etc. and these pollutants have a very serious impact upon the human health (Dhaubanjar, Nakarmi, & Bajracharya, 2019). Studies have shown that prolonged and continuous exposure to $PM_{2.5}$ can cause to health diseases like COPD, IHD, stroke and lung cancer which can ultimately lead to premature death (Chowdhury & Dey, 2016). The Black Carbon emission is more hazardous to human health than the $PM_{2.5}$ exposure. A microgram per cubic meter volume has severe impact upon human health than the $PM_{2.5}$ and PM_{10} exposure which clearly shows BC exposure is very strong compared to the $PM_{2.5}$ (Janssen, et al., 2011). Therefore, it is evident that these fuels not only provide energy for cooking but also comes with detrimental effects on health condition of the user. Thus, it is always a better option to reduce the consumption of combustion based cooking energy resources like fuel wood and LPG by replacing it with better alternatives that are in harmony with nature and human health.

A study, "Cooking Cost Comparison using LPG, Rice Cooker, Induction and Infrared Cooker", conducted by Shrestha et. al. at Center for Energy studies (CES) highlighted the need for Nepal to cut down the import of LPG and replace it with much cleaner and indigenous fuel available inside the country. The study showed that cooking 0.5 kg of rice in the induction stove is much cheaper than cooking the same amount of rice using the LPG stove. It's a high time to promote fuel switching from LPG to electricity in order to reduce a high sum of money that is being drawn outside of the country to import the cooking fuel alone (Shrestha, Raut, & Shrestha).

2.2 Description of the location of case study

The location selected for the case study is Kageshwori Manohara Municipality ward no.5, a representative urban setting of the country. The ward is formed by combining ward no.7, 8 and 9 of earlier Danchhi VDC. Kageshwori Manohara ward no.4 lies towards the east and ward no.6 of the municipality lies towards the west. The northern and southern areas of the ward is bordered with the Gokarneshwor Municiaplity and the Bhaktapur District respectively. All together there are 3,328 households in this ward with a total population of 12,847 people. The total area of the ward is 4,224 square k.m. The average household size of the ward is 3.86 person per household. Population distribution by caste shows that Brahmin (32.71 %), Chhetri (31.96 %), Newar (10.72 %), Tamang (9.73 %), Magar (2.4 5%), Rai (2.13 %), Sarki (1.54 %), Kami (1.54 %) and others (7.10 %) live in the ward. (Kageshwori Manahara Municipality, 2022) .



(Kageshwori Manohara Municipality Office, 2022)

Figure 2.1 Geographical location of the Kageshwori Manahara Municipality Ward 05.

It is clear from Figure 2.1 that more than one third of the topography of the ward is covered by the forest, Gokarna Forest located at the western sector of the ward. It is a government forest, firewood and leaves collection is prohibited by the forest authorities. Bagmati river, flowing from the northern direction of the forest flows from the north to south of the ward. The river from the water is used to irrigate the cultivation land close to the river. The river originates at Bagdwar, Shivapuri and lodged towards Sundarijal before taking its direction to this ward. People get their drinking water from the Sundarijal drinking water treatment plant, the plant collects the water at Sundarijal processes through necessary steps before delivering to the public.

People in the ward are involved in various economic activities. If we ponder upon the detail it can be observed at least two or more people from a household are engaged in the economic activities.

Table 2.2 Engagement of the person involved in the economic activities

S.N.	Engagement	Share (%)
1.	Agriculture	1.04
2.	Manufacturing	20.72
3.	Electricity, Watery Supply & Construction	1.14
4.	Wholesale & Retail Trade	37.73
5.	Transportation, Storage, Information & Communication	0.36
6.	Accommodation & Food	12.69
7.	Finance & Insurance	2.98
8.	Education	16.33
9.	Human Health & Social Work	1.00
10.	Real Estate, Professional, Scientific, Administration, Arts	6.01

(Kageshwori Manahara Municipality, 2022)

Above table, Table 2.2, shows that out of the total population 3,617 people are engaged in the various economic activities. The top three economic activity engagement are Wholesale & Retail Trade, Manufacturing and Education. Wholesale & Retail Trade chiefly includes the people engaged in the grocery shops, electronics shops, electric shop, diary, clothing store, fruits and vegetable shops etc. Similarly, manufacturing includes those who are engaged in carpet factories, cemented block factories, plastic factory, pottery, bakery, carpentry, garment factory etc. And Education sector includes who have their own educational institution or people working for the institution (Kageshwori Manahara Municipality, 2022).

Fuel wood is the only indigenous source of fuel in the municipality, Besides this, the municipality does not have any other indigenous source for energy. Commercial solar energy plant is not installed, which could have been the indigenous energy source. The sectors that are liable to the energy consumption in this ward are mainly residential, industrial, transportation, commercial and agricultural ones. Since this study is focused upon the residential cooking the energy mix of the households by fuel usually used for cooking is tabulated below.

Table 2.3 Households by fuel usually used for cooking

S. N.	Cooking fuel	Number of Household	Percentage share (%)
A.	Non-Combustion based cooking		
1.	Electricity	27	0.8
B.	Combustion based cooking		
2.	LPG	3192	95.9
3.	Others (Wood, kerosene, biogas, cow dung)	108	3.3
	Total	3327	100%

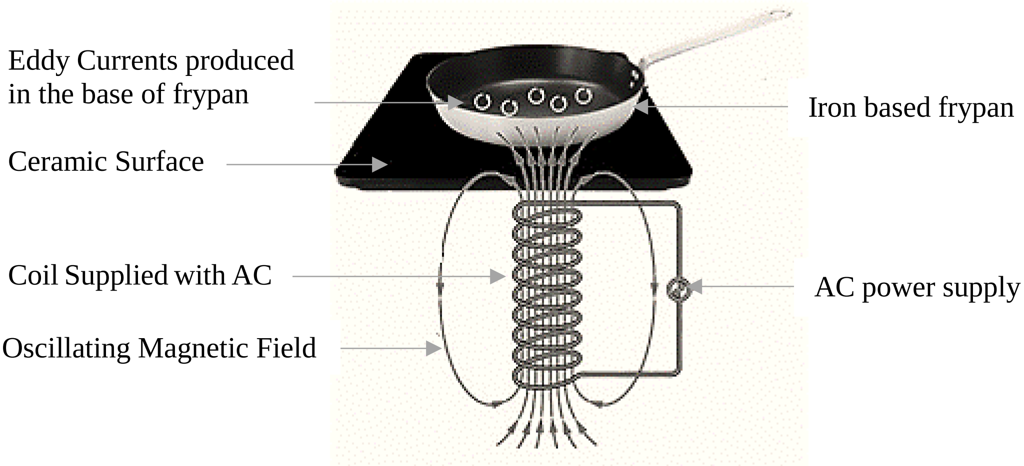
(Kageshwori Manahara Municipality Office, 2022)

The above table Table 2.3 shows the number of household that depend upon particular type of fuel for cooking purpose. It can be seen that the most of the households depend upon combustion based cooking technologies. The households are highly dependent upon LPG, 3192 households out of 3327 household rely upon LPG. Similarly, 108 households are still relying on other combustion based cooking like wood, kerosene, biogas and cow dung. Whereas 27 household rely upon electricity for cooking.

2.3 Induction Stoves

In the context of Nepal, induction stoves are gradually being noticed in the residential cooking. The Government of Nepal is also looking forward to increasing the consumption of hydroelectricity domestically and in this sense as well the government has accorded to promote the induction stoves. Several studies have been done to study about its competence in the Nepali Cooking fuel market and these studies also suggest that induction stove has got the capability to overtake the traditional fuels. Induction cooking is the technology which uses the principle of electromagnetic induction, thus the cookware that has to be heated has to be metallic (especially ferro magnetic) in order to be used. Induction stoves operate with AC electricity, as AC current is supplied to the heating coil placed under the cookware a varying magnetic field is created which causes the creation of the Eddy current and due to the resistance of the eddy current by the cookware the heat is generated. Thus, generated heat is localized. In induction stoves there is minimum heat loss and as a result most of the energy is used to cook the food due to which the efficiency of the induction stoves are higher (Sadhu, Pal, & Bandyopadhyay, 2010).

Study conducted by Sweeney et. al. also suggests that the induction stove is one of the efficient technologies in the cooking sector (Sweeney, Dols, Fortenbery, & Sharp, 2014). In case of the induction stoves the induced eddy currents that are developed in the oscillating magnetic field are excited in the ferromagnetic cookware, the heat generated from the induced current is utilized for cooking purposes. As a result, very less heat is lost because of inefficient conduction of heat between the heating element and cookware (Sweeney, Dols, Fortenbery, & Sharp, 2014). A schematic diagram of the induction stove is shown below.



(Tiandho, Putri, & Afriani, 2021)

Figure 2.2 Induction stove working principle

A typical induction cook stove is comprised of several switching power electronics, which provides a fairly high frequency current to a loop of wire, which is embedded beneath the cooking surface, made up of ceramic or glass. The oscillating magnetic field and the cookware are magnetically coupled as a result eddy currents are induced in the base of the cookware. The power dissipated during the process is given by Ohm’s law, i.e. I^2R, where I is the symbol for current measured in amperes and R is the resistance of the cookware measured in the ohms. Magnetic permeability, the resistivity of the cookware and excitation frequency of the AC are the major factors associated affecting the performance of the induction stoves. For the generation of sufficient heat, there must be high permeability and the resistivity. The typical operating frequencies of induction cookers range in between 25kHz to 50 kHz (Sweeney, Dols, Fortenbery, & Sharp, 2014).

In case of the induction stoves, a flat or a hemispherical coil (in case of the wok type induction stove) is under the cookware, and a medium frequency current helps the coil inducing eddy current and generating heat (Meng, L.C., Cheng, K.W.E, & Chan, 2016). A better magnetic coupling is possible where there is a very minimum gap of 0.05mm to 3 mm between the coil and the vessel (Sadhu, Pal, & Bandyopadhyay, 2010). But the gap should be optimum in such a manner that it can maintain insulation and very sufficient air flow (Sadhu, Pal, & Bandyopadhyay, 2010). The cookware that are used with induction should be compatible with the induction technology by that it means the cookware must have a very high permeability and high resistivity (Sadhu, Pal, & Bandyopadhyay, 2010). The heating coils are made up of conducting materials and these coils might get subjected to the heat induced in the cookware, so a fan type forced convective cooling is maintained to continuously cool the coil (Sadhu, Pal, & Bandyopadhyay, 2010).

The efficiency of the induction stove was measured to be 85.56% by Adhikari et. al. The efficiency was calculated as a ratio of output power to the input power where the output power was calculated using the thermodynamic relations and the input power for the induction stove was calculated by using the values of voltage and current recorded while operating the induction stove. The same study also found that the simulation based efficiency was found to be 87% (Adhikari, Shrestha, & Shakya, 2016).

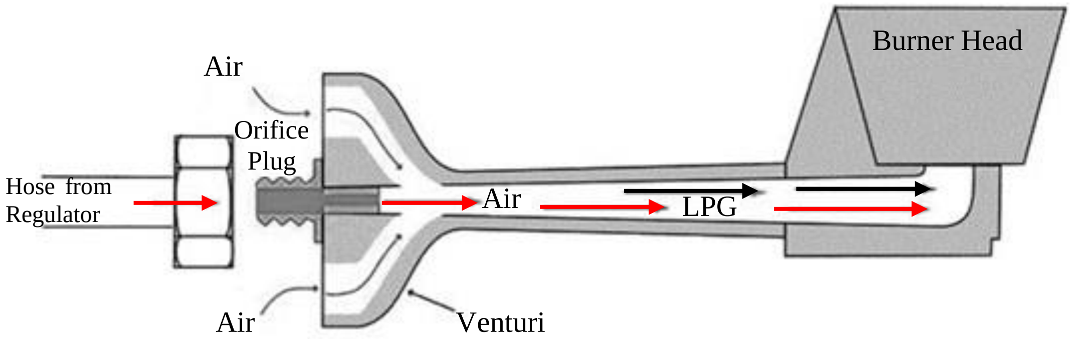
In contrary to the combustion based cooking techniques the induction stove does not produces flame (fire), this old habit is very hard to change. Since the ancient times, human beings are accustomed to use fire flame while cooking due to which modern day consumers also find it weird to adopt to flameless cooking. Thus, the consumer should be aware that induction cook stoves can be used for cooking even it does produce flame. Awareness level of the consumers is linked with the education level. According to Acharya and Mahrold, households having lower education levels are to consume consumption of dirty cooking fuels like kerosene and biomass, whereas household ownership having access to information about renewable energy lead to a preferred selection of more modern, cleaner fuels (Acharya & Marhold, 2019).

There always have been concern regarding the effect on the human health by the use of the induction stoves and the electromagnetic field (EMF) associated with it. The electromagnetic field associated with the induction cook stoves are non-ionizing and they do not affect the human cells. The National Cancer Institute, United States have concluded that these EMFs are not harmful to humans (National Cancer Institute, 2023). American Heart Association (AHA) has a list of devices that should be avoided if anyone has implantable cardioverter defibrillators (ICDs) and pacemakers. Induction stove is not there on that list (American Heart Association, 2023).

2.4 LPG stoves

LPG stoves use LPG as a fuel, the LPG is extracted during the crude oil refining process. LPG stoves are combustion-based cooking stoves which uses liquefied petroleum gas the fuel for combustion. LPG is composed of propane, butane, propylene, butylene and isobutane. The mixture of these highly inflammable hydrocarbon gases influences the chemistry behind the combustion. LPG is widely accepted as fuel in household cooking.

LPG stoves function on the principle called Venturi effect. In LPG stoves the air and the LPG has to be mixed before the combustion in the throat portion, stoichiometric ratio to burn LPG in air is 15.6:1. As the LPG coming out the cylinder regulator passes through the hose, the hose is connected with a valve with the orifice plug. When pipe gets narrow at the hole maintained by the valve, the flow of gas is more rapid. On passing the gas in a faster flow rate through the narrow sections the pressure decreases. The LPG gas thus moves into the mixing chamber where the air from the surrounding is attracted due to the sudden decrease in pressure around the LPG gas jet. The mixture of air and the LPG eventually is pushed out of the burner holes that are finely and evenly spread along the periphery and burns with the ignition (Khan & Saxena, 2013).



(Khan & Saxena, 2013)

Figure 2.3 LPG stove working principle.

The petroleum product import and distribution in the country is led by the government owned sector, Nepal Oil Corporation (NOC) and so far NOC has got the monopoly in importing, sorting and distributing all petroleum products in Nepal (Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019). Hotels and restaurants are two main sectors that consistently consume LPG gas in Nepal, several cylinders per day are consumed by these sectors (Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019). Households that mainly rely on LPG for their cooking solution also intend to have the LPG in their stock so that they can meet their energy demand in case of any unprecedented scenarios. Thus, households tend to keep 2-3 extra LPG cylinders (Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019). In case of the rural households, these households mainly rely on fuelwood, biomass and kerosene, the price of the LPG and the income level of the household in the rural areas may be one of the reasons for such situation (Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019). Most of the LPG imported in the country is consumed inside the Kathmandu Valley alone, out of 10 cylinders Kathmandu valley alone consumes 6 cylinders (Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019). If we have look at the data of price of LPG the price has been soaring up every year (Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019).

2.5 Environmental factors

The effect of combustion based cooking in the environment cannot be overlooked. The worldwide temperature is rising due to which the vegetation and the human health is being directly affected. Therefore, there is a deep concern regarding the reduction of GHGs and pollution.

During the residential cooking the energy consumed during the process also contribute to the formation of carbon dioxide (CO_2) and nitrous oxide (N_2O). CO_2 gas has a GWP of 1 whereas the N_2O has a GWP of 310 (Randall Spalding-Fecher, 2002). Similarly, for residential LPG use the emission factor for CO_2 is 63100 kg/TJ (2.88 kg of CO_2 emitted per 1 kg of LPG consumed) whereas for N_2O is 3.5 kg/TJ (0.16g of N_2O emitted per 1 kg of LPG consumed) (IPCC, 2006) .

A study was conducted by Pokhrael, et. al. in the 824 households regarding the $PM_{2.5}$ level in the kitchen as a result of the type of primary fuel used for cooking. The study was done to find the numerical value of $PM_{2.5}$ emissions due to four primary fuels i.e biomass, kerosene, LPG and electricity. The study found that the amount of $PM_{2.5}$ in the air in year is 656µg/m^3 (standard deviation (SD):924) µg/m3 from biomass; 169 (SD: 207) µg/m3 from kerosene; 101 (SD: 130)µg/m3 from LPG; and 80 (SD: 103) µg/m3 from electric stoves. The $PM_{2.5}$ level found in the kitchen using electric stoves were same as the ambient environment's $PM_{2.5}$ level (Pokhrael, et al., 2015).

2.6 Monte Carlo Simulation

Monte Carlo Simulation is the simulation that is guided by the Monte Carlo Method (MCM). MCM refers to the technique in which random sampling is done to find the solution. More specifically, MCM refers to finding the solution of problem as parameter of the hypothetical population and thereafter statistical estimates are drawn from the parameter. During the generation of the hypothetical population the random numbers and their associated probability distribution are also generated to be taken as input variables (Fred, 1980).

Monte Carlo Simulation has a very wide range of applications in the field of economics, business, finance, data science, corporate office etc. Considering the data available in the various field this simulation yields important, that provides crucial statistical result on the hands of the data analytics, scientists, managers or any top level executive staff. This simulation technique is thus the one of the oldest and most widely used statistics based approach to draw inferences from a small sample data set as well.

2.7 Crystal Ball

Crystal Ball (CB) is a basically a Microsoft excel add on package that uses Monte Carlo technique into the excel sheets to forecast risk and variance much accurate and better fashion. Decisioneering Inc. in 1986 introduced CB which has many major upgrades over the years. Some of the major feature of the CB are Time Series Forecasting, Monte Carlo Simulation, Optimization and Real option analysis, Hypersonic Strategic Finance Planning etc. In the year 2007 Oracle Corporation took over the company from Hperion which had earlier taken it from Decioneering Inc. And currently Oracle Corporation is in the charge.

2.8 Fuel Switching: Theories and Behavior

The adjustment of energy utilization by the citizens in Nepal is related with changing context of energy generation, energy accessibility and expectations for everyday comforts of individuals. Fuel changing from traditional and contaminated wellsprings of fuel to cleaner sources is subject to average household age, education, household size, and accessibility and cost of the fuel (Bhandari & Pandit, 2018). Energy ladder and energy stacking models stand as the two main models to analyze energy choice and fuel transition for any households (Elias & Victor, 2005) . These models are rooted to the categorization of energy resources as traditional, transitional and modern types (Joshi & Bohara, 2017).

The energy ladder model is often used to analyze household energy consumption patterns in developing countries (Adamu, Adamu, Ade, & Akeh, 2020). With an increase in wealth, households are expected to substitute existing fuels with less polluting fuels (Masera, Saatkamp, & Kammen, 2000). There is a one to one relationship between the income and the consumption of fuels (Toole, 2015). According to the energy ladder model fuel switching by a household is mainly influenced by the income of the household, relative fuel prices among the various fuels and the accessibility of the fuel. But several studies have noted the constraints of the energy ladder model (Masera, Saatkamp, & Kammen, 2000). In practice it is never easy to completely forego one fuel and transit into another fuel. Generally, households are reluctant to have 100% shift from one fuel to another (Toole, 2015). Inability to fully incorporate the cultural and habitual factors while analyzing the fuel transition are some shortcomings in the energy ladder theory (Toole, 2015).

Energy stacking model presents an more inclusive and updated behavior of fuel switching as compared to the energy ladder model thus it can viewed as an substitute to the energy ladder model (Joshi & Bohara, 2017). The use of multiple fuels is known as ‘stacking’. As the living standard grows, households adopt modern fuels but also often continue to use traditional fuels (Choumert-Nkolo, Motel, & Roux, 2019). Households do prefer energy mix in their daily consumption. This very model also reflects that the socio-economic aspects of households tend to govern the fuel switching (Joshi & Bohara, 2017). Different studies have found different factors besides the income that influence fuel switching pattern. One of the study conducted in Nigeria regarding the type of fuel consumption for household cooking came to the conclusion that the financial capability for per capita expenditure was found to be a major determinant factor for the use of electricity and gas (Yuni, Nwokoye, Urom, & Ozor, 2017). Besides, fuel switching behavior is affected by the mix of several social factors as well viz. size of the family, age composition of the household, amount of time spent inside the home, urbanization, type of abode, level of literacy and adaptability play a vital role (Bhattarcharjee, 2011).

It is not necessary that in the case of the developing countries the fuel switching does linearly follow the energy ladder model theory (Elias & Victor, 2005). Studies show that energy stacking is the dominant fuel usage theory adopted by households in developing countries (Acharya & Marhold, 2019). Even if the fuels are not health friendly, households cannot give up on those fuels and replace it with other. Various socio-cultural factors are there which cause an obstruction for a complete fuel switching process. Thus it can be sensed that the energy ladder model is moreover one eyed model primarily focusing on income which does not incorporate the social factors that also play a very important role. In the Nepalese context, the fulfillment of required energy and maintaining energy security through energy stacking is a hackneyed phenomenon (Sharma, 2019). The major determinants of the household's energy demand are the availability of various fuels as an option in the market that are cleaner and have better ergonomics, education level, household size and the presence of animal husbandry (Sharma, 2019). Nonetheless, the energy ladder model cannot be fully discarded. Income is not the one and only factor which influences the fuel switching, but it is one of the factors have a deep effect. Studies have shown that income is a major driver for fuel transitions (Muller & Yan, 2018). A study performed in Zimbabwe too supports the notion that as income level rises fuel switching can be seen into effect (Hosier & Dowd, 1987). In the case of Burkina Faso as well the fuel switching from natural gas to kerosene was triggered due to the rise in the income (Ouedraogo, 2006). Similar result can be found in the study by Baiyegunhi & Hassan which supports that the transition from fuel wood to kerosene, natural gas and electricity occurred due to rise in the income (Baiyegunhi & Hassan, 2014). Transition of fuel from fuelwood to the kerosene was largely influenced by the rise in the capacity of the citizens to make that expenditure (Gupta & Kohlin, 2006). When the fuel price increases, fuel consumption decreases (Muller & Yan, 2018). This means that the level of income and the fuel prices have a very important part to play in fuel choice and fuel transition.

2.9 Sampling

Sampling is defined as the selection of some part or the total part of a population for the purpose of study. Since, there are various constraints such as financial, time, size of the population while collecting data for any kind of study then samples are chosen in such a way that they can be used to estimate the population parameter. Sample has to be selected in such a way that it should be able to truly represent the population in the best way.

Generally there are two approaches to sampling. The first one is "to specify the precision of estimation desired and then to determine the sample size necessary to insure it" the second one is "Bayesian statistics to weigh the cost of additional information against the expected value of the additional information" (Kothari, 2004) . On the basis of the first approach the study requires the precision I with which it wants to come to the result, the value of the variate (z) at the required confidence level for that precision, population size (N), standard deviation (σ_p) of the population to calculate the sample size (n).
Mathematically,

$$n = \frac{z^2 \times N \times \sigma_p^2}{e^2 \times (N-1) + z^2 \times \sigma_p^2} \quad (2.1)$$

2.10 Development of the situation

One of the prominent sector for the energy demand in the context of Nepal is the cooking sector, during the past decade alone, the import of LPG has increased by more than three folds (Bhandari & Pandit, 2018). The main challenges for energy security form the country's perspective are the subsidy burden to adopt modern fuels and the increasing demand for LPG (Bhandari & Pandit, 2018). By 2035, LPG demand is projected to be more than 58 million GJ for high growth rate scenarios and in order to enable substitution of LPG with electricity by 2035, an additional power generation of 2626 MW would be required (Bhandari & Pandit, 2018).

In recent years, LPG usage has increased in a very high growth rate, in urban areas more than 58.5% of the household rely on LPG for cooking (Central Bureau of Statistics, 2016). LPG is the second most used fuel for cooking purposes in the country (Bhandari & Pandit, 2018) .

Nepal heavily relies on LPG and petroleum imports from India (Bhandari & Pandit, 2018). Energy security is one of the key issues between India and Nepal because of the socio-politics (Jewell, 2011). The trade deficit caused by the enormous volume of imported fuel puts the country in vulnerability where the country could be plagued of negative impacts on economy and society, intentional border blockades and intermittent or zero supply of fuels (Bhandari & Pandit, 2018).

Several studies have already been done in Nepal regarding the choice of the household fuel by the individuals, switching among the various household fuels and interventions. But only handful of studies are found on the switching from LPG to electricity. There are some handful of studies have been resorted towards the electric cooking in households (Pradhan & Limeechokchai, 2017).

A financial analysis report had been prepared regarding the indoor air pollution mitigation in Nepal, Kenya, and Sudan. In case of Nepal the Rasuwa district, a mountainous region in Northern Nepal was chosen for the preparation of the financial report (Malla, Bruce, Bates, & Rehfuess, 2011). It was based on WHO guidelines of cost-benefit analysis (Malla, Bruce, Bates, & Rehfuess, 2011). This study concluded that over ten years, the benefit would exceed the cost.

The impact of indoor air pollution on the health of the people was observed in an study in Kathmandu in the year 2007 to value the indoor air pollution reduction in financial terms. The health effects of indoor air pollution were analyzed for chronic bronchitis, asthma, and (Acute Respiratory Infection) ARI, though the study mentions that it was medically difficult to identify such cases from the household samples (Pant, 2007). Undoubtedly the fuel switching to more cleaner cooking technologies have a positive impact on the betterment of the health conditions, especially in the case of the rural household (Pant, 2007). This study concluded that the adoption of improved stoves could reduce the health costs by NRs 1,354 per year, which is more than the market price of the improved stove (Pant, 2007). Similarly, the same study depicts that the adaptation of biogas as cooking technology helps to attain health saving of NRs 326 per person per year (Pant, 2007).

A study on using electricity for cooking in Nepal was conducted in 2018 in which The Long-range Energy Platform (LEAP) model was selected for the analysis, LEAP is a scenario-based environmental modeling tool to compute the future energy demand and local, national, regional, and global emissions and supply (Bhandari & Pandit, 2018). The study showed that annual expenses on the electricity in all scenarios The study concluded that the yearly cost of electricity in all scenarios, i.e., business as usual (BAU), medium growth rate (MGR), and high growth rate (HGR) was cheaper than the LPG (Bhandari & Pandit, 2018). LEAP model has been incorporated to perform several studies to forecast and backcast energy demand (Bhandari & Pandit, 2018). For example, the very LEAP model was sought to simulate the supply and demand scenario of electricity for more or less nearly two decades of duration (Park, Yun, & Jeon, 2013). A production function, translog was used to compute the fuel substitution elasticity between the hydroelectricity and other fossil fuels (Awasthi & Adhikari, 2019). The result of the study put a clear picture that other fuels except kerosene contributed to create economic benefit (Awasthi & Adhikari, 2019). For the study period, the elasticity output of hydroelectricity was found to be the largest (Awasthi & Adhikari, 2019). This study also showed that the electricity has enormous potential to come into play to replace other fossil fuels like petrol, diesel, kerosene, and gas. Similarly, the study also highlighted about the creation of suitable mechanisms for incentives and subsidies in electricity to promote the usage of cleaner fuels and to move forth on the process of replacing the conventional fuels.

2.11 Study Gaps

Several studies on the fuel switching and interventions, as mentioned above have been done in the context of Nepal. But there are very few studies that perform a cost-benefit analysis of replacing the LPG with the electricity (e.g., induction stoves) in the rural households of Nepal. A study had been done, incorporating the LEAP model, to study the viability of substituting LPG by electricity. In this study, past data sets and the visualizations of residential energy demand were taken as input for LEAP. Models created for the energy planning are very data intensive, thus these models gather data from several sources to visualize energy demand and supply (Bhandari & Pandit, 2018).

Those models proceeded into simulation considering changes in different variables like national population, economic activity, and energy intensity supply (Awasthi & Adhikari, 2019). The data taken for this model are secondary data. Secondary data do not always correctly predict the scopes, opportunities, and prerequisites for the fuel transition.

Models, in a way, are a systematic mathematical way of coherently predicting things that have possibility to occur in the future, taking reference of past conditions or given scenario. The scenario on ground can be better visualized through the collection of the primary data and these data help to have more realistic study than the models that rely exclusively on secondary data. This study analyzes the scenario in multiple faces i.e. provides a real overview of LPG consumption patterns of the households, electricity consumption pattern of the Induction stove users, yearly savings/benefits, and NPV if induction stoves replace LPG for cooking purposes. The direct survey of the households and the financial analysis of the collected data provide an opportunity to examine fuel switching dynamics in an urban setting.

CHAPTER THREE: METHODOLOGY

The methodology of this study will be focused on efficiency calculation and financial analysis. The efficiency calculation will be done for the Induction stove and the LPG gas stove to compute the thermal energy. Financial analysis will be carried out to compute the NPV for both LPG and Induction stoves and the payback period for LPG gas stove replacement by the Induction stove.

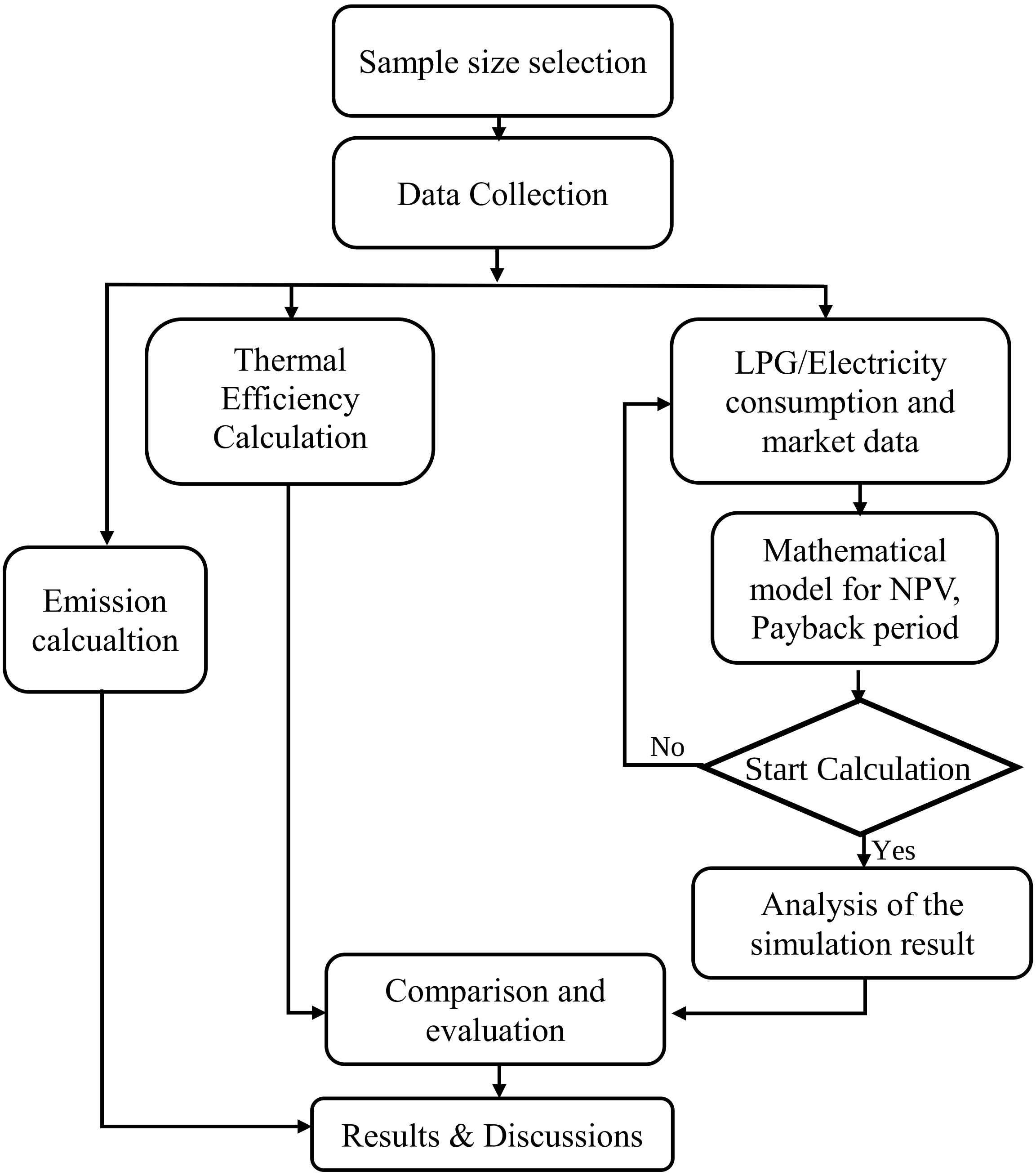


Figure 3.1 Methodological Flow Chart of the Thesis

3.1 Sample Size Selection

The techno economic evaluation of LPG gas replacement by the Induction Cook stove study is conducted on the households of Kageshwori Manahara Municipality Ward no.5. The ward is located at 9.4 km east of the capital city Kathmandu. According to the Municipality records, the ward has a total population of the ward is 12,847 with a total household number of 3,328. The ward has a total area of 4.224 sq. km. The grid reference of the ward number 5 is **27°43'42.7"N 85°24'23.5"E.**

In order to define the sample size the precision value was taken to be ± 20%, the variate was taken to be 1.96 for the confidence level 95%, population size 3,192 for the LPG using household, standard deviation 0.57 and population size 27 for the electricity using household. Sample size was computed using the equation ((2.1), this resulted a sample size of 30 households for LPG and 17 household for electricity. The thirty households were selected in such a way that these households bear maximum similarity in their lifestyle, social and economic conditions. The sample household size ranged from 3 to 7, comprising all together 127 family members.

Table 3.1 Sample household taken for LPG consumption and their respective household size

S.N.	Number of Households	Household Size	Population
1.	10	3	30
2.	9	4	36
3.	6	5	30
4.	4	6	24
5.	1	7	7
Total			127

It is evident from the above Table 3.1 that the most household size taken as the sample were of household size 3, number of households as 10. Similarly, 9 households had household size 4, 6 household had household size 5, 4 household had size 6 and only 1 household had the household size of 7 family members. According to the Kageshwori Manahara Municipality at least two or more person from a household are engaged in the economic activity. The selected sample of household also offers very similar spectrum, 56 of 127 persons in the total household are engaged in various sort of economic activities. Detail of the economic activity engagement is mentioned in the Table 3.2. A more comprehensive detail of the Household size and specific income source of study population is presented in the APPENDIX A.

Table 3.2 Sample household (for LPG consumption) population engagement in various economic activities

S.N.	Engagement	Number of person
1.	Agriculture	3
2.	Manufacturing	3
3.	Electricity, Watery Supply & Construction	1
4.	Wholesale & Retail Trade	7
5.	Transportation, Storage, Information & Communication	2
6.	Accommodation & Food	5
7.	Finance & Insurance	5
8.	Education	10
9.	Human Health & Social Work	2
10.	Real Estate, Professional, Scientific, Administration, Arts	12
11.	Others (House rent, Pensioners)	6
Total		56

To compare the LPG consumption data with the consumption of electricity by induction stoves, households with Induction stoves were identified and the data of energy consumed in kWh is recorded. Altogether 17 household's data of induction use has been recorded.

Table 3.3 Sample household taken for electricity consumption by induction stove and their respective household size

S.N.	Number of Households	Household Size	Population
1.	5	3	15
2.	6	4	24
3.	4	5	20
4.	2	6	12
Total			71

The engagement of the population sampled for electricity consumption by the induction stove in various economic activity engagement is mentioned in the Table 3.4. A more comprehensive detail of the Household size and specific income source of study population is presented in the APPENDIX A.

Table 3.4 Sample household (for induction stove) population engagement in various economic activities

S.N.	Engagement	Number of persons
1.	Agriculture	2
2.	Manufacturing	2
3.	Electricity, Watery Supply & Construction	0

S.N.	Engagement	Number of persons
4.	Wholesale & Retail Trade	4
5.	Transportation, Storage, Information & Communication	0
6.	Accommodation & Food	4
7.	Finance & Insurance	4
8.	Education	9
9.	Human Health & Social Work	1
10.	Real Estate, Professional, Scientific, Administration, Arts	1
11.	Others (House rent, Pensioners)	5
Total		32

3.2 Data Collection

All the households selected during the study had similar lifestyle, their sources of income and economic activity engagement tries to portray the scenario of the ward. Family member of the study households are literate, at least one member of the family holds a bachelor's degree. The major source of the income for the household is the service sector (banking, teaching, hotel service, pesticide control service, health). The study household also have their own land for where they can grow paddy, maize, corn and other agricultural products.

In this study the weight of the LPG gas cylinder of every household under study is weighed every weekend (on Saturday) to keep the data of the weekly LPG gas consumption. A weighing instrument that has a least count of 0.001 kg is used to weigh the cylinder every week and the difference between the previous week's weight of the cylinder and the current week's measured weight of the cylinder is calculated and noted down. The reference weight of a cylinder filled completely with LPG is 29.50 kg, the weight of the empty cylinder is 15.30 kg and the weight of the LPG gas inside the cylinder is 14.2 kg (Nepal Oil Corporation Limited, 2022). During the household survey the LPG consumption data was recorded as follows:

$$C = R_p - R_c \tag{3.1}$$

$$C = R_p + 14.kg - R_c \tag{3.2}$$

Where,

C : Consumption of LPG in a week, unit kg.

R_p : Recorded Weight (in kg) of the LPG gas cylinder on the previous week

R_c : Recorded Weight (in kg) of the LPG gas cylinder on the current week

Above mentioned Equation 3.1 is used to compute the household LPG consumption during a week when the household has not replaced their LPG cylinder. Whereas if any household has replaced their LPG cylinder during the week, then the weight of consumed LPG gas during the week is calculated using Equation 3.2.

To record the electricity consumption of the household under study separate sub meter (or any other electricity consumption measuring device) had to be installed. Therefore, portable sub meters were used to measure the electricity consumption by the induction stoves of the 17 households that were selected during the study.

The data collected during the study regarding the consumption of LPG and the electricity consumption is presented in the APPENDIX D respectively.

NPV for LPG and induction stove is computed for the period of 12 years. We can see from the APPENDIX H that the average installation cost associated with the LPG stove is NPR. 11,710, similarly during the survey period only 3 households reported maintenance of their LPG stoves. The maximum cost associated with the maintenance was NPR 750, incurred to replace the gas regulator, which was the worst case scenario in terms of cost associated with the maintenance. Among the households having maintenance related issue, a household had to repair LPG burner which cost NPR. 150 and another household had to replace LPG gas pipe which cost NPR.450. Majority of the households, 27 households reported smooth use of LPG, no maintenance related issues i.e. zero maintenance cost – best case scenario. During the survey it was observed that the maintenance related issues are not common in LPG stoves. The operation cost represents the cost to operate the LPG stoves per year (excluding maintenance cost) to cook, the operation cost obtained for 20 weeks was linearly forecasted to compute the annual operation cost. The data collected for the cost associated with the LPG is summarized in Table 3.5.

Table 3.5 Costs taken under consideration for LPG stove NPV calculation

Cost	Household Size			
	Three	Four	Five	Six
Average Installation Cost	11,710	11,710	11,710	11,710
Operation Cost per year	19,004	24,257	26,282	28,337
Worst Scenario Maintenance Cost per year	750	750	750	750

Similarly, the average installation cost associated with the induction stove is found to be NPR. 12,154 which is presented in the APPENDIX I. During the survey period 3 households- two households had to replace the fuse costing NPR.40.00 in their induction stove and NPR. 800 was used to replace the IGBT for another household. The maximum cost associated with the maintenance was NPR. 800, incurred to replace the IGBT, which was the worst case scenario in terms of cost associated with the maintenance. Majority of the households, 27 households reported no maintenance related issues i.e. zero maintenance cost – best case scenario. In case of the induction stoves also, the maintenance cost is not frequent. The operation cost represents the cost to operate the induction stoves per year (excluding maintenance cost) to cook, the operation cost recorded for 20 weeks during the survey which was linearly forecasted to compute the yearly operation cost. The data collected for the cost associated with the LPG is summarized in Table 3.6.

Table 3.6 Costs taken under consideration for Induction stove NPV calculation

Cost	Household Size			
	Three	Four	Five	Six
Average Installation Cost	12,154	12,154	12,154	12,154
Operation Cost per year	12,205	16,375	18,215	19,610
Worst Scenario Maintenance Cost per year	800	800	800	800

3.3 Technical Analysis

As a part of the technical analysis, efficiency of the induction stoves and LPG stoves are computed. In order to compute the efficiency of these stoves a water boiling test is conducted. In this test various LPG and Induction stoves are taken into consideration for the efficiency computation. For every stove, under efficiency computation, two kg of water is boiled to the temperature of 100℃. The thermal energy required to raise the temperature of the liquid is calculated using the heat equation:

$$Q = ((m_w \times s_w + m_c \times s_i) \times (T_f - T_i)/1000000 \qquad (3.3)$$

Where,

Q : Thermal energy required to boil the water (MJ)

m_w : Mass of the water (kg)

s_w : Specific heat capacity of the water (J/kg°C)

m_c	:	Mass of the cooking pot (kg)
s_i	:	Specific heat capacity of the iron (J/kg℃)
T_i	:	Initial Temperature of the water, (℃)
T_f	:	Initial Temperature of the water, (℃)
$\Delta\theta$	:	Change in the temperature, $T_f - T_i$ (℃)

3.3.1 Efficiency calculation of LPG stoves

The calorific values of LPG in terms of LHV and HHV are 45.7 MJ/kg and 50.15 MJ/kg, respectively (Chitragar, Vijayalakshmi, Vighnesha, & Bedar, 2016). For this study the calorific value of LPG is taken as 45.7 MJ/kg. Thus, while using LPG stoves, when a kilogram of LPG is consumed during the cooking then the energy equivalent to the 1 kg LPG is 45.7 MJ of energy.

Efficiency of the LPG stove is calculated as follows:

$$\eta = \frac{Q}{E_{lpg}} \times 100\ \% \qquad (3.4)$$

Where,

η	: Efficiency
Q	: Thermal energy required to boil water given by equation 3.3, (MJ)
E_{lpg}	: Energy Consumed during the process while using LPG (MJ)

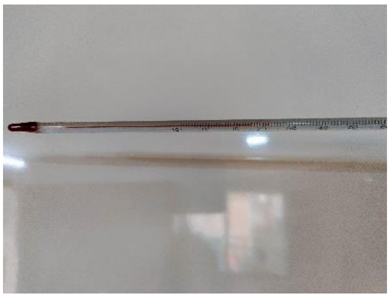
For this experimental process same cookware is used to conduct experiment on the 5 different LPG stoves of varying life (viz. 2 years, 6 years, 9 years, 11 years, 15 years).The process is illustrated below:

Step I: Take a Cooking pot

Step II: Measure the weight of empty pot

Step III: Fill the pot with 2 kg water

Step IV : Take an alcohol thermometer



Step V : Cover the top with a lid with a thermometer attached with it. Note the initial temperature.

Step VI: Take the weight of the cylinder before and after boiling the water. Note the change in the weight.

3.3.2 Efficiency calculation of Induction stoves

For the calculation of efficiency of the induction stoves various aged Induction stoves were used (viz. 1 year, 2 year, 3 years, 4 years). A sub meter was used to monitor the electricity consumption by the induction stove to boil 2kg of water to 100 degree Celsius. Efficiency of the Induction stove is calculated as follows:

$$\eta = \frac{Q}{E_{ind}} \times 100\ \% \qquad (3.5)$$

Where,

η : Efficiency

Q : Thermal energy required to boil water given by equation 3.3, (MJ)

E_{ind} : Energy Consumed during the process while using induction (MJ)

Energy consumed during the process while using the induction stove is calculated as mentioned below:

E_{ind} = kWh (data recorded from the sub meter) × 3600/1000.

The steps to measure the efficiency of the induction stove are same upto step IV of LPG stove. The steps after step IV are illustrated below:

Step V : Cover the top with a lid with a thermometer attached with it. Note the initial temperature.

Step VI: Take the initial and the final reading of the submeter. Note the differences

The theoretical energy consumption was calculated as follows:

m_w	:	2 kg
s_w	:	4200 J/kg℃
m_c	:	0.673 kg
s_i	:	460 J/kg℃
T_i	:	25℃
T_f	:	100℃
$\Delta\theta$	:	$T_f - T_i$ = 75℃

Theoretical energy required (in MJ) to boil water is given by the heat equation:

$$Q = ((m_w \times s_w + m_c \times s_i)\ \Delta\theta)/1000000$$

$$Q = (2 \times 4200 + 0.673 \times 460)75)/1000000$$

$$Q = 0.6532185 \text{ MJ}$$

3.4 Financial Analysis

Financial analysis assess the viability, stability and profitability of a business or any project. In this project financial study is conducted to compare the Net Present Value (NPV) of the investment made on LPG and Induction stove by a family over a period of 12 years. Similarly, as a part of the financial analysis payback period computation of the LPG replacement by the Induction stove is also carried out.

3.4.1 Net Present Value (NPV) Analysis

NPV calculates the current valuation of a future stream of cash flows that an investment will unfold. A stipulated time frame and a discount rate, equal to the minimum acceptable rate of return is taken as reference for the NPV calculation. An investment with positive NPV is generally considered good to invest. However, in this thesis, there is not any cash inflows associated with the LPG and the induction stoves. Over the life of these stoves, there are only cash out flows chiefly on three overheads viz: Cost of Installation, Cost of Operation and Cost of Maintenance. So, a comparative study of the NPV is necessary.

The total cost during every year is recorded and totaled. Later on, all the total cost is discounted to the year 1 to calculate the present value. The cost of installation depends upon the preference of the user and the maintenance cost is associated with the typical product and its usage. In this thesis, the cost of installation for the respective stoves are referenced on the basis of the current market price. The maintenance cost is used on the basis of the household survey. The cost of operation for LPG gas is taken as Rs.1800 per 14.2 kg LPG gas and the cost of operation for induction is taken according to the price slab of NEA for single phase lower voltage scale.

kWh per month	5 Amp		15 Amp		30 Amp		60 Amp	
	A	B	A	B	A	B	A	B
0 - 20	30	0.00	50	4.00	75	5.00	125	6.00
21 - 30	50	6.50	75	6.50	100	6.50	125	6.50
31 – 50	50	8.00	75	8.00	100	8.00	125	8.00
51 – 100	75	9.50	100	9.50	125	9.50	150	9.50
101 - 250	100	9.50	125	9.50	150	9.50	200	9.50
Above 250	150	11.00	175	11.00	200	11.00	250	11.00

A : Monthly Minimum Charge (NPR.)

B : Energy Charge (NPR./kWh)

The formula to compute the NPV is given below:

$$\text{NPV} = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \tag{3.6}$$

Where:

R_t	:	Net Cash inflow/outflows during a single period
i	:	Discount rate of return
n	:	Total number of period
t	:	t^{th} period

3.4.2 Payback period calculation

The terminology 'payback period' refers to the time duration required to recuperate from the investment. In other words, it can be understood as the time to reach the point of breakeven for any investment made. Thus, a shorter payback period usually indicates attractive investment opportunity. But the payback period evaluation do have its shortcomings, it does not consider the time value of the money.

In this thesis, a simple payback period method is used to calculate the payback period for the LPG gas replacement by the Induction stove. The cost of replacement of LPG gas by the induction stove is calculated by taking the following cash flows in consideration.

(a) Cash Outflow (Investment)

i. Cost of the Induction Stove
ii. Cost of the cookware for induction stove

(b) Cash Inflow (Annual savings)

i. Operation and Maintenance saved annually: The differences in the cost incurred for annual operation and maintenance cost of LPG gas stove and the annual operation and maintenance cost of induction stove.

Mathematically, the investment and the cash annual savings are described below:

(a) **Investment** = Cost of cooking pot compatible with induction stove + Cost of Frying Pan compatible with induction cooking + Cost of Induction Stove + Cost of pressure cooker compatible with induction stove

(b) **Annual Savings** = (Operation Cost of LPG stove + Maintenance Cost of the LPG stove) - (Operation Cost of Induction stove + Maintenance Cost of the Induction stove)

Thus, the pay pack period is calculated as follows:

$$\mathrm{PB} = \frac{\mathrm{I}}{\mathrm{S}} \times 12 \tag{3.7}$$

Where,

PB : Payback Period (Month)

I : Investment (NPR.)

S : Annual Savings (NPR. / year)

Monte Carlo Simulation using Crystal ball is performed to compute the payback period. For the simulation, randomly selected variables were assumed to have triangular distribution of probability where most likely values were assumed to be the average value of the data collected during the study. A hundred thousand iterations were done using the crystal ball to forecast the payback period.

3.4.3 Sensitivity Analysis

From the perspective of finance, the selection of Induction stove over the LPG stove for cooking is dependent upon the cost associated with both of these cooking technologies. On the one hand efficiency of these stoves are the factor that reflects how much input resources are actually delivered for the end use, cooking. But the consumer behavior tend to be guided by their pocket that means consumer's first concern would be "how much is the new technology financially sensitive to the environment in which it has to perform". Sensitivity Analysis is thus performed in order to visualize how an independent variable affects a particular dependent variable under a set of assumptions.

In this study CB is used to perform the sensitivity analysis as well. The sensitivity is reflected through the rank correlation. The rank correlation is obtained by using the Spearman's rank correlation coefficient. The formula for calculating the rank correlation is given below:

$$R = 1 - \frac{\Sigma\, d^2}{n^3 - n} \tag{3.8}$$

Where:

R : Spearman's Rank Correlation Coefficient

d : Difference in Rank of the variable compared

n : Number of variables

The value of the rank correlation coefficient ranges from '-1' to '+1'. The value of the rank correlation coefficient closer to '-1' indicates that the input variable has a strong negative relationship with the output value, in this case the output value is the payback period. That means, increase in the value of the input variable have a strong impact to reduce the value of the payback period. Similarly, if the value of the rank correlation coefficient is closer to '+1' then the input variable has a strong impact to increase the value of the payback period.

Sensitivity chart for the payback period is obtained using the crystal ball. The crystal ball generates the sensitivity chart with rank correlation while running the simulation to forecast the payback period.

3.5 Emission calculation

The amount of carbon dioxide and Nitrous Oxide emitted during the use of LPG by the household living in the ward annually is computed using the following formula.

$$W_C = N_{lpg} \times W_{lpg} \times 2.88 \times 365 \tag{3.9}$$

$$W_N = N_{lpg} \times W_{lpg} \times 0.16 \times 365 \tag{3.10}$$

Where,

W_c : Weight of the Carbon dioxide emitted by the households, (kg)

W_N : Weight of the Nitrous Oxide emitted by the households, (kg)

N_{lpg} : Number of household using LPG

W_{lpg} : Average household LPG consumption, (kg)

2.88 : CO_2 emitted per 1 kg of LPG consumed, (kg)

0.00016 : N_2O emitted per 1 kg of LPG consumed, (kg)

365 : No. of days in a year

CHAPTER FOUR: RESULTS AND DISUSSION

In this Chapter the results obtained after processing the collected data according to the adopted methodology of thesis is presented and the necessary discussion of the result is also done. The results of efficiency computed for the LPG stove and the Induction stove is included along with the description of their significance. Similarly, results observed with the NPV analysis, payback period and Sensitivity Analysis is also mentioned here in this Chapter.

4.1 Efficiency of the LPG stoves and the Induction Stoves

The efficiency of the LPG stoves and the induction stoves are calculated as discussed in the methodology section of this report. The data taken for the calculation of the efficiency are included in the Appendix B and Appendix C of this report.

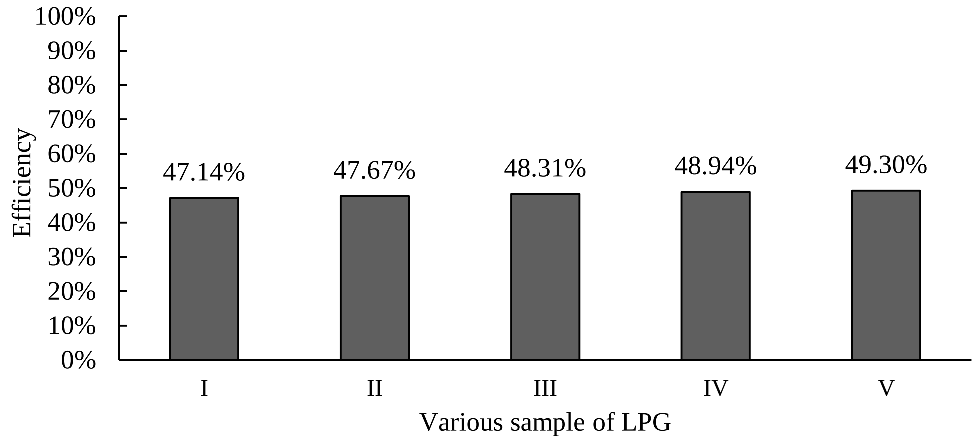


Figure 4.1 Thermal Efficiency of the LPG stoves

Figure 4.1 shows the line graph that represents the thermal efficiency of the LPG stoves. The thermal efficiency of the LPG stoves was observed for five different stoves. From the above bar graph, it is clear that the thermal efficiency of the LPG stoves is always lesser than 50%. The average efficiency of the LPG stove is calculated to be 48.27%. The slight variation in the efficiency result might be due to the age, operating condition and the maintenance status of the LPG.

Similarly, the bar graph presented in the Figure 4.2 shows the thermal efficiency of the computed for various induction stoves. The data taken during the study are mentioned in the Appendix C. From this bar graph, it is evident that the efficiency of the induction stove was found to be as high as 90.88%. The least thermal efficiency for induction stove was calculated to be 86.45%. Thus, in an average we can see that the average value of the efficiency of the induction stove is 88.62%.

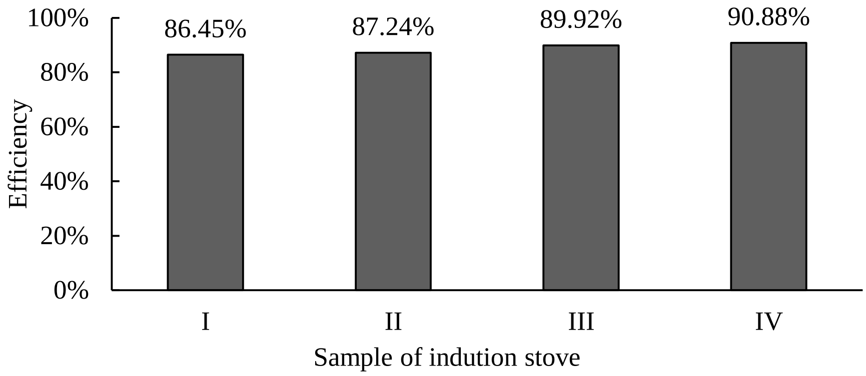


Figure 4.2 Thermal efficiency of the induction stoves

4.2 LPG gas consumption

The LPG gas consumption data was recorded for 30 households for 20 weeks. The data collected during the household survey is mentioned in the APPENDIX D. The house hold size of the thirty households under study are mentioned below:

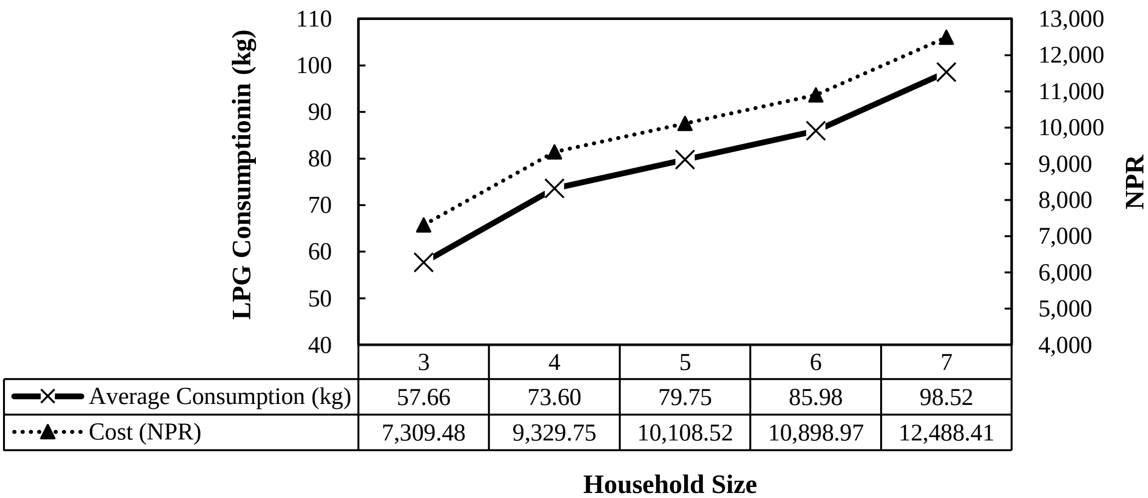
(a) HH size: 3 = 10 households

(b) HH size: 4 = 9 households

(c) HH size: 5 = 6 households

(d) HH size: 6 = 4 households

(e) HH size: 7 = 1 household

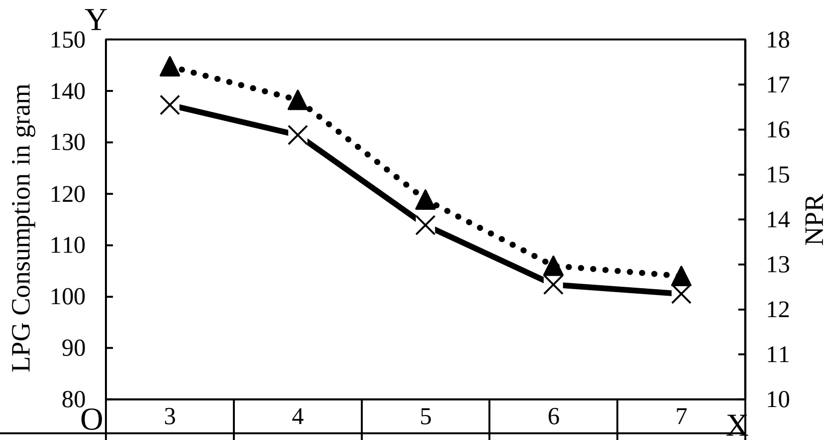


	3	4	5	6	7
Average Consumption (kg)	57.66	73.60	79.75	85.98	98.52
Cost (NPR)	7,309.48	9,329.75	10,108.52	10,898.97	12,488.41

Figure 4.3 Average Household LPG Consumption in kg and the cost for 20 weeks

The average household LPG consumption from the above Figure 4.3 shows that as size of the household increases the LPG consumption for the house hold also increases. For, average household LPG consumption for household size of 3 person is 57.66 kg, for the house hold size of 4 person is 73.60 kg, for the household size of 5 person is 79.75 kg, for the household size of 6 person is 85.98 kg and for the household size of 7 person is 98.52 kg. The coefficient of variance for the sample data is well below 1. Figure 4.3 also shows the average cost of LPG for specified household for the period of 20 weeks (from jestha to kartik, year 2079).

But however, per person per day average consumption of the LPG shows an opposite trend. If per person per day average consumption of LPG is calculated based upon the household size, it can be observed that as the household size increases the amount of LPG required for a person to cook decreases.



	3	4	5	6	7
per person per day average consumption (g)	137.29	131.43	113.92	102.36	100.53
Cost per day per person (NPR)	17.40	16.66	14.44	12.97	12.74

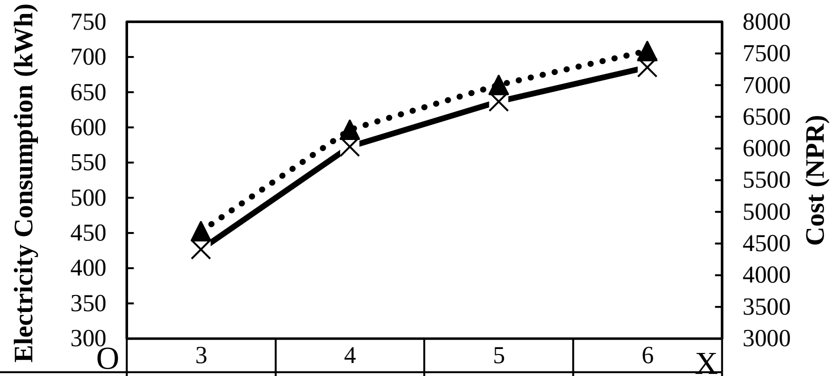
Household size

Figure 4.4 Average Cost of LPG per person per day for specific household

Above mentioned Figure 4.4 shows that for a household size of 3 person the per person per day LPG gas consumption is 137.29 g. The figure shows this value decreased to 131.43 for household size of 4 person. The decreasing trend still continues, the average LPG consumption per person per day is 113.92g for household size of 5 person, 102.36 g for household size of 6 person and 100.53 g for household size of 7 persons. In an average the per person per day LPG gas consumption in the ward is 121.5 g.

4.3 Electricity consumption for Induction stove users

The electricity consumption (kWh) was recorded for 17 households for 20 weeks (jestha to kartik, 2079). The data collected during the household survey is mentioned in the APPENDIX F. Electricity consumption due to the use of the induction stove is mentioned in the Figure 4.5.



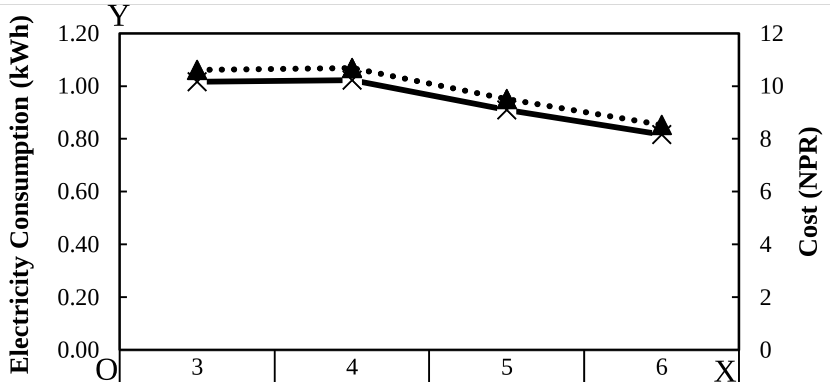
	3	4	5	6
Electricity Consumption (kWh)	426.76	572.57	636.89	685.67
Cost (NPR)	4694.39	6298.26	7005.80	7542.33

Household Size

Figure 4.5 Average Electricity consumption in kWh and the cost for 20 weeks

The average electricity consumption from the above Figure 4.5 shows that as size of the household increases the electricity consumption for the house hold also increases. For, average household electricity consumption for household size of 3 person is 426.76 kWh which would account for NPR.4,694, for the house hold size of 4 person the electricity consumed in unit is 572.57 kWh costing Rs.6,298 for the household size of 5 person is 636.89 kWh which costs Rs.7,005, and for the household size of 6 person is 685.67 kWh which costs Rs.7,542. The coefficient of variance for the sample data is well below 1.

But however, per person per day average consumption of electricity while using the induction stove indicates a contrasting trend as compared to the average household electricity consumption accounted by the induction. If per person per day average consumption of electricity due to induction usage is calculated based upon the household size, it can be observed that as the household size increases the amount of electricity unit required for a person to cook decreases. Figure 4.6 depicts the same.



	3	4	5	6
Electricity Consumption (kWh)	1.02	1.02	0.91	0.82
Cost (NPR)	10.62	10.68	9.51	8.53

Figure 4.6 Average Cost of Electricity per person per day for specific household by using Induction Cook stove

4.4 Financial results

Various cost associated with the LPG stoves and the induction stoves are mentioned in appendices section of this thesis. In order to compute the cost of stoves, frying pans, cooking pots, pressure cooker an average of various brands were taken. Maintenance cost was chosen on the basis of the household survey.

4.4.1 NPV of LPG and Induction

The NPV values are forecasted for the various combination of the variables such as installation cost, inflation rate, discount rate, operation cost and maintenance cost several outcomes were calculated. A total of 10,00,000 iterations were performed using crystal ball to conduct the Monte Carlo Simulation to come to the result. The values of NPV calculated during the iterations are presented in the figures below. It is of very much interest to observe some particular values of NPV, best case scenario – where the forecasted NPV value would be least and the worst case scenario – where the forecasted NPV value would be the highest.

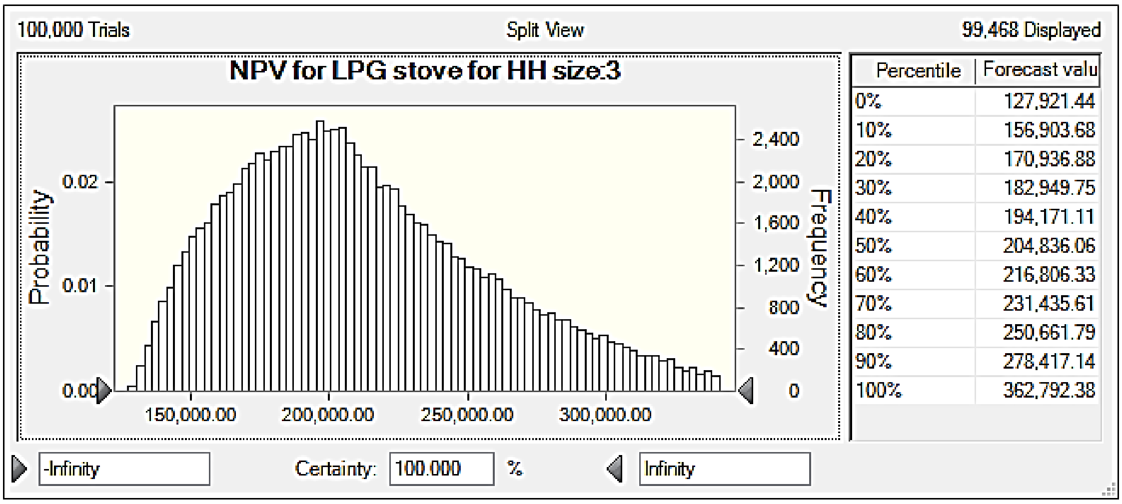


Figure 4.7 Result Obtained for NPV for LPG for the household size 3

The result obtained from the trials performed are mentioned in the above figure. The observed result distribution shows a close resemblance to a gamma distribution. It can be clearly seen that, the NPV for the investment made in the LPG and its operation and maintenance cost for over the period of 12 years for the household size 3 can range from the best case scenario value of NPR. 127,921 to the worst case scenario of NPV NPR. 362,792. Furthermore, the percentile chart implies that there is a probability of 10% or lower chance of NPV to lie between NPR. 127,921 to NPR. 156,903, the probability increases up to 20 % for the NPV to lie between NPR. 156,903 to NPR. 170,936, the probability is 30 % or lower for the NPV to lie between NPR. 170,936 to NPR. 182,949 and so on.

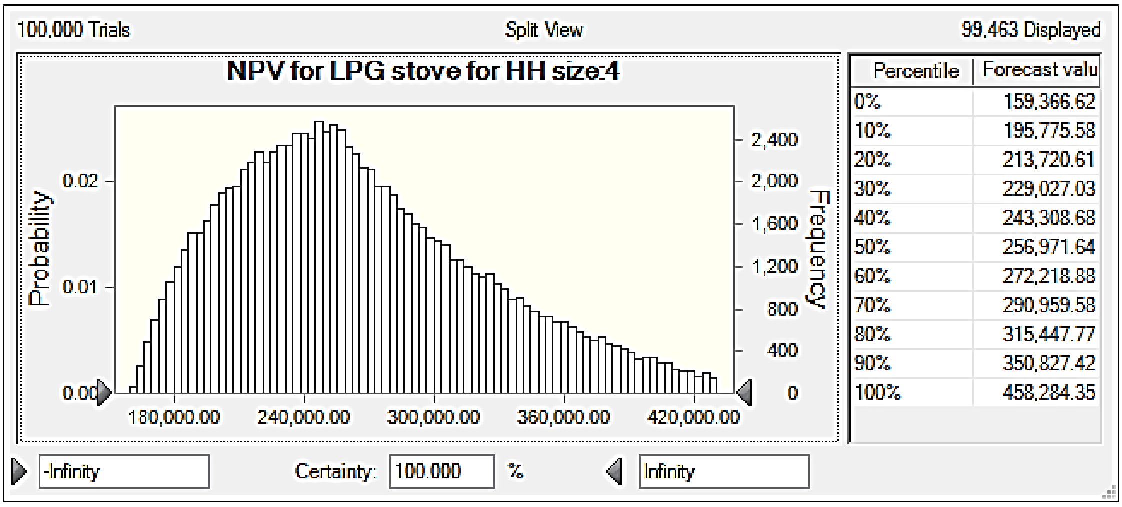


Figure 4.8 Result Obtained for NPV for LPG for the household size 4

The results obtained from the ten thousand trials performed for the various combination of the inflation, operation cost, installation cost the results achieved are mentioned in the Figure 4.8. The observed result distribution shows a close resemblance to a gamma distribution. It can be clearly seen from the above figure that the NPV for LPG for the household size of 4 people can range from the best case scenario value of NPR. 159,366 to the worst case scenario of NPV NPR. 458,284. The percentile chart gives information about the probability of the occurrence of the corresponding forecasted NPV value.

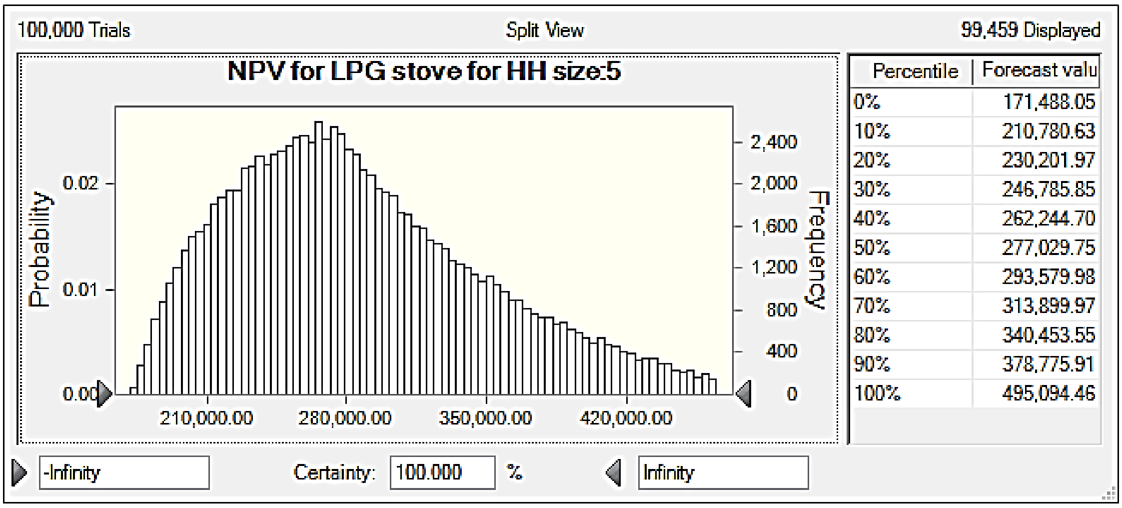


Figure 4.9 Result Obtained for NPV for LPG for the household size 5

Figure 4.9 shows the results achieved from the ten thousand trials performed to compute the NPV for LPG for the household size of 5 people. The observed result distribution shows a close resemblance to a gamma distribution. The NPV for LPG for the household size of 5 people can range from the best case scenario value of NPR. 171,488 to the worst case scenario of NPV NPR. 495,094. The percentile chart in the figure indicates the probability of the corresponding forecasted value of NPV.

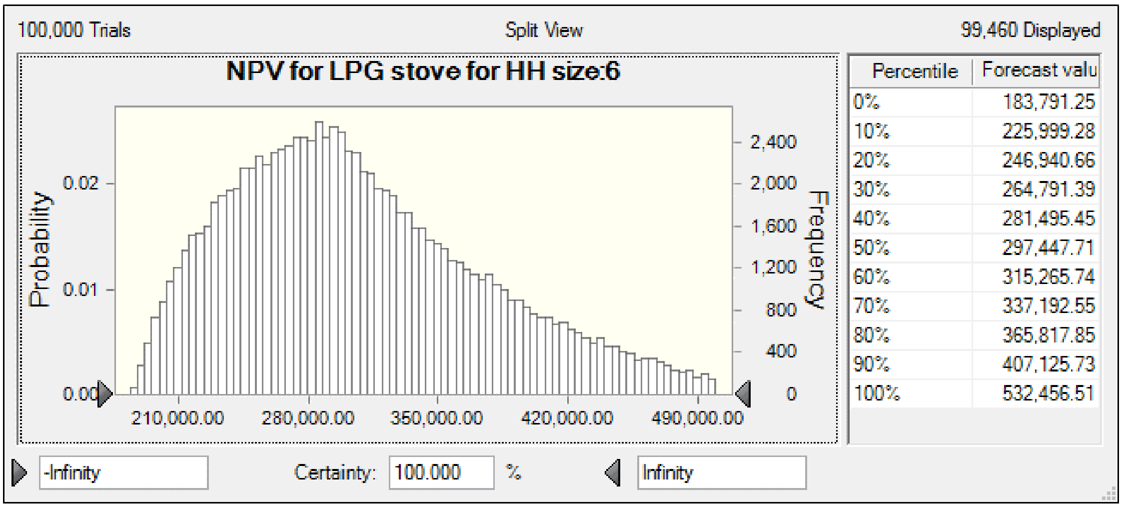


Figure 4.10 Result Obtained for NPV for LPG for the household size 6

Figure 4.10 also shows the results obtained from the multiple iterations during the NPV calculation for household size 6. The output data distribution shows a close resemblance to a gamma distribution. The calculation has shown that the NPV for LPG for the household size 6 can range from the best case scenario value of NPR. 183,791 to the worst case scenario of NPV NPR. 532,456. The percentile chart in the figure indicates the probability of the forecasted values of NPV.

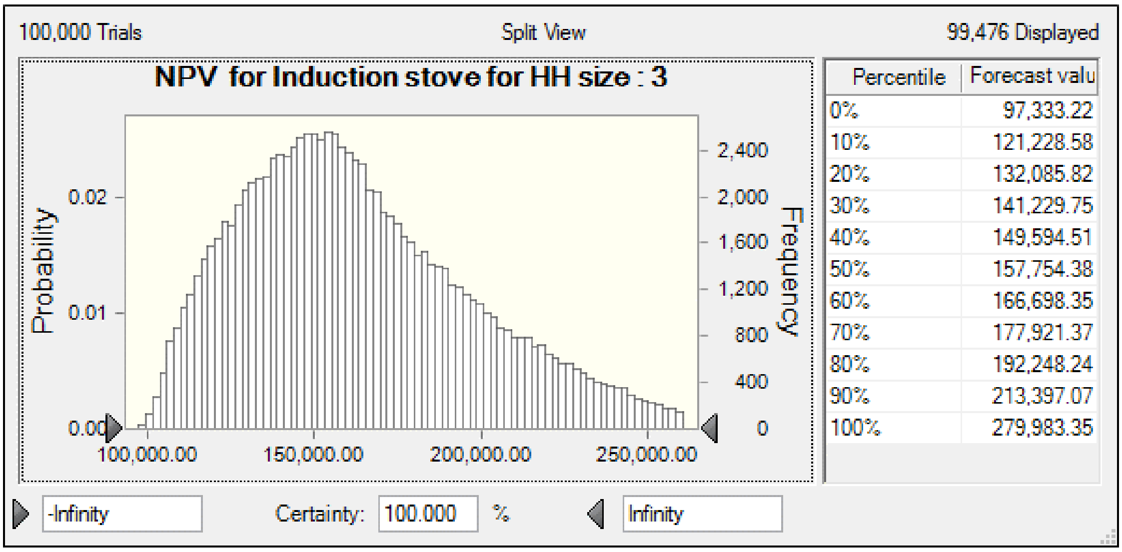


Figure 4.11 Result Obtained for NPV for induction stove for the household size 3

Figure 4.11 shows iteration result for the 100,000 trials performed during the NPV calculation for the induction stove for the household size of 3. The output data, NPV probability distribution shows a close resemblance to a gamma distribution, likewise to the probability distribution in the case of the LPG stove. Figure 4.11 also show that the NPV for induction stove for the household size 3 can range from the best case scenario value of NPR. 97,333 to the worst case scenario of NPV NPR. 279,983. The percentile chart in the figure implies the probability of the corresponding forecasted value of NPV.

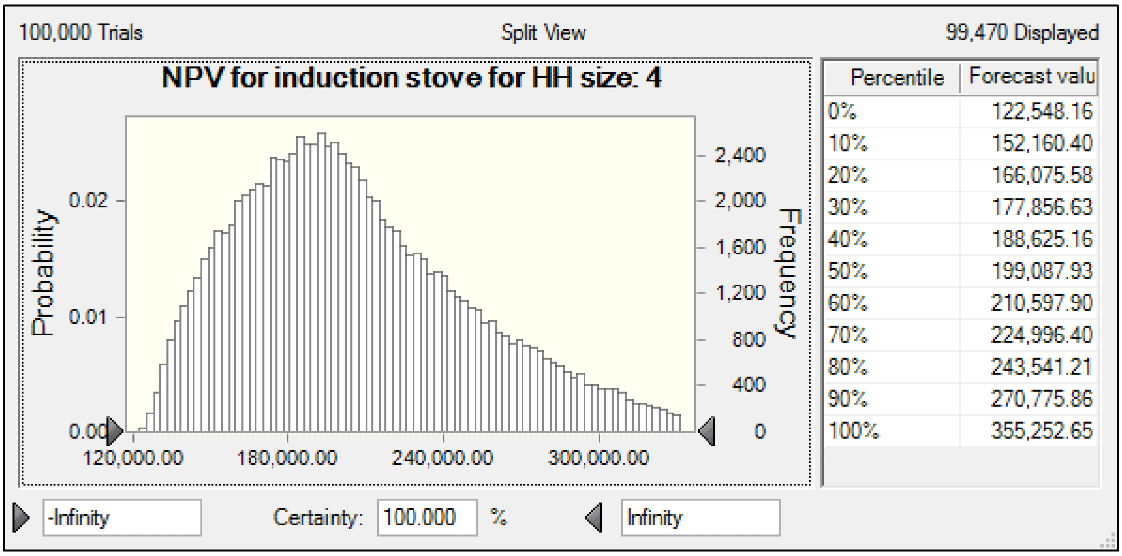


Figure 4.12 Result Obtained for NPV for induction stove for the household size 4

Figure 4.12 shows iteration result for the 100,000 trials performed during the NPV calculation for the induction stove for the household size of 4. The NPV probability distribution shows a close resemblance to a gamma distribution. Figure 4.12 also shows that the NPV for induction stove for the household size 4 can range from the best case scenario value of NPR. 122,548 to the worst case scenario of NPV NPR. 355,252. The percentile chart in the figure indicates the probability of the forecasted value of NPV.

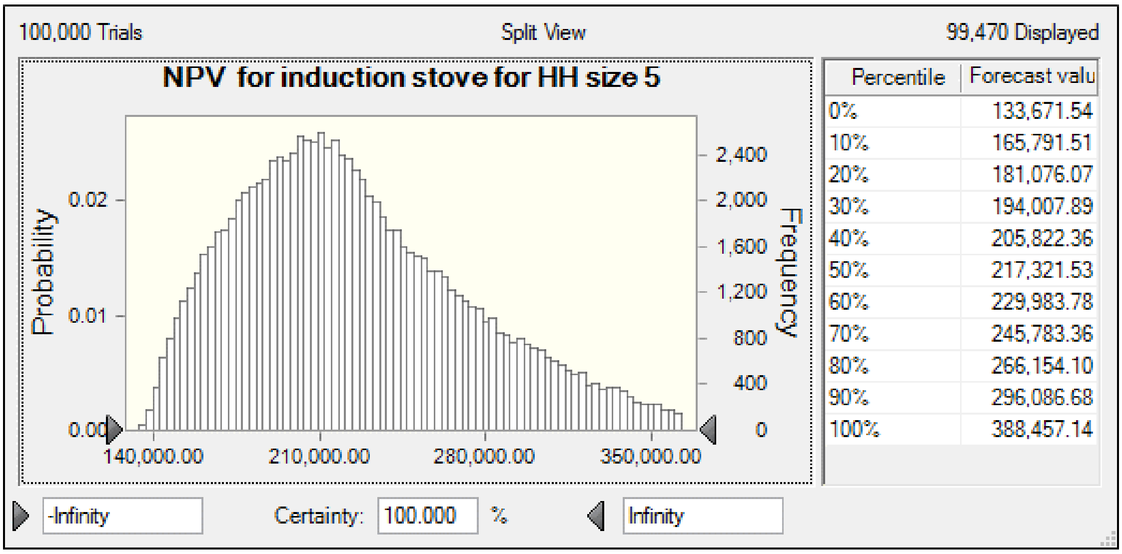


Figure 4.13 Result Obtained for NPV for induction stove for the household size 5

Above mentioned figure shows the iteration result for the 100,000 trials performed during the NPV calculation for the induction stove for the household size of 5. The NPV probability distribution shows a close resemblance to a gamma distribution. Figure 4.13 also shows that the NPV for induction stove for the household size of 5 people can range from the best case scenario value of NPR. 133,671 to the worst case scenario of NPV NPR. 388,457. The percentile chart in the figure indicates the probability of the forecasted value of NPV.

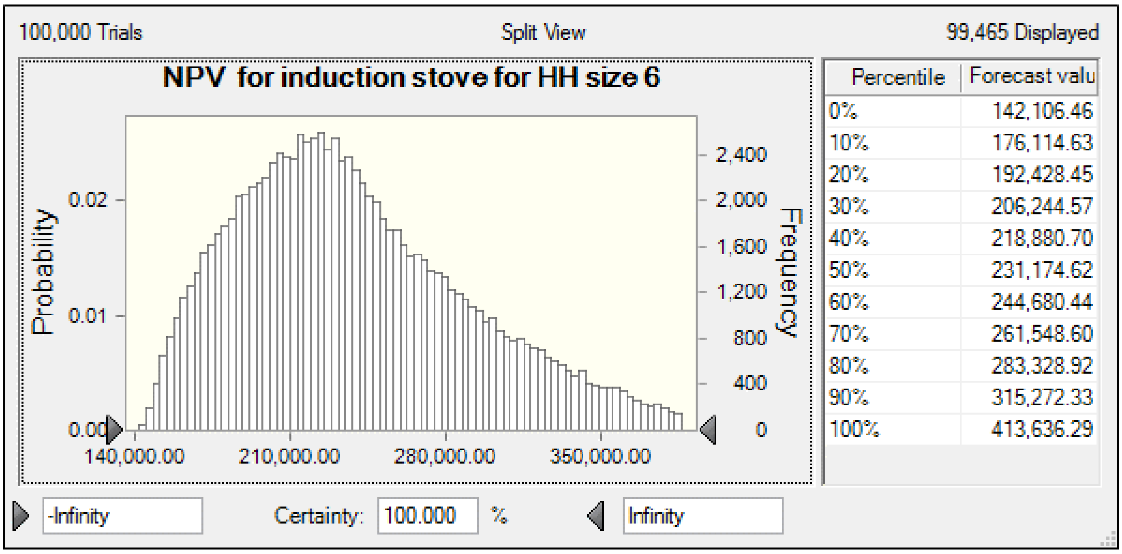


Figure 4.14 Result Obtained for NPV for induction stove for the household size 6

Above mentioned figure, Figure 4.14 shows the iteration result for the 100,000 trials performed during the NPV calculation for the induction stove for the household size of 6. The NPV probability distribution shows a close resemblance to a gamma distribution. Above mentioned also shows that the NPV for induction stove for the household size of 6 people can range from the best case scenario value of NPR. 142,106 to the worst case scenario of NPV NPR. 413,636. The percentile chart in the figure indicates the probability of the forecasted value of NPV.

Above mentioned figure displays NPV outcomes obtained for a particular stove technology of household size. These individual results have to be compared to analyze the financial performance. For the comparative evaluation of the NPV of the LPG stove and the induction stove, a chart is produced by plotting the outcome of NPV from the iterations. The comparative analysis is presented in the Figure 4.15.

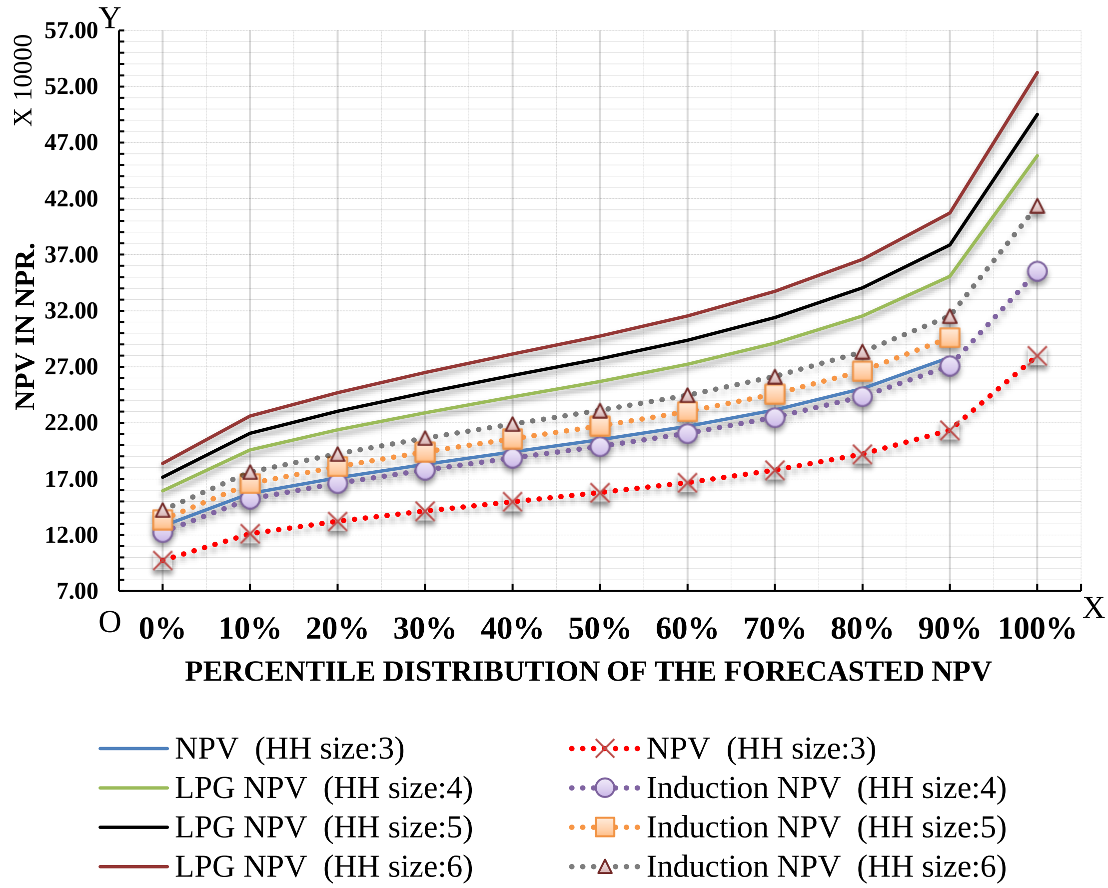


Figure 4.15 Comparative chart of results obtained for NPV for the LPG stove and the induction stove for various household

The data associated with Figure 4.15 is mentioned in the APPENDIX J. The dotted lines in the comparative chart represents the NPV for the induction stove whereas the continuous lines represent the NPV for the LPG. The movement of lines away from the origin in the horizontal axis represents increase in the range of probability of getting the NPV result equivalent to the corresponding range of NPV indicated by the movement of lines away from the origin in the vertical axis. For example, in the case of Induction stove users of household size of 3 represented by dotted red line, it can be observed that while moving from left (0%) to right (10%) in the horizontal axis the chances of occurrence of the corresponding range of NPV has increased up to 10%, while the dotted red line further moves away from the origin in the horizontal axis the probability will also gradually increase and at the same time corresponding NPV range will also increase.

The comparative chart represented by the Figure 4.15 shows smooth lines that representing the NPV of the LPG stoves are above the dotted lines representing the NPV of the induction stoves for the same household size. These lines also show that NPV for the investment made in the induction stoves are comparatively lower than the investment made in the LPG stoves.

Another interesting observation made from the Figure 4.15 is that, for a given value of the probability of occurrence of the corresponding NPV range of Induction stove the same value of NPV range of LPG stove have a lesser probability. For example, from the figure it can be seen that the value of NPV of induction stove for a household size of 3 person to lie between NPR. 97,333 to NPR. 157,754 holds a probability of 50% to occur but the NPV of the LPG stove for the household size of 3 people to lie between NPR. 127,921 to NPR. 156,903 holds a probability of lower than 10%. In the cases of the other households with same size for the induction stove and the LPG stove similar results can be deduced. Thus, it makes a vivid announcement that the in a comparative NPV study of similar household size, investment made in the induction stove tend to have lesser NPV than the investment made in the LPG stove.

4.4.2 Payback period

As suggested in the methodology of this study a simple payback period was computed. The payback period for household size 3, 4, 5 and 6 is computed using the CB and the results are presented in the figures below.

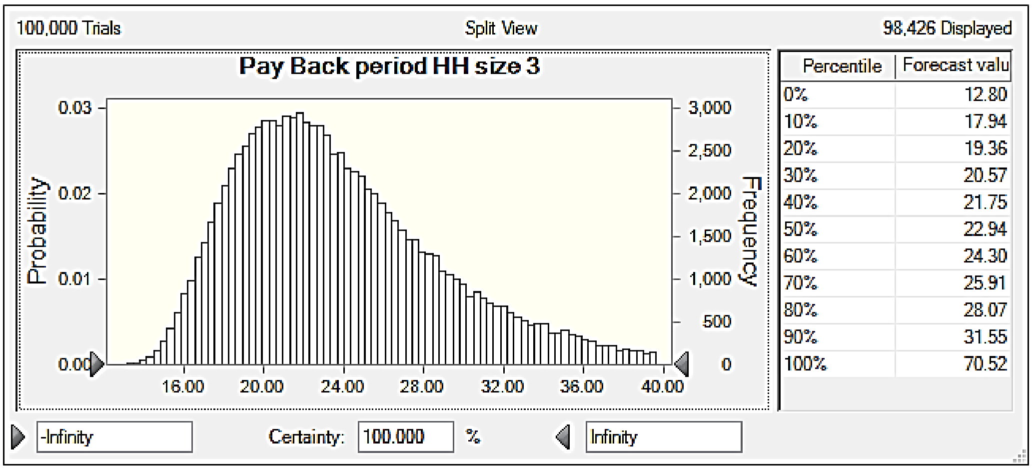


Figure 4.16 Payback period for the replacement of LPG stove by the induction stove for the household size 3

Above mentioned Figure 4.16 displays about the payback period in months for the replacement of the LPG stove by the induction stove for the household size of 3 person for the 100,000 trails performed using various values of installation cost of induction stove, O&M cost of the LPG stove and the O&M cost of the induction stove. The payback period is mentioned in the horizontal axis whereas the corresponding probability of occurrence of that probability is mentioned in the left vertical axis. The right vertical axis represents frequency of the output (payback period) obtained during the trial. The figure shows that the payback period ranges from 12.80 months, best case scenario to 70.52 months, worst case scenario.

Similar analysis were performed to compute the payback period for the household size of 4,5 and 6 persons whose results are mentioned in the later figures.

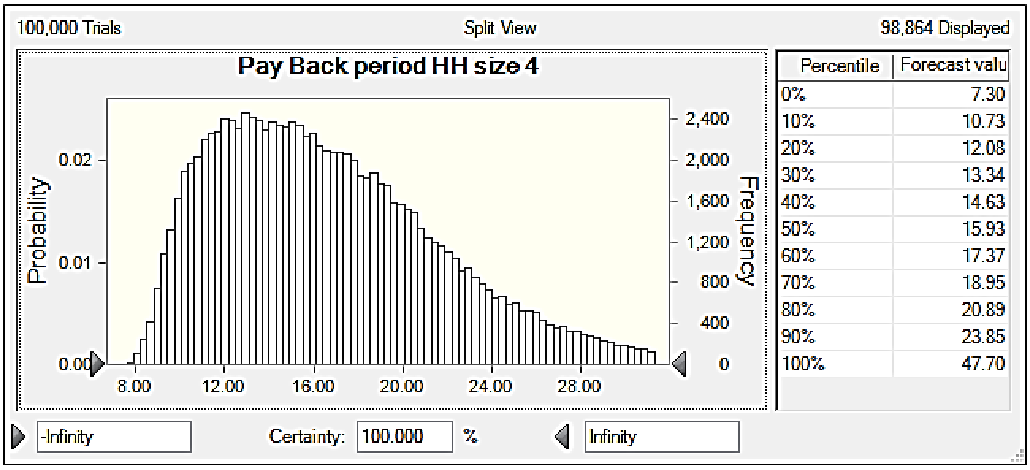


Figure 4.17 Payback period for the replacement of LPG stove by the induction stove for the household size 4

The Figure 4.17 shows that the payback period ranges from 12.68 months, best case scenario to 30.41 months, worst case scenario.

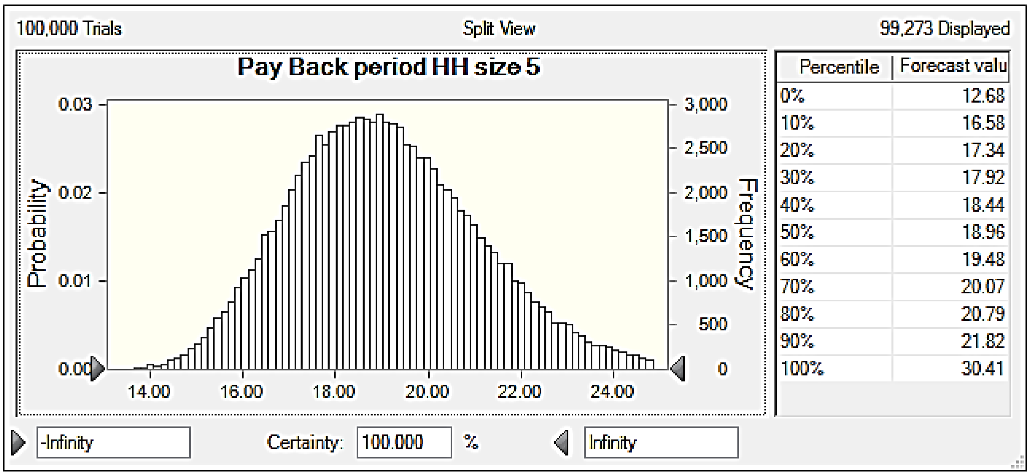


Figure 4.18 Payback period for the replacement of LPG stove by the induction stove for the household size 5

The Figure 4.18 shows that the payback period ranges from 12.68 months, best case scenario to 30.41 months, worst case scenario.

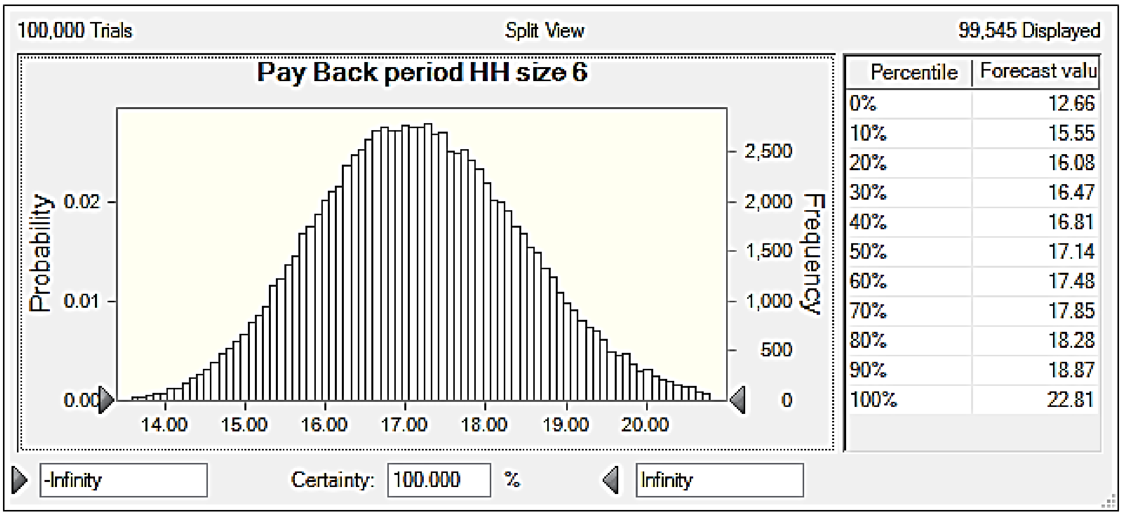


Figure 4.19 Payback period for the replacement of LPG stove by the induction stove for the household size 6

The Figure 4.19 shows that the payback period ranges from 12.20 months, best case scenario to 21.4 months, worst case scenario.

Table 4.1 Probability of occurrence of payback period

Probability	Payback Period in months			
	HH Size:3	HH Size:4	HH Size:5	HH Size:6
10% <	12.80 to 17.94	7.30 to 10.73	12.68 to 16.58	12.66 to 15.55
Less than 20%	12.80 to 19.36	7.30 to 12.08	12.68 to 17.34	12.66 to 16.08
Less than 30%	12.80 to 20.57	7.30 to 13.34	12.68 to 17.92	12.66 to 16.47
Less than 40%	12.80 to 21.75	7.30 to 14.63	12.68 to 18.44	12.66 to 16.81
Less than 50%	12.80 to 22.94	7.30 to 15.93	12.68 to 18.96	12.66 to 17.14
Less than 60%	12.80 to 24.30	7.30 to 17.37	12.68 to 19.48	12.66 to 17.48
Less than 70%	12.80 to 25.91	7.30 to 18.95	12.68 to 20.07	12.66 to 17.85
Less than 80%	12.80 to 28.07	7.30 to 20.89	12.68 to 20.79	12.66 to 18.28
Less than 90%	12.80 to 31.55	7.30 to 23.85	12.68 to 21.82	12.66 to 18.87
10 to 100%	12.80 to 70.52	7.30 to 47.70	12.68 to 30.41	12.66 to 22.81

Table 4.1 represents the payback period range for various household size and the associated probability. The table indicates that with the growth in the household size the probability of occurrence of the payback period reduces. Considering all households, it can be seen that there is 90% probability of having the payback period 31.55 months or lesser for the LPG gas by the induction stove.

4.4.3 Sensitivity

A sensitivity analysis was also performed to understand the sensitivity of the output, payback period with respect to the changes in the input values. The sensitivity data represented in terms of rank correlation obtained during the Monte Carlo Simulation is presented in the Table 4.2.

Table 4.2 rank correlation obtained during payback period calculation for various household sizes

S.N.	Variables	Correlation rank for various HH size			
		HH : 3	HH : 4	HH : 5	HH : 6
1.	Cost of Induction stove	0.18	0.12	0.32	0.46
2.	Cost of Cooking Pot compatible with induction stove	0.11	0.07	0.22	0.29
3.	Cost of Frying Pan compatible with induction stove	0.08	0.06	0.16	0.22
4.	Cost of Pressure Cooker compatible with induction stove	0.16	0.11	0.31	0.42
5.	Operation Cost of LPG stove	-0.87	-0.97	-0.66	-0.53
6.	Cost of maintenance of LPG stove	-0.15	-0.07	-0.25	-0.31
7.	Operation Cost of induction stove	0.33	0.1	0.34	0.13
8.	Cost of maintenance of induction stove	0.09	0.04	0.13	0.16

Above table makes it vivid that the operation cost and the maintenance cost associated with LPG has a negative rank correlation value. And as a result if these costs increase payback period will decrease. Operation cost of LPG stove always have the highest absolute value of rank correlation among the other costs, this implies that change in operation cost of LPG stove has the most prominent impact upon the payback period. Similarly, the rank correlation of the cost on induction stove, cost of cooking pot compatible with induction stove, cost of frying pan compatible with induction stove, cost of pressure cooker compatible with induction stove, operation cost of induction stove and cost of maintenance of induction stove are all positive. These costs associated with the induction stove implies that their increment will cause the payback period to increase.

4.5 Reduction in GHG gases

At present 3,192 households in the ward are relying upon LPG for cooking, if all of these households completely switch into induction cook stoves then the CO_2 and the NO_2 production will be reduced by 15,73,663 kg/year and 240 kg/year annually.

CHAPTER FIVE CONCULSIONS & RECOMMENDATIONS

5.1 Conclusions

Following conclusions have been drawn from the study:

- Thermal efficiency of the LPG stoves and the Induction stoves were computed. The average thermal efficiency of the LPG was found to be 48.27% and the average thermal efficiency of the induction stove was found to be 88.62%. The thermal efficiency of the induction stoves were found higher than the LPG stoves.
- As the household size increases energy consumption per person per day decreases. In case of LPG stove per person per day energy consumption value is 6.27 MJ for household size 3, this value decreases to 6.01 MJ for household size 4, for household size 5 the value is 5.21 MJ and for households with six person this value is just 4.68 MJ. Similarly, in the case of the induction stoves also as this value shows a decreasing trend from 3.68 MJ (1.022 kWh) , 3.28 MJ (0.910 kWh) to 2.94 MJ (0.816 kWh) for household size of 4, 5 and 6 people respectively.
- Although the average installation cost for Induction stoves is found to be costlier than the installation cost of the LPG stoves, NPR. 12,154 the operating cost for induction stove is cheaper than the LPG stoves. Under the current scenario of the cost of LPG, NPR. 1800 per cylinder and the cost of electricity set by NEA, the operation cost for induction stove with household size 3 is NPR. 12,205, whereas the operation cost for the same household size relying on LPG stove is NPR. 19,004. Similarly, for the household size 4, 5 and 6 the operation cost associated with induction stove is NPR. 16,375, NPR. 18,215 and NPR.19,610 respectively, the operation cost associated with the LPG stove for same household size is NPR. 24,257, NPR. 26,282.15, NPR. 28,337 respectively.
- A comparison of NPV of expenditures related with the LPG stoves and the induction stoves for a period of 12 years makes it clear that LPG stoves tend to be more expensive than the induction stoves.

- For the household size taken under consideration during the study, the payback period calculation showed that the probability of coming to the breakeven point within 31 months for replacement of the LPG stove by the induction stove is 90%.
- The payback period is highly sensitive to the changes in the operation cost of the LPG stove. In a scale of '-1' to '+1'the sensitivity associated with the operation cost of the LPG stove is -0.87, -0.9, -0.66,-0.53 for household size 3, 4,5 and 6 respectively.
- Currently the ward has 3,192 households using LPG as their primary fuel. A complete fuel switching from LPG into electric cooking will contribute to the reduction on annual $PM_{2.5}$ production by 101 $\mu g/m^3$on those households.
- If all households that are currently relying upon LPG for cooking have a complete fuel switch into induction cook stoves then the CO_2 and the NO_2 production will be reduced by 15,73,663 kg/year and 240 kg/year annually. The GWP of NO_2 is 310.

5.2 Recommendations

- At least a whole year data of the energy consumption by the LPG stove and the induction stove is required to study the effect of seasonal change on cooking. Therefore, it is recommended to collect at least a whole year data of the energy consumption of the LPG stoves and the induction stoves.
- Single burner induction stoves were focused in this study. So, further research on techno-financial analysis could be carried considering the effect of multiple burner type induction stove as well.
- Infrared stoves, a type of electric stoves are also available in the Nepali market, they claim to be more than 60% efficient in terms of energy conversion. Unlike induction stoves, the infrared stoves are compatible with versatile cooking vessels. Cooking vessels that are compatible with the LPG stoves are also compatible with the infrared stoves and this will have an impact upon the NPV and the payback period.

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APPENDIX A : HOUSEHOLD SIZE & SECTORAL INCOME

Table A.1 Household size and income source of study population for LPG

S.N. (a)	HH size (b)	Source of Income (c)		Family Member (d)
		Sector	Specific	
1.	5	Finance, Education	Banking-1, High School Teacher -1	2
2.	4	Finance, agriculture	Finance Cooperative - 1, seasonal vegetable farming -1	2
3.	6	Wholesale & Retail Trade	Grocery Shop owner – 2	2
4.	6	Education, Agriculture	Education Consultancy -1, Poultry -1	2
5.	3	Finance	Banking - 1,	1
6.	5	Wholesale & Retail Trade	High School Teacher - 1 , Grocery shop owner -1	2
7.	4	Manufacturing	Carpentry – 3	3
8.	4	Others	Pensioner -1, House rent -1	2
9.	3	Education	Higher Secondary Teacher -2	2
10.	3	Wholesale & Retail Trade	Electronics Shop -1	1
11.	3	Administration, others	Government office - 1, house rent -1	2
12.	3	Accommodation & Food	Hotel – 2	2
13.	4	Human Health, Education	Pharmacy -1, Lower Secondary School Teacher -1	2
14.	4	Others	Car buy and Sell -1	1
15.	4	Accommodation & Food	Bakery – 2	2
16.	5	Education	High School Teacher – 2	2
17.	7	Finance, Education & others	Banking -1, High School Teacher -2, Priest -1	3
18.	3	Finance	Insurance -1	1
19.	3	Education	Education Consultancy -1	1
20.	3	Electricity	TV network company -1	1
21.	3	Administration	Government office -1	1
22.	5	Administration	Government office -2	2
23.	6	Education , Food	Education -1, Hotel -1	2
24.	6	Service, Others	Priest -1, Government office -2	3
25.	4	Wholesale & Retail Trade	Pesticide Control -2	2

26.	3	Administration	Nepal Telecom -1	1
27.	4	Administration	Government office -2	2
28.	4	Realstate	Free lancer -2	2
29.	5	Realstate	Land and property broker -2	2
30.	5	Transportation, Agriculture	Driver -1, seasonal vegetable farming – 2	3
TOTAL				56

Table A.2 Household size and income source of study population for induction

S.N. (a)	HH size (b)	Source of Income (c)		**Family Member (d)**
		Sector	Specific	
1.	4	Finance, Education	Banking-1, High School Teacher -1	2
2.	6	Manufacturing	Carpentry – 2	3
3.	5	Accommodation & Food	Hotel – 2	2
4.	6	Education, Agriculture	Education Consultancy -1, Seasonal vegetable farming -1	2
5.	5	Finance	Banking - 1,	1
6.	3	Education	High School Teacher – 2	2
7.	4	Finance, agriculture	Finance Cooperative - 1, seasonal vegetable farming -1	2
8.	3	Others	Pensioner -1, House rent -1	2
9.	4	Education	Higher Secondary Teacher -2	2
10.	4	Wholesale & Retail Trade	Electronics Shop -1	1
11.	3	Administration, others	Government office - 1, house rent -1	2
12.	3	Accommodation & Food	Hotel – 2	2
13.	4	Human Health, Education	Pharmacy -1, Lower Secondary School Teacher -1	2
14.	4	Others	Car buy and Sell -1	1
15.	5	Wholesale & Retail Trade	Grocery Shop owner – 2	2
16.	3	Wholesale & Retail Trade	High School Teacher - 1 , Grocery shop owner -1	2
17.	5	Finance, Education & others	Banking -1, High School Teacher -2	3
TOTAL				33

APPENDIX B : EFFICIENCY OF LPG STOVES

Table B.1 LPG stoves taken as sample for the thermal efficiency computation

Sample	Date and time of measurement	Number of burner	LPG Stoves	
			Commissioning year	Age
I.	2079-03-04, 11:00 AM	Single	2007	15 years
II.	2079-03-11, 11:00 AM	Single	2011	11 years
III.	2079-03-18, 11:00 AM	Single	2013	9 years
IV.	2079-03-25, 11:00 AM	Single	2016	6 years
V.	2079-03-32, 11:00 AM	Single	2020	2 years

Table B.2 Efficiency of the LPG stove purchased in the year 2020 (life: 2 years)

Obsn	Weight of the cylinder in kg			Water Temperature in ℃		Equivalent energy (MJ)	Theoretical energy reqd to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Difference	Initial	Final				
1.	21.35	21.324	0.028	25	100	1.2796	0.653	51.0%	
2.	21.32	21.295	0.029	25	100	1.3253	0.653	49.3%	
3.	21.295	21.266	0.029	24.5	100	1.3253	0.653	49.3%	
4.	21.266	21.237	0.029	24.5	100	1.3253	0.653	49.3%	
5.	21.237	21.207	0.03	25	100	1.371	0.653	47.6%	
Average efficiency								49.3%	

Table B.3 Efficiency of the LPG stove purchased in the year 2016 (life: 6 years)

Obsn	Weight of the cylinder in kg			Water Temperature in ℃		Equivalent energy (MJ)	Theoretical energy reqd to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Difference	Initial	Final				
1	19.350	19.321	0.029	24	100	1.3253	0.653	49.3%	
2	19.321	19.291	0.03	24	100	1.371	0.653	47.6%	
3	19.291	19.262	0.029	24.5	100	1.3253	0.653	49.3%	
4	19.262	19.233	0.029	24.5	100	1.3253	0.653	49.3%	
5	19.233	19.204	0.029	24	100	1.3253	0.653	49.3%	
Average efficiency								48.9%	

Table B.4 Efficiency of the LPG stove purchased in the year 2013 (life:9 years)

Obsn	Weight of the cylinder in kg			Water Temperature in ℃		Equivalent energy (MJ)	Theoretical energy reqd to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Difference	Initial	Final				
1	25.280	25.251	0.029	23	100	1.3253	0.653	49.3%	
2	25.251	25.220	0.031	23.5	100	1.4167	0.653	46.1%	
3	25.220	25.191	0.029	24	100	1.3253	0.653	49.3%	
4	25.191	25.161	0.03	24	100	1.371	0.653	47.6%	
5	25.161	25.132	0.029	24	100	1.3253	0.653	49.3%	
Average efficiency								48.3%	

Table B.5 Efficiency of the LPG stove purchased in the year 2011 (life:11 years)

Obsn	Weight of the cylinder in kg			Water Temperature in ℃		Equivalent energy (MJ)	Theoretical energy reqd to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Difference	Initial	Final				
1	22.320	22.291	0.029	25	100	1.3253	0.653	49.3%	
2	22.291	22.261	0.030	25	100	1.371	0.653	47.6%	
3	22.261	22.232	0.029	24.5	100	1.3253	0.653	49.3%	
4	22.232	22.201	0.031	24.5	100	1.4167	0.653	46.1%	
5	22.201	22.170	0.031	25	100	1.4167	0.653	46.1%	
Average efficiency								47.7%	

Table B.6 Efficiency of the LPG stove purchased in the year 2007 (life:15 years)

Obsn	Weight of the cylinder in kg			Water Temperature in ℃		Equivalent energy (MJ)	Theoretical energy reqd to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Difference	Initial	Final				
1	17.210	17.179	0.031	25	100	1.4167	0.653	46.1%	
2	17.179	17.147	0.032	25	100	1.4624	0.653	44.7%	
3	17.147	17.119	0.028	25	100	1.2796	0.653	51.0%	
4	17.119	17.087	0.032	25	100	1.4624	0.653	44.7%	
5	17.087	17.058	0.029	25	100	1.3253	0.653	49.3%	
Average efficiency								47.1%	

APPENDIX C: EFFICEINCY OF THE INDUCTION STOVES

Table C.1 Sample of Induction stoves taken as sample for efficiency calculation

Sample	Date and time of measurement	Number of burner	Induction Stoves	
			Commissioning year	Age
I.	2079-04-07, 11:00 AM	Single	2018	4 years
II.	2079-04-14, 11:00 AM	Single	2019	3 years
III.	2079-04-21, 11:00 AM	Single	2020	2 years
IV.	2079-04-28, 11:00 AM	Single	2021	1 year

Table C.2 Efficiency of the Induction stove purchased in the year 2021 (life:1 year)

Obsn.	Water Temperature in℃		Reading of the sub meter				Theoretical energy reqd. to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Initial , kWh	Final, kWh	Difference, kWh	Reading in MJ			
1.	25	100	6472.30	6472.49	0.19	0.684	0.63	92.1%	
2.	25	100	6472.49	6472.69	0.20	0.72	0.63	87.5%	
3.	25	100	6472.69	6472.88	0.19	0.684	0.63	92.1%	
4.	25	100	6472.88	6473.09	0.21	0.756	0.63	83.3%	
5.	25	100	6473.09	6473.28	0.19	0.684	0.63	92.1%	
Average efficiency								89.4%	

Table C.3 Efficiency of the Induction stove purchased in the year 2022 (life:2 years)

Obsn.	Water Temperature in℃		Reading of the sub meter				Theoretical energy reqd. to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Initial , kWh	Final, kWh	Difference, kWh	Equivalent reading in kilo joules			
1.	25	100	6434.80	6435.01	0.21	0.756	0.63	83.3%	
2.	25	100	6440.24	6440.43	0.19	0.684	0.63	92.1%	
3.	25	100	6442.73	6442.92	0.19	0.684	0.63	92.1%	
4.	25	100	6445.62	6445.83	0.21	0.756	0.63	83.3%	
5.	25	100	6447.03	6447.22	0.19	0.684	0.63	92.1%	
Average efficiency								88.6%	

Table C.4 Efficiency of the Induction stove purchased in the year 2019 (life: 3 years)

Obsn.	Water Temperature in℃		Reading of the sub meter				Theoretical energy reqd. to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Initial , kWh	Final, kWh	Difference, kWh	Equivalent reading in kilo joules (h)			
1	25	100	6452.02	6452.2	0.2	0.72	0.63	87.5%	
2	25	100	6457.45	6457.7	0.2	0.72	0.63	87.5%	
3	25	100	6459.95	6460.2	0.21	0.756	0.63	83.3%	
4	25	100	6462.86	6463.1	0.19	0.684	0.63	92.1%	
5	25	100	6464.25	6464.4	0.19	0.684	0.63	92.1%	
Average efficiency								88.5%	

Table C.5 Efficiency of the induction stove purchased in the year 2018 (life: 4 years)

Obsn.	Water Temperature in ℃		Reading of the sub meter				Theoretical energy reqd. to boil the water, MJ	Efficiency	Remarks
	Initial	Final	Initial, kWh	Final, kWh	Difference, kWh	Equivalent reading in kilo joules (h)			
1	25	100	6475.33	6475.52	0.19	0.684	0.63	92.1%	
2	25	100	6480.75	6480.95	0.2	0.72	0.63	87.5%	
3	25	100	6483.25	6483.44	0.19	0.684	0.63	92.1%	
4	25	100	6486.14	6486.34	0.2	0.72	0.63	87.5%	
5	25	100	6487.54	6487.75	0.21	0.756	0.63	83.3%	
Average efficiency								88.5%	

APPENDIX D: HOUSEHOLD LPG CONSUMPTION

A household survey of 30 households of various household size was conducted every week in order to collect data of the LPG gas consumed. The weight of LPG gas inside the cylinder is 14.2 kg (Nepal Oil Corporation Limited, 2022). And to calculate the cost of LPG Rs. 1800 per cylinder is taken.

Table D.1 Household LPG consumption data in kg during a week for a household

S.N.	HH size	LPG consumption in kg in weeks																		
		1st	2nd	3rd	4rth	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	20th
1.	5	3.54	3.15	3.36	4.39	4.31	4.01	3.79	4.15	3.93	4.13	3.78	4.31	4.22	3.7	4.2	4.56	4.44	3.2	4.68
2.	4	3.72	3.1	2.52	3.49	3.99	3.86	3.72	4	3.86	3.98	3.71	3.95	4.07	3.63	4.01	4.22	3.2	3.3	2.78
3.	6	4.33	4.62	4.07	5.19	3.68	4.23	4.24	4.37	4.38	4.35	4.23	4.32	4.44	4.15	4.82	3.49	4.78	4.96	5.02
4.	6	4.37	4.45	4.12	5.19	4.15	3.85	4.22	3.99	4.36	5.1	4.21	3.94	5.19	5.13	4.68	5.2	4.96	5.35	4.2
5.	3	2.21	2.06	2.10	2.58	2.55	2.98	3.2	3.12	2.56	3.1	2.41	2.85	3.19	2.35	2.88	2.75	2.38	3.22	4.2
6.	5	3.71	3.92	3.50	4.28	4.55	4.47	4.42	4.61	4.56	4.59	4.41	4.56	4.68	4.35	4.66	5.3	4.54	4.43	4.88
7.	4	3	3.08	2.83	3.41	3.91	4.27	3.9	4.41	4.03	4.39	3.88	4.36	4.06	3.82	4	3.56	3.34	3.6	2.97
8.	4	3.02	2.94	2.91	3.36	2.96	4.3	4.04	4.44	3.58	4.42	3.43	4.39	3.61	3.37	3.55	2.75	4.6	3.68	3.65
9.	3	2.29	2.18	2.21	2.52	2.1	2.56	2.88	2.7	2.86	2.68	2.71	2.65	2.89	2.65	2.79	3.63	2.68	2.92	3.2
10.	3	2.31	2.56	2.23	2.48	2.32	2.74	2.92	2.88	2.78	2.86	2.63	3.62	2.81	2.57	3.48	3.15	2.79	2.84	2.85
11.	3	2.33	2.73	2.31	2.47	2.56	2.35	2.46	2.49	2.6	2.47	2.45	2.39	2.63	2.39	3.01	3	2.61	2.41	2.98
12.	3	2.35	2.04	2.31	2.46	2.44	3.56	2.56	3.7	4.3	3.68	2.99	3.56	3.68	2.93	3.56	2.85	3.66	3.23	3.21
13.	4	3.16	3.22	3.08	3.25	3.13	4.45	4.18	4.59	3.95	4.57	3.8	4.49	3.98	3.74	3.92	3.26	3.39	2.88	3.25
14.	4	3.19	3.32	3.14	3.25	4.20	3.69	4.32	3.83	4.45	3.81	4.3	3.73	4.48	3.21	2.96	3.24	4.01	3.84	3.45

S.N.	HH size	LPG consumption in kg in weeks																		
		1st	2nd	3rd	4rth	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	20th
15.	4	4.23	31.6	3.16	3.23	3.21	4.48	4.35	4.62	4.49	4.6	4.34	4.52	4.5	4.25	4.44	2.86	3.25	3.62	4.26
16.	5	4.06	4.13	3.99	4.03	4.5	3.5	4.03	3.64	4.17	3.62	2.98	3.54	4.18	4.08	4.16	3.65	4.69	4.95	4.92
17.	7	5.73	5.93	5.64	5.57	4.32	4.8	4.58	4.94	4.72	4.92	4.57	5.03	4.73	5.75	5.62	5.3	4.98	5.86	5.53
18.	3	2.48	2.39	2.44	2.37	2.49	2.98	3.53	3.12	4.2	3.1	4.05	4	4.21	2.5	3.2	3.2	4.19	2.8	3.2
19.	3	2.5	2.58	2.48	2.37	3.1	3.88	4.14	3.25	3.28	4	3.13	3.5	3.29	3.44	3.01	3.42	3.27	3.03	2.98
20.	3	2.52	2.67	2.48	2.37	2.95	4.3	4.2	3.38	4.34	4.42	4.19	2.98	4.35	4.2	2.85	2.92	4.33	2.87	4.3
21.	3	2.54	2.69	2.50	2.23	3.92	3.12	4.21	3.26	4.35	3.24	4.2	3.35	4.36	3.68	3.26	2.97	4.34	3.28	4.26
22.	5	4.27	4.41	4.17	3.71	4.2	4.27	3.37	4.41	3.51	4.39	3.36	4.5	3.52	4.77	3.5	4.32	4.83	5.66	4.36
23.	6	5.17	4.62	5.08	4.45	3.15	4.6	4.31	4.74	4.45	4.72	4.3	5.68	4.46	4.98	4.98	5.3	4.89	4.56	4.9
24.	6	5.21	4.2	5.12	4.45	4.34	3.4	4.21	3.54	4.35	3.52	4.2	3.63	5	4.88	5.2	4.68	4.92	4.69	4.73
25.	4	3.5	2.52	3.44	2.96	3.49	4.03	4	4.17	4.14	4.15	3.99	4.26	4.15	2.89	4.09	3.98	4.1	4.34	3.67
26.	3	2.65	2.6	2.60	2.17	4.06	2.9	3.93	3.04	3.01	3.02	2.86	2.87	2.91	3.51	3.83	3.75	2.89	2.87	3.4
27.	4	3.56	3.3	3.53	2.87	4.13	4.27	4.04	4.41	3.86	4.39	3.71	4.24	3.76	3.73	3.7	4.01	3.23	3.62	5.01
28.	4	4.22	3.85	3.56	2.83	3.61	2.92	3.37	3.06	3.51	3.04	3.36	2.89	3.41	4.26	3.35	3	3.19	2.89	3.25
29.	5	4.52	4.16	4.48	3.42	4.27	4.42	4.14	4.56	4.28	4.54	4.13	4.39	4.18	4.23	4.16	4.4	4.1	4.62	4.96
30.	5	4.55	3.5	4.55	3.35	4.31	4.25	4.17	4.39	4.31	4.37	4.16	4.22	4.21	3.98	4.19	3.99	4.66	4.2	4.56

APPENDIX E: LPG CONSUMPTION DATA ANALYSIS

Table E.1 Household LPG consumption data analysis

HH Size	Consumption for 20 weeks (kg)		Per person consumption in 20 weeks (kg)		Per Person Per day Consumption (g)	
	Total	Average Consumption	Total	Average Consumption	Total	Average Consumption
3	52.68	57.66	17.56	19.22	125.43	137.29
3	51.10		17.03		121.66	
3	52.82		17.61		125.75	
3	48.64		16.21		115.81	
3	59.07		19.69		140.63	
3	60.44		20.15		143.91	
3	60.65		20.22		144.40	
3	66.61		22.20		158.60	
3	65.76		21.92		156.57	
3	58.87		19.62		140.18	
4	69.11	73.60	17.28	18.40	123.41	131.43
4	70.80		17.70		126.43	
4	69.00		17.25		123.22	
4	70.29		17.57		125.51	
4	70.41		17.60		125.73	
4	104.02		26.00		185.75	
4	71.86		17.96		128.32	
4	73.36		18.34		131.01	
4	63.56		15.89		113.50	
5	75.84	79.75	15.17	15.95	108.35	113.92
5	84.42		16.88		120.60	
5	76.82		15.36		109.74	
5	79.53		15.91		113.61	
5	81.95		16.39		117.08	
5	79.91		15.98		114.16	
6	83.67	85.98	13.94	14.33	99.61	102.36
6	86.66		14.44		103.17	
6	89.34		14.89		106.36	
6	84.25		14.04		100.30	
7	98.52	98.52	14.07	14.07	100.53	100.53

APPENDIX F: HOUSEHOLD ELECTRICITY CONSUMPTION DUE TO INDUCTION STOVE

Table F.1 Household electricity consumption in kWh during a week for a household

S.N.	HH size	Age of stove	Electricity consumption in kWh in weeks																			
			1st	2nd	3rd	4rth	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
1.	4	2	28.58	23.82	19.36	26.82	30.66	29.66	28.58	30.73	29.66	30.58	28.51	30.35	31.27	27.89	30.81	32.42	24.59	25.36	21.36	21.30
2.	6	1	33.22	33.86	31.31	39.51	31.57	29.28	32.10	30.35	33.16	38.79	32.02	29.97	39.48	39.02	35.60	39.55	37.73	40.69	31.95	23.89
3.	5	2	27.16	24.20	25.82	33.71	33.12	30.81	29.12	31.89	30.20	31.73	29.04	33.12	32.42	28.43	32.27	35.04	34.12	24.59	35.96	19.69
4.	6	3	33.28	35.54	31.34	39.95	28.27	32.54	32.62	33.62	33.69	33.46	32.54	33.23	34.15	31.92	37.08	26.85	36.77	38.15	38.62	20.66
5.	5	1	28.22	29.82	26.62	32.57	34.61	34.00	33.62	35.06	34.68	34.91	33.54	34.68	35.60	33.09	35.45	40.31	34.53	33.70	37.12	21.14
6.	3	2	16.94	15.81	16.14	19.79	19.59	22.90	24.59	23.97	19.67	23.82	18.52	21.90	24.51	18.06	22.13	21.13	18.29	24.74	32.27	27.95
7.	4	1	22.79	23.43	21.51	25.91	29.72	32.48	29.63	33.54	30.65	33.39	29.51	33.16	30.88	29.06	30.43	27.08	25.40	27.38	22.59	28.34
8.	3	2	18.07	15.65	17.75	18.88	18.75	27.35	19.67	28.43	33.04	28.28	22.97	27.35	28.28	22.51	27.35	21.90	28.12	24.82	24.66	28.46
9.	4	3	24.34	24.77	23.69	24.98	24.08	34.23	32.12	35.31	30.38	35.15	29.23	34.54	30.62	28.77	30.15	25.08	26.08	22.15	25.00	27.96
10.	4	4	23.28	22.63	22.42	25.86	22.80	33.10	31.06	34.18	27.56	34.02	26.40	33.79	27.79	25.94	27.33	21.17	35.41	28.33	28.10	30.59
11.	3	3	17.93	21.00	17.77	19.01	19.69	18.08	18.92	19.15	20.00	19.00	18.85	18.38	20.23	18.38	23.15	23.08	20.08	18.54	22.92	28.47
12.	3	2	17.59	16.78	16.94	19.36	16.14	19.67	22.13	20.75	21.98	20.59	20.82	20.36	22.21	20.36	21.44	27.89	20.59	22.44	24.59	30.67
13.	4	2	32.50	24.28	24.31	24.81	24.70	34.42	33.42	35.50	34.50	35.34	33.35	34.73	34.58	32.66	34.12	21.98	24.97	27.81	32.73	33.80
14.	4	2	24.53	25.51	24.10	24.96	32.27	28.35	33.15	29.43	34.19	29.27	33.04	28.66	34.42	24.66	22.74	24.89	30.81	29.51	26.51	30.75
15.	5	1	30.88	31.41	30.35	30.62	34.23	26.62	30.65	27.69	31.72	27.53	22.67	26.93	31.79	31.03	31.64	27.76	35.67	37.65	37.42	32.16
16.	3	1	17.57	19.49	16.93	18.85	17.65	20.84	22.21	21.91	21.15	21.75	20.00	27.53	21.37	19.55	26.47	23.96	21.22	21.60	21.68	34.69
17.	5	2	32.81	33.88	32.00	28.51	32.27	32.81	25.89	33.88	26.97	33.73	25.82	34.58	27.05	36.65	26.89	33.19	37.11	43.49	33.50	33.87

APPENDIX G: ELECTRICITY CONSUMPTION DATA ANALYSIS

Table G.1 Household electricity consumption data analysis

HH size	Consumption for 20 weeks (kWh)		Per person Consumption for 20 weeks (kWh)		Per Person Per day consumption (kWh)	
	Total	Average	Total	Average	Total	Average
3	426.07	426.76	142.02	142.25	1.014	1.016
3	477.73		159.24		1.137	
3	393.86		131.29		0.938	
3	413.28		137.76		0.984	
3	422.88		140.96		1.007	
4	558.97	572.57	139.74	143.14	0.998	1.022
4	566.89		141.72		1.012	
4	569.13		142.28		1.016	
4	559.11		139.78		0.998	
4	611.84		152.96		1.093	
4	569.49		142.37		1.017	
5	613.41	636.89	122.68	127.38	0.876	0.910
5	675.93		135.19		0.966	
5	615.03		123.01		0.879	
5	643.20		128.64		0.919	
6	693.85	685.67	115.64	114.28	0.826	0.816
6	677.48		107.27		0.766	

APPENDIX H: COSTS ASSOCIATED WITH LPG

Table H.1 Cost of LPG cook stoves available in Nepali market.

S.N.	Sample	Unit	Quantity	Per unit price including VAT (NPR)
1	Sample no.1	set	1	1,800
2	Sample no.2	set	1	1,750
3	Sample no.3	set	1	3,135
4.	Sample no.4	set	1	3,000
5	Sample no.5	set	1	2,125
6	Sample no.6	set	1	2,475
Average Cost of the cook stove (a)				2,380

Table H.2Cost of LPG compatible frying Pans available in Nepali market

S.N.	Sample	Dia.	Unit	Qty.	Per unit price including VAT (NPR)
1.	Sample no.1	18 inch	pcs	1	1,000
2.	Sample no.2	18 inch	pcs	1	1,500
3.	Sample no.3	18 inch	pcs	1	1,800
4.	Sample no.4	18 inch	pcs	1	1,200
5.	Sample no.5	18 inch	pcs	1	1,350
	Average Cost of frying pan (b)				1,370

Table H.3 Cost of LPG compatible cooking pot available in Nepali market

S.N.	Sample	Volume	Unit	Qty.	Per unit price including VAT (NPR)
1.	Sample no.1	2 ltr.	pcs	1	1,200
2.	Sample no.2	2 ltr.	pcs	1	1,450
3.	Sample no.3	2 ltr.	pcs	1	2,000
4.	Sample no.4	2 ltr.	pcs	1	1,350
5.	Sample no.5	2 ltr.	pcs	1	950
	Average Cost of Cooking Pot (c)				1,390

Table H.4 Cost of LPG compatible pressure cooker available in Nepali market

S.N.	Sample	Volume	Unit	Quantity	Per unit price including VAT (NPR)
1.	Sample no.1	5 ltr.	Pcs	1	2,500
2.	Sample no.2	5 ltr.	Pcs	1	2,800
3.	Sample no.3	5 ltr.	Pcs	1	2,300
4.	Sample no.4	5 ltr.	Pcs	1	3,000
5.	Sample no.5	5 ltr.	Pcs	1	2,750
	Average Cost of Pressure Cooker (d)				2,670

Therefore the average installation cost associated with the LPG stove is the sum of above mentioned average costs (a + b + c + d) and cost of a cylinder (NPR. 3,900) i.e. NPR 11,710.

Table H.5 Maintenance Cost associated with the LPG

S.N.	HH size	Maintenance Cost noted during weekly visit																		
		1st	2nd	3rd	4rth	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	20th
1.	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.	6	-	-	-	750*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12.	3	-	-	-	-	-	-	-	150**	-	-	-	-	-	-	-	-	-	-	-
13.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16.	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17.	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

S.N.	HH size	Maintenance Cost noted during weekly visit																		
		1st	2nd	3rd	4rth	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	20th
19.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22.	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23.	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24.	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26.	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28.	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	450***	-	-	-
29.	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30.	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* NPR 750 was used to replace the regulator.

** NPR 150 was used to repair the LPG stove burner.

*** NPR 450 was used to replace the gas pipe.

APPENDIX I: COSTS ASSOCIATED WITH INDUCTION STOVE

Table I.1Cost of Induction cook stoves available in Nepali market

S.N.	Sample	Power (kW)	Unit	Quantity	Price incl. VAT (NPR)
1.	KONKA	2000	Set	1	3,599
2.	PRESTIGE	2000	Set	1	4,800
3.	CG	2000	Set	1	4,259
4.	CRYSTAL	2000	Set	1	3,900
5.	YASUDA	2000	Set	1	3,240
6.	MIDEA	2000	Set	1	4,750
7.	BALTRA BIC	2000	Set	1	3,935
8.	CROMPTON	2000	Set	1	5,432
9.	AURA	2000	Set	1	3,999
10.	BETTER	2000	Set	1	3,735
Average Cost					4,164

Table I.2 Cost of Induction Stove compatible frying Pans available in Nepali market

S.N.	Sample	Volume	Unit	Quantity	Per unit price including VAT (NPR)
1.	Sample no.1	2 ltr.	Pcs	1	1,800
2.	Sample no.2	2 ltr.	Pcs	1	2,100
3.	Sample no.3	2 ltr.	Pcs	1	2,700
4.	Sample no.4	2 ltr.	Pcs	1	1,650
5.	Sample no.5	2 ltr.	Pcs	1	1,700
	Average Cost of the frying pan				1,990

Table I.3 compatible cooking pot available in Nepali market

S.N.	Sample	Volume	Unit	Quantity	Per unit price including VAT (NPR)
1.	Sample no.1	5 ltr.	pcs	1	2,000
2.	Sample no.2	5 ltr.	pcs	1	3,200
3.	Sample no.3	5 ltr.	pcs	1	1,800
4.	Sample no.4	5 ltr.	pcs	1	1,900
5.	Sample no.5	5 ltr.	pcs	1	2,200
	Average Cost of Cooking Pot				2,220

Table I.4 Cost of LPG compatible pressure cooker available in Nepali market

S.N.	Sample	Unit	Quantity	Per unit price including VAT (NPR)
1.	Sample no.1	pcs	1	3,500
2.	Sample no.2	pcs	1	2,800
3.	Sample no.3	pcs	1	4,800
4.	Sample no.4	pcs	1	4,500
5.	Sample no.5	pcs	1	3,300
Average Cost of Pressure Cooker				3,780

Therefore the installation cost associated with the Induction stove is the sum of above mentioned average costs i.e. **NPR 12,154.**

Table I.5 Maintenance Cost Associated with the Induction Stove

S.N.	HH size	Age of stove	Electricity consumption in kWh in weeks																			
			1st	2nd	3rd	4rth	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
1.	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.	6	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.	5	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40.00***
4.	6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5.	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6.	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.	4	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8.	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9.	4	3	-	-	-	-	-	-	-	-	-	-	-	-	800.00**	-	-	-	-	-	-	-
10.	4	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11.	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12.	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13.	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14.	4	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15.	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16.	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17.	5	2	-	-	-	40.00*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* NPR 40 was used to replace the fuse,** NPR 800 was used to replace the IGBT, *** NPR 40 was used to replace the fuse.

APPENDIX J: NPV RESULTS

Table J.1 NPV outcomes for LPG stove for the various household size

Probability	NPV in NPR.			
	HH size:3	HH size:4	HH size:5	HH size:6
Less than 10%	127,921 to 156,903	159,366 to 195,775	171,488 to 210,780.	183,791 to 225,999
Less than 20%	127,921 to 170,936	159,366 to 213,720	171,488 to 230,201	183,791 to 246,940
Less than 30%	127,921 to 182,949	159,366 to 229,027	171,488 to 246,785	183,791 to 264,791
Less than 40%	127,921 to 194,171	159,366 to 243,308	171,488 to 262,244	183,791 to 281,495
Less than 50%	127,921 to 204,836	159,366 to 256,971	171,488 to 277,029	183,791 to 297,447
Less than 60%	127,921 to 216,806	159,366 to 272,218	171,488 to 293,579	183,791 to 315,265
Less than 70%	127,921 to 231,435	159,366 to 290,959	171,488 to 313,899	183,791 to 337,192
Less than 80%	127,921 to 250,661	159,366 to 315,447	171,488 to 340,453	183,791 to 365,817
Less than 90%	127,921 to 278,417	159,366 to 350,827	171,488 to 378,775	183,791 to 407,125
Less than 100%	127,921.44 to 278,417	159,366.61 to 458,284	171,488.05 to 495,094	183,791.24 to 532,456

Table J.2 NPV outcomes for Induction stove for the various household size

Probability	NPV in NPR.			
	HH size:3	HH size:4	HH size:5	HH size:6
Less than 10%	97,333 to 121,228	122,548 to 152,160	133,671 to 165,791	142,106 to 176,114
Less than 20%	97,333 to 132,085	122,548 to 166,075	133,671 to 181,076	142,106 to 192,428
Less than 30%	97,333 to 141,229	122,548 to 177,856	133,671 to 194,007	142,106 to 206,244
Less than 40%	97,333 to 149,594	122,548 to 188,625	133,671 to 205,822	142,106 to 218,880
Less than 50%	97,333 to 157,754	122,548 to 199,087	133,671 to 217,321	142,106 to 231,174
Less than 60%	97,333 to 166,698	122,548 to 210,597	133,671 to 229,983	142,106 to 244,680
Less than 70%	97,333 to 177,921	122,548 to 224,996	133,671 to 245,783	142,106 to 261,548
Less than 80%	97,333 to 192,248	122,548 to 243,541	133,671 to 266,154	142,106 to 283,328
Less than 90%	97,333 to 213,397	122,548 to 270,775	133,671 to 296,086	142,106 to 315,272
Less than 100%	97,333 to 279,983	122,548 to 355,252	133,671 to 388,457	142,106 to 413,636

APPENDIX K: SPECIFICATIONS

Table K.1 Specification of induction stoves taken as sample for efficiency calculation

S.N.	Parameters	Sample			
		I	II	III	IV
1.	Model	HL-A5	PIC 23.0	BIC 124	CGIC20A02T
2.	Trade Mark	Konka	Prestige	Baltra	CG
3.	Origin	China	India	India	Nepal
4.	Year of Manufacture	2018	2019	2020	2021
5.	Number of burners	Single	Single	Single	Single
6.	Power (Watt)	2000	2000	2000	2000
7.	Digital Display	Yes	Yes	Yes	Yes
8.	Variable power input	Yes	Yes	Yes	Yes
9.	Operating Voltage	220 V 50Hz	220 V 50Hz	220 V 50Hz	220 V 50Hz
10.	Weight (kg)	1.95	2.62	2.8	2.3

			
Sample I	Sample II	Sample III	Sample IV

Table K.2 Specification of LPG stoves taken as sample for efficiency calculation

S.N.	Parameters	Sample				
		I	II	III	IV	V
1.	Model	2B SUPER	NA	NA	NA	GTMC-02
2.	Trade Mark	Fortune	Bawa	Sunflower	Butterfly	Prestige
3.	Origin	India	India	India	India	India
4.	Mfd. Year	2007	2011	2013	2016	2020
5.	Number of burners	Double	Double	Double	Double	Double
6.	Control type	Knob	Knob	Knob	Knob	Knob

				
Sample I	Sample II	Sample III	Sample IV	Sample V

Table K.3 Specification of weighing machine used

S.N.	Parameter	Description	Image
1.	Model	Bench 50	
2.	Trade Mark	Sunrise	
3.	Origin	India	
4.	Mfd. Year	2020	
5.	Platform	Knob	
6.	Display	Digital	
7.	Least Count	0.001 kg	
8.	Voltage	220 V , 50 Hz	

Table K.4 Specification of submeter

S.N.	Parameter	Description	Image
1.	Type	Single phase watt hour meter	
2.	Trade Mark	Trishul	
3.	Origin	India	
4.	Mfd. Year	2020	
5.	Accuracy	Class 1	
6.	Display	Analog	
7.	Least Count	0.01 unit	
8.	Voltage	220 V , 50 Hz	