DEVELOPMENT OF A FRAMEWORK FOR SUSTAINABLE RURAL ELECTRIFICATION IN THE HILLY TERRAINS OF NORTH BENGAL WITH SOLAR EQUIPMENT & MICROGRID SOLUTIONS

A Thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Management (Power)

By
Archan Bhanja

December 2020

Supervisor(s):
Prof. (Dr) Anil Kumar
Prof. (Dr) Anshuman Gupta
Dr. Arijit Kumar Gupta

UPES
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Department of Energy Management
School of Business
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Dehradun – 248007: Uttarakhand

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DECLARATION

I declare that the thesis entitled ***Development of a Framework for Sustainable Rural Electrification in the Hilly Terrains of North Bengal with Solar Equipment & Microgrid Solutions*** has been prepared by me under the guidance of ***Prof. (Dr.) Anil Kumar***, ***Professor & Head of the Department of Energy Management (Supervisor)***, and ***Prof. (Dr.) Anshuman Gupta***, ***Professor of the Department of Economics & International Business (Co-supervisor)***, ***School of Business, University of Petroleum & Energy Studies***. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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ABSTRACT

Access to affordable energy is a pre-requisite for economic development and rural electrification is a challenging issue for India where 70% of the population and the majority below the poverty line belongs to rural area. Decentralized Distributed Generation, especially stable & reliable renewable energy (RE)-based microgrid solutions through solar power is a feasible solution for rural electrification and efficiency in electricity supply ecosystem, in order to ensure comprehensive development of the rural population of India, when National-grid connectivity is not cost effective. This thesis is an attempt to examine the perceptions of rural consumers and the different socio-economic & techno-commercial criteria & key factors for the preference towards solar-power microgrid and/or RE-microgrid through a survey-driven analysis in the Kalimpong district of North Bengal, India along with International electrification framework analysis, in order to develop a sustainable Rural Electrification framework for India, using solar-power Equipments & microgrid solutions. Responses obtained from the study area sample households were cross validated against responses of other stakeholders including academics and sector experts through stakeholder interviews. Information obtained was statistically analysed using a range of techniques, including correlation & regression, Chi-square test and factor analysis to identify the key drivers around a future, sustainable framework of RE-microgrid-based rural electrification. For this study, the findings provide directions to develop the framework for solar-power equipment & microgrid-based rural electrification, in order to accelerate socio-economic development of the hilly terrains of North Bengal, through rural co-operative driven, multi-provider license-based microgrid, preferably with the abundant renewable energy sources like solar power, in the initial government patronages like subsidies and funding for rural electrification, ensuring reliable and affordable access of electricity for the rural population.

Keywords: Rural Electrification, Solar-Power, Micro-grid, Socio-economic development, Rural Co-operative, Hilly terrains, Rural population

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The work is an extension of my work experience in the contemporary Energy & Utilities and Smart Microgrid industry. The work is also an outcome of series of interactions with several Global E&U sector leaders, E&U industry veteran subject matter experts and Academicians, to whom I am grateful for the inputs of material so widely collected on the subject matter including the Qualitative study analysis data & insights.

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INTRODUCTION AND BUSINESS PROBLEM

1.1 BACKGROUND OF THE STUDY

As of 2020, the population of India is projected to be around 1.380 billion, or 1,380 million, or 138 crore, out of which 65% live in rural areas and 35% in urban areas (Ministry of Statistics and Programme Implementation, 2020). About four hundred million rural inhabitants, which are more than the entire US population, still do not have access to electricity, which means India is facing an acute energy crisis. Energy access is a development imperative. At the same time, economic growth calls for high national energy requirements. It is expected that domestic energy demand in India will exceed 16% by 2030 (Bairiganjan et al., 2010). Since India gives priority to power generation, the installed capacity of its power plants has reached 1,64,509 MW. The generation of hydro energy stands at 37,086 MW (25%), thermal energy at 1,06,433 MW (65%), nuclear energy at 4,560 MW (2.9%), and renewable energy at 16,429 MW, or 7.7% of the total energy generated in the country (Saxena & Kumar, 2010).

The Indian energy sector focuses on conventional systems, where centralized electricity generation relies on coal-based thermal power plants and large dams. There is conclusive evidence for the inability of this centralized system to balance demand and supply. This has led to inequities and environmental degradation, as a result of which 40% of India's rural population lives in the dark. Large-scale reforms have been repeatedly tried in the past. A lot more needs to be achieved in the field of rural access to electricity in India. As much as 35% of the global population having no access to electricity resides in India, and only 44% of the rural Indian households have access to electricity. Going by the 2001 census, out of the total 13.8 crore households in the country, 6.02 crore consider electricity as the primary source of energy for lighting

(Kaundinya et al., 2009). According to a latest study commissioned by the United Nations Development Programme (UNDP), the achievement of the Millennium Development Goals (MDGs) gets critically hampered by energy insecurity and poverty. Even at present almost 78 million people of India who stay in rural terrains, or 56% of rural households of the nation, do not have access to reliable & sustainable electricity supply for their day to day livelihood. Rural electrification is the most critical part among all the potential initiatives for the development of rural India. The power sector in India is a diversified ecosystem where the Energy-mix for power generation vary in a wide range, with the combination of the traditional Energy sources like Coal, Lignite, natural gas, oil, hydro, and nuclear power as the commercial resources for Power Generation, whereas solar energy, wind farm, and agricultural & domestic waste are considered as the non-conventional sources of power generation. The demand for electricity in the country is growing rapidly (Samanta, 2015b).

Power generation through traditional fossil fuel results in harmful biproduct chemicals & sometimes Green House Gases etc. that are not at all good for the environmental sustainability & health of the overall ecosystem. Such emissions are major threat to the future of the Earth. It has become essential & extremely critical now to come up with a viable alternative for power generation. It is a major challenge for scientists and engineers now to make conventional energy sustainable and renewable energy available. The major problems for the mankind like global warming, GHG effect and climate change need to be handled comprehensively worldwide with a global outlook. ‘Think global act local’ is the mandate of the recent time, as the potential solutions might not be unique. Problems would vary from geography to population areas, while the solutions would also vary accordingly. Leading countries across the continents have taken up initiatives to control the negative impact on the ecosystem & energy-related climate changes. Both for on-grid and off-grid power systems, renewable energy resources such as solar, wind, bio, and hydro energy are desirable (Murthy, 2012).

Electricity can be supplied to communities with the help of distributed microgrids, which are the decentralized distributed power supply systems for localized energy ecosystems (generation, transmission, and distribution). They are technically feasible and even operationally available in rural and semi-urban areas of developing and some of the developed countries. Currently around 1.2 billion people across the world do not have access to electricity, including circa. 550 million people in Africa and 300 million people in India (International Energy Agency, 2012). The traditional method of extending the centralized National grid is prevalent in most of these regions. This approach is far from the reality of an energy efficient ecosystem for a plethora of reasons like capital budget/ investment crisis, insufficiency in energy services, poor grid reliability & very high Transmission – Distribution Loss (T&D Loss), extended time in building, construction complexities in connecting Electricity grid infrastructure to remote geographies, Commercial loss due to power theft & poor unorganized revenue management systems etc. Many of these critical challenges could be overcome or optimized by sufficiently financed and functioning distributed decentralized microgrid ecosystems, which are mostly powered by renewable and suitable localized resources as per their abundance & availability in the nearby geographies. This, in turn, can lead to more effectively operational electrification strategies (Schnitzer et al., 2014).

Research interest in distributed decentralized microgrids has grown over the last several years. A DC microgrid that can generate < 1.5 kW of power can independently function in island mode if and when the loads are supplied from locally distributed energy resources. Hence, it is advantageous to use microgrids, and they are used quite popularly across certain parts of rural or semi-urban India nowadays. Because of their benefits, microgrids have attracted a lot of research attention. They are reliable, secure, highly efficient, environmentally friendly, and self-healing. Ever-rising cost of power generation with traditional sources and especially the diminishing traditional-fossil fuel sources are the key challenges of the Electrical power systems. Correspondingly, there is increasing pollution due to the burning of oil and gas, in addition to greenhouse gases, which pose the biggest threat to the ozone layer. DC microgrids have the following advantages:

1. Frequency or phase control is not necessary.

2. It is possible to avoid the rectification stage, meaning there will be a 5–7% increase in efficiency of the DC systems. This is higher than the efficiency rate of AC systems.
3. DC systems are more compact than their corresponding AC systems.
4. Compared to AC systems, DC grids help to achieve both hardware and operational cost savings.
5. DC systems have much simpler power conditioning and stability control mechanisms (Sen et al., 2015).

The hilly and remote rural forest areas of India are home to most of the deprived & neglected people of the nation. These remote geographies are mostly deprived from any access to electricity supply and other basic facilities, such as clean water, health & hygiene, basic education and cooking fuel, which are mandatory for a comfortable and healthy human life. The inaccessibility of these remote terrains from the mainland, compel these far away population to live in a deprived condition in terms of infrastructure and social development. Conventional methods are not applicable in such areas. The use of RE-microgrids or decentralized renewable power supply system would encourage a combination of new age technologies, sustainability aspects, renewable energy resources, and policy mechanisms, thereby optimizing the problems associated with traditional National-grid expansion to such remote geographies. This has a positive impact on the lives of the rural Indian population with respect to power supply (Dharmala, 2015). Since India has high potential for solar energy (approx. 4–7kWh/m2/day), it offers a promising solution for electrification and black-out issues. The rural northern and north-eastern regions face an acute shortage of energy. In those areas distributed generation can yield better results than the national, centralized grid. Microgrids are more cost-effective for energy storage and renewable integration in the northern and north-eastern regions than grid expansion. Microgrids can help to reach the emission targets, besides satisfying the electrification goals (Fairman et al., n.d.).

Recent reports released by the government of West Bengal claim that about 94.32% of rural households have electricity, and that 95.4% households in the erstwhile Darjeeling district now enjoy electricity (Power for All – West Bengal, 2016). However, the Planning Commission of the central government and the Ministry of Power report that only about 41.5% of the rural households in West Bengal have electricity, while the situation is even worse in the North Bengal hills [Census 2011, MOP 2016, WEBREDA 2010]. North Bengal has diverse biological resources that are protected by the dense forests and the hilly terrains of the Himalayas (Das, 2017). North Bengal comprises the north-western regions of Bangladesh and the northern region of West Bengal (The Info List, 2017). North Bengal has three regions: i) Malda and Dinajpur, ii) Darjeeling, Kalimpong, Cooch Behar, Alipurduar, and Jalpaiguri, and iii) North Dinajpur (West Bengal, 2004). The Human Development Index (HDI) reveals that the regions of North Bengal have low levels of HDI, with the exception of the Darjeeling town, which ranks fourth in terms of HDI, because of its being a major tourist spot. The development of Darjeeling as a global tourist spot, which the British started and is still happening (Bhattacharya, 2013), facilitated improvements in the HDI for the town, whereas other regions are far from catching up.

1.2 CONCEPTS AND OPERATING DEFINITIONS

The following section provides a brief introduction to the various resources of energy, rural electrification, and electrification technologies including off-grid electricity systems, solar energy, and microgrids.

1.2.1 RENEWABLE AND NON-RENEWABLE RESOURCES

A growing global population and industrialization around the world have significantly increased the demand for energy, leading to the sustained development of energy generation technologies using various energy resources. However, traditional energy development technologies have serious implications for the environment in the form of air pollution, public health deterioration, loss of wildlife, water pollution, and carbon emission. This has led to the development of various alternative energy resources that can significantly lessen the detrimental effects on the environment caused by the burning of traditionally used energy resources. According to the U.S. Energy Information Administration, "Renewable energy is energy from sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration.” The following figure represents the various types of solar PV systems:

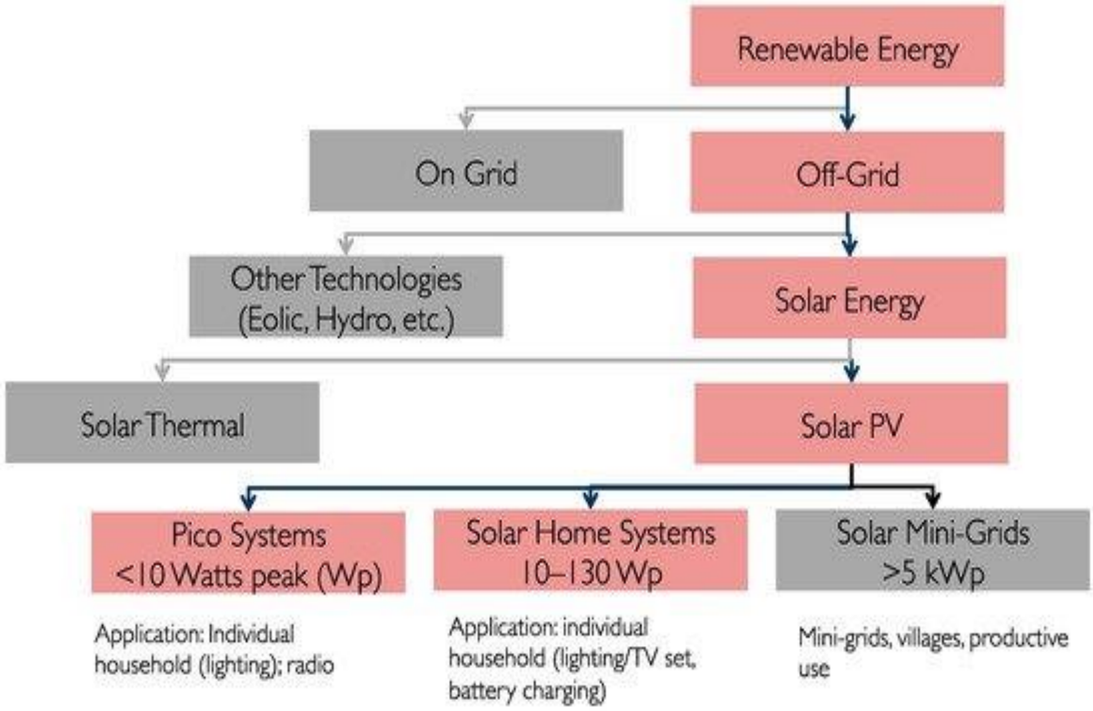


Figure 1.1: Overview of Various Solar PV Systems

Renewable energy resources include solar, wind, hydropower, and biomass, all of which can be harnessed directly for generating energy or can be mixed with other renewable resources for ease of convenience. For instance, biomass can be used to produce fuels such as ethanol, and wind can be harnessed using wind turbines to generate electricity. Advancements in renewable energy technologies, along with the environmental concerns related to climate change due to the over-reliance of non-renewable resources for energy needs, have led to the increasing usage of renewable resources across the world (Maheswari & Ramkumar, 2017).

The primary source of all renewable resources is the sun, whose radiation can be either directly utilized for heating purposes in the form of solar heaters, or indirectly harnessed to generate necessary energy through various power systems such as hydroelectric power systems, wind energy-based power systems, and bio-fuel-based power systems. Important renewable energy resources include hydropower, biomass, solar energy, geothermal, and wind energy. Hydropower is the most widely used renewable resource for generating energy. It is followed by biomass fuel, which is mostly extracted from agricultural and industrial waste. Renewable energy resources are favoured across the globe for energy production as they generate clean and environmentally friendly energy, thus resulting in the conservation and sustainability of natural resources for our future generations and fostering environmental protection (DMME, 2019).

Replenishment of fossil fuels like natural oil, a non-renewable energy resource, takes millions of years (Wiley, 2016). It may be possible for geological processes to generate fresh stocks of these energy forms, but it may take a vast geological time, for the processes to finish. Harmful Greenhouse gases are also generated due to burning of fossil fuels for Power Generation, and this accelerates the negative impact of climate change drastically. It is not sustainable for humankind to rely on such modes of energy production (Energy Envoys, 2012).

Non-renewable resources like fossil fuels are exhausting quickly due to their continuous extraction by human-beings. The finite nature of these resources, their inability to be regenerated, and the increasing demand for non-renewable resources around the world contribute to their steady decline (Forinash, 2017). There are three types of non-renewable resources, e.g., metals, fossil fuels, and minerals. Metals are extracted to be used either as pure elemental substances or as alloys, the latter being the mixture of two or more metals. Metals such as iron, aluminium, and copper are primarily used for manufacturing machines, tools, and building materials, whereas precious metals such as gold and platinum are used for making jewellery and artistic items, although they also have some industrial applications. Fossil fuels such as charcoal, crude oil, and natural gas are the other forms of non-renewable resources, but they take more than a thousand years to regenerate, and rapid industrialization has resulted in the increasing mining of fossil fuels and the consequent depletion of their sources. The third important class of non-renewable resources includes minerals such as asbestos, gypsum, and limestone, which are mined primarily for the industrial production of cement and building materials. With rapid industrialization in the developed countries, the per-capita consumption of energy has grown exponentially, leading to an over-dependence on non-renewable resources for the production of energy needed for industrial purposes (Dalhousie University, 2018).

1.2.2 SOLAR ENERGY

Solar energy is an important source of renewable resources that involve the utilization of solar radiation and converting solar energy into a usable form of electricity. Being a source of green renewable energy, solar energy leaves a lower carbon footprint than fossil fuels do, and thus it does not accelerate climate change (International Energy Agency, 2019). There are primary and passive uses of solar energy. Solar water heaters are in the first category, which comprises active sources. Greenhouses are an instance of passive solar design. Greenhouses collect solar energy on sunny days in winter in order to use the energy to keep houses warm at night. There are multiple benefits of solar energy from the perspective of easy availability and utility. It is clean; it can be used independently or with other conventional energy resources. Though it is freely available, the mechanism for storing such energy is expensive and its availability is not constant (Penn State Extension, 2016). There are different types of equipment powered by solar energy, and these include pico-solar lanterns and pico-solar home systems. The costs of these vary depending on the purpose of the equipment. While a pico-solar lantern is a discrete light source and comes with LED lights, the pico-solar home system, which is the least economical of the solar energy equipment systems, comes with a small-sized solar panel, a battery, and a charger unit capable of charging a light source, a mobile phone, and transistor radios. These types of equipment are widely used in the interior regions of African countries like Rwanda and Tanzania. These solar power-based energy kits are very useful in regions with low-density populations, as they offer significant financial savings for the community, provide opportunities for additional earnings, and benefit sectors like education and public health (Quak, 2018).

1.2.3 SOLAR ENERGY AND ELECTRICITY GRID

Wind and solar energy are the two resources of renewable energy which can reduce our dependence on fossil fuels and greenhouse gas emissions in the power sector. However, solar photovoltaics (PV) sometimes generate an uncertain or “intermittent” output (Smith & Parsons, 2007). An electricity grid is an interconnected system of electricity generation and distribution networks, where different energy resources make different contributions to the grid to match the supply and demand levels of the electricity, which are subject to change constantly. The operation of the complex grid network can be run through the only energy resource and needs a good mix of non-renewable and renewable energy resources to achieve cost-effective energy production that does not have any major impact on the environment. To maximize the benefits of solar energy, solar energy needs to be integrated with the centralized electricity grid to facilitate the proper deployment of solar energy in order to meet the ever-increasing need for household energy. Solar energy is not a finite energy resource, nor does it cause air pollution or have any detrimental effects on public health as it does not contribute to global warming, unlike the burning of fossil fuels. Some of the key solar technologies include solar photovoltaics, solar heating, and cooling which convert solar radiation into usable energy forms (NREL, 2020).

1.2.4 MICRO ELECTRICITY GRID

A micro electricity grid is a localized energy grid that can operate independently even when it is connected to the central grid. It can control the generation and distribution of electricity during power outages in the event of certain climatic phenomena like storms. The US Department of Energy defines a microgrid in the following terms:

> A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.

A microgrid is an interconnected system of load networks and distributed energy resources (DERs) that can operate either in connection or in disconnection with the main grid. A microgrid can be used effectively to balance the electricity demand from household and commercial establishments located in a particular area with the overall supply of electricity generated from both non-renewable and renewable resources such as solar energy and wind (US Department of Energy, 2017). Renewable power resources like solar panels, along with batteries and distributed generators, are used to operate a microgrid. There are major benefits of establishing microgrids as they provide the necessary backup for the grid and thus ensure an uninterrupted supply of electricity to the area where the microgrids are located. Those specific areas can be energy-independent, as the electricity produced by a microgrid is cost-effective and environmentally friendly, mainly in those microgrids where alternative energy resources are used for electricity generation (Stadler, 2018). The key advantage of a microgrid is that it functions in standalone mode or main-grid-disconnection mode. It can then function autonomously. Generally, generation and loads in a microgrid are interconnected at low voltage (Ahmed et al., 2015). Smaller in size than a mini grid, a microgrid provides direct current (DC) (Ministry of New And Renewable Energy, 2011).

1.2.5 SUSTAINABLE ELECTRICAL ENERGY

Sustainable energy is commonly defined as an energy system that serves present requirements without compromising the ability of future generations to meet their needs. The organizing principle for sustainability is sustainable development, which includes four interconnected domains—ecology, economics, politics, and culture. Sustainability science is the study of sustainable development and environmental science. The greatest challenge faced by both developed and developing countries around the world is how to provide people with an adequate supply of energy which is sustainable and environmentally benign. The increasing awareness among the world economies about the importance of generating electricity through sustainable energy resources has resulted in sustainable, environmentally friendly energy technology innovations and development. Numerous studies in the field of renewable energy resources have led to the development of electricity generation technologies that use renewable energy resources, especially solar and wind energy (International Energy Agency, 2019)

Generating electricity from solar and wind energy as a standalone system is a major challenge due to the disparity in the demand and supply levels of electricity. There have been major developments in solar PV technology and wind turbines, leading to increased efficiency in harnessing the abundant natural resources for generating sustainable electrical energy. The extraordinary innovations in these technologies have resulted in significant cost reduction and made them more affordable for the consumer (World Nuclear Association, 2019).

1.2.6 OFF-GRID ELECTRICAL POWER

Standalone electrical systems and mini-grid electrical systems not connected to the larger national grid are called off-grid energy systems. In remote locations around the world, off-grid energy technologies have seen a lot of development in recent years and are the best possible electricity solutions for the cooking and lighting needs of rural populations. As per the International Renewable Energy Agency (IRENA) report, in 2016, off-grid energy solutions provided access to electricity for lighting and cooking for nearly 133 million people living in rural regions around the world. In recent years, solar home systems have enhanced the access to electricity to the vast majority of the world's rural population due to the plummeting costs of solar energy-based electricity generation technologies (IRENA, 2017). Micro-financing schemes and subsidies have greatly reduced the cost burden on the individual household, allowing the rural community to have access to a variety of electrical services. Solar photovoltaic (PV) technology harnesses solar radiation by converting sun energy into electrical energy, thereby providing electricity access to millions of rural inhabitants and communities not serviced by the national grid. Wind turbines are another excellent off-grid energy system and harness the abundant wind energy to generate electricity, depending on factors like the speed and density of wind (IRENA, 2016b).

1.2.7 ENERGY SECURITY

The United Nations (UN) defines energy security as "the continuous availability of energy in varied forms, in sufficient quantities and at affordable prices. The key aspect of energy security is long-term security, which indicates resource availability or in other words, the actual quantities of physical resources available across the world. Short-term security is another issue of energy security that necessitates reliable systems, for instance, the perennial supply of electricity to match the demands of the consumer at any point in time" (US DOE, 2017; Speight, 2019). Energy security itself is also dynamic, since the perspective may depend on the timeframe analysed. For example, analysts studying longer timeframes tend to value stability over cost-effectiveness (von Hippel et al., 2011). Overall, the differences in perspectives and priorities have led to a debate among scholars on how energy security will change over time and how best to respond to this change (Ciută, 2010). Johansson (2013) proposed a distinction between: i) when the energy system is analysed as an object that is exposed to threats, commonly referred to as "security of supply" or "security of demand", and ii) when the energy system works as an agent that generates or enhances security, for example, caused by a perceived political or economic value.

The security of energy supply plays a critical role in the formulation of energy policy strategies. Many countries depend on energy imports (or energy exports) because crude oil and natural gas purchases and/or sales affect these countries' balance of payments (Speight, 2011). To ensure energy security and ecologically sustainable development, India needs to take concrete measures. Recent government policy decisions regarding energy security and climate change issues have taken a pragmatic turn. India's policymakers now understand the importance of and linkages between economic development, energy security, and environmental sustainability. Two recent major policies make this pragmatism evident—the 2006 Integrated Energy Policy (IEP) and the 2008 National Action Plan on Climate Change (NAPCC) (Bisht, 2012).

Lack of energy security is now linked to the adverse economic and social implications of the material unavailability of energy and to non-competitive or highly volatile prices (US DOE, 2017). From a historical perspective, for many countries, energy security was mainly associated with the supply of crude oil. In the international oil market, prices are allowed to adjust to fluctuations in supply and demand, and the risk of material unavailability occurs in extreme events. But in many instances, Petro- or geo-politics plays a role, thus affecting crude oil imports (Speight, 2011). Consequently, supply security concerns are chiefly related to the economic damage triggered by extreme price hikes.

1.2.8 ELECTRICITY ACTS AND POLICIES OF THE GOVERNMENT OF INDIA

The government of India considers electricity as the basic human need and has formulated major legislative acts and policies regarding the generation, transmission, and distribution of electricity in the country. The Electricity Act of 2003 oversees the various electricity policies formulated by the Ministry of Power (MOP). As per the National Electricity Plan (NEP), the power sector aims to achieve pan-India electrification as mandated under Section 6 of the Electricity Act of 2003 (Ministry of Power, 2019).

The India government now recognizes the development of locally available renewable resources in order to meet its economic and environmental goals, and it now promotes this development through policy decisions. In 1992, the government established MNRE, the world's first ministry dedicated to the renewable energy sector. The MNRE seeks to expand contributions of renewable energy in all end-use sectors in India and undertakes activities to that end. The MNRE also oversees national renewable energy institutes like the Solar Energy Centre and the Centre for Wind Energy Technology. The Indian Renewable Energy Development Agency (IREDA) incentivizes renewable energy and energy efficiency projects with funds from the central government and other lending agencies. The IREDA also oversees many renewable energy incentive programmes launched by the central government. There are several other units under the Ministry of Power, the Planning Commission, and the Prime Minister's Council on Climate Change that are directly responsible for renewable energy initiatives.

The India government has several policies to back the renewable energy sector (Scribd, 2010).

- Electricity Act 2003: This act mandates that each State Electricity Regulatory Commission (SERC) establish minimum renewable power purchases; permits the Central Electricity Regulatory Commission (CERC) to set a preferential tariff for electricity generated from renewable resources; allows licensed renewable power generators to have access to the transmission and distribution system.

- National Electricity Policy 2005: It allows SERCs to set preferential tariffs for electricity produced from renewable resources.
- National Tariff Policy 2006: It stipulates that each SERC enter into a renewable purchase obligation (RPO) with distribution companies and that purchases be made through an open bidding process.
- Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) 2005: This scheme backs the extension of electricity to all rural and below-poverty-line households through a 90% subsidy on equipment costs for energy systems.
- Eleventh Plan 2007–12: It planned to achieve 10% of power production capacity from renewable resources by 2012 (goal already reached); supports phasing out of investment-linked subsidies over performance-based ones.

1.2.9 RURAL ELECTRIFICATION

Rural electrification refers to the process of bringing electrical power to rural and remote areas. As Lahimer et al. put it: "*Rural electrification is a complicated issue because of user affordability, rural inaccessibility and remoteness, low population densities and dispersed households, low project profitability, fiscal deficit, scarcity of energy resources, population growth, lack of professionalism, and over-dependence on subsidies*" (Lahimer et al., 2012). Rural electrification plays a major role in the socio-economic development of the community and has positive impacts on public health, education, job creation, household productivity, and the overall quality of life of rural inhabitants. Moreover, lack of access to electricity forces rural people to rely on firewood or fuels like kerosene for their energy needs. This has many negative environmental implications such as increasing air pollution, deforestation, and depletion of resources. The burning of fuels can lead to public health hazards. To end energy poverty in the rural regions, many countries focus on deploying a number of electrification technologies such as country-wide grid extension, off-grid systems like mini and microgrids, and more (Litzow et al., 2017). About a billion people globally still have no access to electricity; this population is equal in size to the total number of people living in the world in the early 19th century. As of the mid-2010s, 200–300 million people in India (15–20% of the population) lacked access to electricity, along with seven out of eight people living in rural Sub-Saharan Africa. A greater number of people have to live with intermittent and poor-quality electricity. In 2012, about 23% of people living in East Java, Indonesia, had no access to electricity, reports a survey conducted in 2013.

According to James et al. (1999), in Namibia, electrification was a marginal issue for small business development in the rural areas. Access to markets, business and finance, and information were more important. Electrification had a minor impact on rural small businesses in Namibia as none of the small businesses having access to electricity reported any boost in income. Wamukonya & Davis (1999) state that for rural households in Namibia, "electrification does not seem to have had any significant impact on growth of income-generating activities". Shockingly, household income was the lowest in households with electricity access. Less than 1% of home businesses used electricity for productive purposes, and this was mainly for lighting. The study concludes that "there are other factors that have to be in place to support business development and that electricity is, at best, a facilitating factor".

Rural electrification in Asian countries has not seen as much progress as in the other developing countries. In 2018, the Sub-Sahara African region recorded only 45% electrification. A staggering 600 million people living in the rural areas of Sub-Sahara African countries such as Kenya, Ethiopia, and Tanzania had no access to electricity (IEA, 2019). By comparison, India has made wholesome progress in this regard, with 100 million Indians having given electricity access in 2018. As per an India government report, 26 million families benefited from the Saubhagya Electrification Scheme until 2017, mainly in the rural regions.

1.2.10 SOCIO-ECONOMIC IMPACT OF OFF-GRID/MICROGRID RURAL ELECTRIFICATION

Reliable electricity accessibility using off-grid energy technologies provides many opportunities for rural communities to achieve socio-economic development in terms of better education, occupation, better household income, and standard of living. According to many reports, gaining access to electricity through PV solar energy provides positive social, economic, and environmental results. Palit & Bandyopadhyay (2016) attempted an extensive literature review to analyse the role of grid and off-grid options in facilitating rural electrification and presented a comparative assessment of their costs and impacts on electrification in South Asian countries. The document concludes that, instead of considering each mode electrification independently and perceiving them as mutually exclusive or competitors to each other, as is commonly perceived in the policy field, off-grid electrification can actually be seen in a complementary and ideally complementary way. It should be integrated with the expansion of the network to serve the greater cause of warranting widespread and sustainable rural electrification in the South Asian countries. The study investigated whether network extension or off-grid solutions (mainly PV solar energy, though not exclusively) were the most beneficial way to electrify rural areas.

Another study by Sarah (2016) seeks to assess the sustainability of rural electrification efforts in Chile with special attention to off-grid PV solutions. The evaluation of rural electrification efforts in Chile considers four dimensions of sustainability, namely institutional, economic, environmental, and sociocultural. The study found that, despite several off-grid PV pilot projects, the utilization of off-grid PV solutions for rural electrification fell behind the country's massive solar potential. The problem here is that decisions that favour other solutions have been made without considering lifetime costs and environmental co-impacts. In addition, social acceptance of off-grid PV technologies has been seriously hampered due to issues related to accuracy (systems could not meet user needs) and reliability (systems often failed due to lack of obligatory standards and vague maintenance).

Kobayakawa & Kandpal (2014) examined the actual operational data of a PV microgrid system on India's Sagar Island to understand the role of the different factors that impact household connectivity, electricity consumption, and potential demands. They propose an approach to plan (and design) a decentralized microgrid-based power supply system. The analysis reveals that the potential demand for electricity within (as well as outside) the current scope of the microgrid is high and future expansion of the system would be effective if a “phased approach” to rural electrification were adopted. The analysis also shows that households with certain socio-economic characteristics are more likely to connect to the microgrid and the relationship can be used to predict supplementary load requirements for network extensions.

Rural electrification based on microgrid technologies offers rural communities improved opportunities for income generation, improved community income, improved social networks, and enhanced community health, thereby ensuring the socio-economic development of the rural population. In addition, rural electrification through off-grid/microgrid technologies enables better irrigation systems for agricultural growth and contributes to the safety of women and children, which are of the utmost importance for socio-economic development (Jha et al., 2016).

1.2.11 INDIAN ELECTRICITY & RURAL ELECTRIFICATION POLICY

Founded in 1969, the Rural Electrification Corporation (REC) is the national and state nodal body for the disbursement of funds for renewable energy. However, there is no official rural electrification fund (REC, 2018). Funding for each project is provided by the national and state budget to the MNRE and its state-level nodal agencies. Three directives fall mainly under the “regulation” type. The first of these is the Electricity Act of 2003, which lists the notified rural regions where tariffs and private electricity supply are not regulated (Central Electricity Regulatory Commission, 2003). The second two are the previous and current standards for solar products that are carrying out work for MNRE. Previous standards required licensing based on specifications set by the International Electrotechnical Commission (Vashishtha, 2012). Current standards from 2017 onwards are the new “Indian standard”, which also stipulates regular testing of products and product lines (MNRE, 2017). The two main programme guidelines, the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) and the Jawaharlal Nehru National Solar Mission (JNNSM), adopt different modes. The DDG takes a direct contractual approach and uses product subsidies for non-governmental service providers as an incentive to participate and reduce costs for end-users (MoP, 2013). By contrast, the JNNSM takes a market-oriented approach that narrows the gap between cost and willingness to pay, thereby widening the potential market for off-grid systems (MNRE, 2012). Finally, there is the National Draft Microgrid Minigrid Policy, whose future is uncertain, but which was occasionally cited in interviews (MNRE, 2016). This programme follows the guidelines established by other state policies (see Bihar and Uttar Pradesh) and offers support, which "can be in the form of upfront capital funding or grant, or low interest loans, generation- based or operational incentives etc., essentially to support the market for Minigrid development" (MNRE, 2016, p.12). However, it also defines tariff regulations for companies that accept government funding. In this sense, it is a market-oriented programme, although with regulatory elements. (MNRE, 2016, p.14). Since this programme is analogous to other state-level mini-grid programmes, it is included here to illustrate such policies. However, it is not further explored as it is not yet an official policy.

Major Rural Electrification Schemes in India

Rural electrification is the mainstay of rural economy and a basic requirement for rapid rural development. It is also the main infrastructure to ensure the rapid growth of the agricultural sector and the agro-industrial infrastructure in rural areas. Some of the rural electrification schemes implemented in the post-independence era are discussed below (Samanta, 2015b):

Pradhan Mantri Gramodaya Yojana (PMGY)

Introduced in 2000–2001, the PMGY provided additional financial support to all states for minimum central government benefits based on 90% loans and 10% subsidies. This covered rural health, education, drinking water, and rural electrification. With a disbursement of about Rs 1,600 crore during the 10th Plan period, the PMGY was coordinated and monitored by the Department of Rural Development of the Planning Commission. More significantly, the PMGY allowed the states to decide on the redistribution of funds to basic services. In this way, states could improve allotments to fast-track rural electrification. The programme was discontinued in 2005.

Kutir Jyoti Programme (KJP)

The KJP was established in 1988–89 to provide all households below the poverty line (BPL) in the country with a single-point light connection (60 W). It offers a 100% grant for one-time costs for internal cabling and service connection fees and provides for 100% metering for the release of grants. The programme connected nearly 60 lakh households in 15 years, or at a rate of about four lakh households per year. To date, the programme has covered nearly 5.1 million households. In May 2004, the programme was integrated into the "Accelerated Electrification of One Lakh Villages and One Crore Households" scheme and is now part of the RGGVY.

Minimum Needs Programme (MNP)

The NPM, meant exclusively for states with less than 65% rural electrification (as defined above), provides 100% loans for last-mile connectivity. The programme resources come from Central Plan Assistance. Rs 775 crore were disbursed during 2001–03 for rural electrification under the NPM. The plan was discontinued in 2004–05 due to implementation difficulties.

Accelerated Rural Electrification Programme (AREP)

In operation since 2002, the AREP provides a 4% interest subsidy to states for renewable energy programmes. The AREP covers rural and household electrification and has an approved disbursement of Rs 560 crore under the 10th Plan. The interest subsidy is available to state governments and electricity service companies on loans from approved financial institutions such as the Rural Electrification Corporation (REC), the Energy Finance Corporation (PFC), and NABARD under the Rural Infrastructure Development Fund (RIDF).

Rural Electricity Supply Technology Mission (REST)

REST began on 11 September 2002 with the aim of progressively electrifying all villages and households by 2012 through local renewable energy resources and decentralized technologies, along with the connection to the conventional grid. The programme proposes an integrated approach to rural electrification and has the following aims: to identify and adopt technological solutions; to review the existing legal and institutional framework and make changes where necessary; to promote, fund, and facilitate alternative approaches to rural electrification; and to coordinate with various ministries, major institutions, and research organizations to assist in the fulfilment of national objectives of “Accelerated Electrification of One Lakh Villages and One Crore Households”. The MNP and Kutir Jyoti schemes have been merged with the RGGVY.

Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY)

The RGGVY is one of the latest national programmes launched for the purpose of rural electrification. Implemented by the Ministry of Power, it is aimed at making the vision a reality on the basis of the recommendations of the 2001 conference of chief ministers. The plan finally took shape in April 2005 and included some of the following objectives:

- Complete electrification of all homes and villages in the country under Village Electrification Infrastructure (VEI), so that there is at least one transformer for distribution in each habitable block and village
- Access of electricity to all the households
- Free distribution of electricity to households affected by poverty
- Creation of a Rural Electricity Distribution Backbone (REDB) so that at least a 33/11 KV (or 66/11 KV) substation is available in each block
- Establishment of Decentralized Distributed Generation (DDG) systems in areas where the network is not feasible

The RGGVY scheme places the importance of rural electricity as a necessary component for human and economic development in a broader sense, beyond the scope of the current framework, by boosting agricultural production through irrigation. In addition to meeting household power needs, the programme monitors the grid’s energy supply in rural areas 24 hours a day to ease industrial activities, thereby also improving the provision of information technology uses and healthcare services.

According to the current pace of the electrification process in the country, the number of new connections added each year is about one million, while the number of households tends to grow by 1.85 million annually. Doing the math makes it clear that out of 138 million households in rural areas, 78 million do not have access to electricity. At the same time, the facilitation of new connections and distributions is also hampered by a lack of trained labour and suitable infrastructure at the district level. Moreover, the efforts made should reflect best practices to implement and address retracements of areas such as tariffs, subsidies, power generation, implementation, and policy monitoring by the government. However, electrification rates have increased dramatically over time. This is due to a rigid classification of a minimum of 10% of households that use electricity services. Therefore, the overall electrification of households still remains below 50% across the country. The expansion of the productive use of electricity is critical to the financial and economic viability of an area. Traditionally, electricity was used to pump water for agriculture in India. But this has led to a problem of huge subsidies, excessive demands, etc. Therefore, this new programme aims to avoid similar mistakes in general, which have been made in the past. The integration of electrification programmes in the rural parts of India has the potential to create synergies for the promotion of agriculture-based activities in the industrial sector.

The majority of people in rural India cannot take advantage of the electrification process. Owing to the lack of a power grid, isolated villages cannot be connected to the central or state networks. More investment is needed for such connections. The government has taken initiatives in this regard to electrify rural areas through renewable and distributed generation resources. People in the suburbs are not far ahead of rural residents in terms of access to electricity. In urban areas, the focus is on electricity quality and reliability issues. This is due to geographical diversity and also because the government sets priorities for the customer sector. In developing countries, microgrids have a wider scope for discussion and a different focus. The use of microgrids has a long way to go in India, although the initiative is there. Some hurdles must be overcome. Framework conditions are there for the promotion of independent renewable energy production. The current electrification programmes for rural areas are in line with renewable energy production (Balijepalli et al., 2010b).

In recent years, India has seen significant developments in the use of renewable energy resources. The following figure shows the installation of the various renewable energy resources used in the country in 2009, and it is expected to reach 50,000 MW of solar energy by 2032 (Balijepalli et al. 2010b). The government of India, with the various energy development agencies, the Ministry of New and Renewable Energy (MNRE), and private actors, oversees the development of renewable energy plants in the country (Ministry of New And Reneweable Energy, 2017). The concept of the microgrid is also gaining in attention and needs to be expanded in India, especially in the rural and hilly regions where access to electricity is still negligible (India, 2017). Rural and poor communities stand to gain from the use of microgrids as these solutions facilitate access to electricity with a lower financial burden. Instead of ownership of a product, agreements can be made with microgrid service providers. With little or no initial investment, the use of microgrids, especially solar energy and micro-networks, could help to meet the goal of rural electrification. (India, 2017). In West Bengal, the West Bengal Renewable Energy Development Agency (WBREDA) oversees the implementation of renewable energy in the region. Developments of solar microgrids began in 1993 in the Sundarbans and the government is keen on making further changes to the implementation of solar microgrids in the state to expand facilities to rural land, especially in the hilly regions of North Bengal. The districts of North Bengal have multiple unconventional power generation resources for the operation of potential microgrid systems (e.g., solar, wind, and hydroelectric power). However, given the high seasonality and fluctuating nature of water resources and wind flow in North Bengal, it would be preferable to have solar microgrid systems, due to the abundant availability of solar radiation and solar energy throughout the year.

The above statements suggest that the use of renewable resources and decentralized microgrids is much preferable in the rural and hilly regions of North Bengal and the north-eastern states, where electrification has not yet taken place. The northern part of Bengal has a special significance as it is one of the most prospective hilly regions of the country (with its immense potential for tourism, trade, and export), whereas in some large rural parts of the country, together with the other hilly regions, there is sparse electrification. Purulia and Bankura districts of West Bengal are two such regions.

1.3 BUSINESS PROBLEM STATEMENT

About 65% of the approximately 1.38 billion Indians live in rural areas, and at least 400 million inhabitants of this rural population do not yet have access to electricity in their homes. Electrification is presently mandatory for the country. More importantly, the country's domestic energy demand is likely to exceed 16% by 2030 (Bairiganjan et al., 2010). The previous section also shows that the north-east part of India has remained far behind in terms of socio-economic development compared to the rest of the country.

Despite abundant natural and human resources, north-eastern India, which consists of eight states and the northern hilly areas of West Bengal, is still lagging behind many Indian states. People in these states are disadvantaged as per various socio-economic indicators. The value of the Multidimensional Poverty Index (MPI) is highest in Assam, but this value is also high in Meghalaya. In 2011–12, the BPL population in Manipur was highest (46.7%), followed by Assam (40.9%) and Arunachal Pradesh (37.4%), exceeding the level of the whole of India (29.5%). There is also inequality in terms of the rate of development (demographic indicators), sanitation (economic conditions indicators), rail density (infrastructure indicators), average years of education, monthly per-capita expenditure, and population below the poverty line. The analysis of access to basic amenities like drinking water, toilets, and electricity reveals major differences at the state level. Inequality in electricity access is highest in the urban sector. Among the north-eastern states, Meghalaya faces the maximum average deprivation in terms of basic amenities, while the most socio-economically disadvantaged state is Nagaland (MPRA, 65407, Konwar et al.).

The twin districts of Darjeeling and Kalimpong in the northernmost part of West Bengal, with the shape of an irregular triangle, belong to the larger north-eastern region of India, as does the state of Sikkim, which shares the border with West Bengal. The northern region of the geography is part of the great Himalayas, which are located at an altitude of 300–12,000 feet above the mean sea level. The Tarai region is located in the south, extending along the base of the hills. The hilly areas of Darjeeling and Kalimpong have been inhabited since ancient times by Lepchas, Limbus, Bhutias, Tibetans, and various Nepalese castes and tribes. On the contrary, the dense forested plains have been home to indigenous tribal groups such as Meche, Koch, Rajbangshi, Dhimal, and others, who lived mainly on nomadic and Jhoom cultivation (Ref. District Gazetteers, Darjeeling, 1907 edition, author - LSS O'Malley, ICS, Superintendent of Census, latest census handbook updated in 2011).

Energy development in India began at the end of the 19th century, with the commissioning of power supply in Darjeeling in 1897. The overall power supply scenario in the hilly districts of Darjeeling and Kalimpong is behind the national average due to the poverty of the potential consumer, lack of resources, lack of political will, poor planning, and electricity theft, whereas urban areas have seen comparatively increased electricity consumption and capacity. While more than 10% of India's 115 backward districts remain in north-eastern India, the districts in North Bengal are comparatively successful due to their potential tea-tourism and timber industry. However, in terms of socio-economic development and per-capita income, the North Bengal districts are well below the national threshold. The average cultivation intensity of the hilly areas of North Bengal is 23% lower than that of the total national average of West Bengal. Agriculture is the main occupation of the people living in the hilly regions of North Bengal (Agriculture Department of West Bengal, 2016). Kalimpong has to grapple with acute water shortage throughout the year due to inadequate power supply and poor quality of electricity (Sharma et. al., 10.2166 / wp. 2019.229). The old and inadequate electricity grid continues to be a challenge for the hilly areas of North Bengal, coming in the way of providing high-quality electricity and of ensuring other socio-economic facilities such as telecommunications. The average technical loss for the districts of North Bengal is about 20% (WBSEDCL 2018). The remote areas, international borders, forests, and hills are the main challenges for faster development and electrification, as well as for the national programme to expand network connectivity in these regions (WBSEDCL 2018). The state of West Bengal, especially the hilly districts of North Bengal, is blessed with abundant renewable energy resources such as solar, wind, biomass, and hydropower. These constant energy resources play an important role in the socio-economic development of the country. In addition, renewable energy resources are significant for ensuring the state's energy security, considering the various environmental constraints and the rapid depletion of fossil fuels. A variety of policies and support measures complement the diffusion of renewable energy technologies. The state has developed a whole set of institutional arrangements for these programmes. The estimated potential for renewable energy in West Bengal is over 1,000 MW. This is without considering solar energy, which is nearly unlimited, especially in the districts of North Bengal. The state has installed capacity to generate more than 80 MW of electricity using renewable energy resources. In the private sector, renewable energy projects capable of generating around 50 MW of electricity are currently being implemented with active support from the state government through JV or PPP models. Nevertheless, there is untapped potential for renewable energy production, and the state government is looking for prospective consultants and partners to develop these capabilities. The current estimated (already identified) potential for renewable energy resources is close to 3,000 MW, more than 40% of which can be produced in the mountainous districts of North Bengal (WBGEDCL, 2019).

The promotion of renewable energy is a strategically important issue to ensure energy security and sustainable development, while encouraging clean technologies for this purpose. In general, renewable power generation projects are entitled to CDM benefits. In addition, renewable energy projects can receive various financial incentives from both state and central government agencies and nodal authorities.

Many parts of West Bengal enjoy abundant solar radiation, which can be converted directly into grid-quality energy. This is done using solar PV cells, which convert the visible spectrum of the incoming solar radiation into electricity and feed the energy directly into the grid. The potential of such electricity generation in West Bengal stands at 16,000 MW, to which North Bengal would contribute about 30%. It is not possible to make use of all the resources, but a much of this potential can be tapped, depending on the availability of sufficient land and such other factors as optimal solar radiation, sufficient hours of sunshine, and network availability. Solar PV power generation has many advantages: the resource is eternal, the power generated is clean and environmentally friendly (no carbon emission), and the maintenance is low. The land needed for installing such systems is generally 3–4 acres per MW, and the approximate cost is currently Rs 20 crore per MW (WBGEDCL 2019) Small and mini hydro power plants (less than 10 MW in capacity) make use of small rivers and streams. In West Bengal, the potential of small hydel power is pegged at 250 MW. Most of these sites are in the hilly districts of Darjeeling and Kalimpong. Most locations in North Bengal are suitable for turbines with high and medium head, and the sites are located at a distance of 2–5 km from the motorable road (WBGEDCL, 2019). Taking all these aspects into account, the following statement on the business problem can be made:

Lack of adequate cost-effective high-quality electricity supply through National Grid system is affecting the socio-economic growth of the Rural Hilly Terrains of India, especially the North Bengal, which warrants the local solutions in the forms of Renewable Energy based Equipments as part of Micro Grid solutions for Rural Electrification.

CHAPTER- 2
REVIEW OF LITERATURE

A growing global population and the industrialization of economies around the world have significantly increased the demand for energy, thereby leading to the sustained development of technologies for energy generation using diverse energy resources. However, traditional energy production technologies have a substantial impact on the environment through air pollution, public health deterioration, loss of wildlife, water pollution, and carbon emission. This has led to the development of various alternative resources of energy that can considerably mitigate the detrimental environmental effects of the burning of traditionally used energy resources. This section reviews the previous literature in this research context. Based on the business problem of the research, it is evident that ample evidence is required for the examination of the business problem and the related research topic. The literature review thus pertains to five specific themes, and studies were evaluated under each theme:

2.1 LITERATURE REVIEW THEME 1

Status of global smart grid and microgrid systems for sustainable energy and socio-economic development

Across the world, there is an increasing focus on the application of microgrids using renewable energy resources such as solar, wind, biomass, and hydropower for rural electrification to promote socio-economic development. Studies on microgrid applications have provided the necessary background for the present researchers to advance the current state of knowledge in the microgrid research field to help develop robust systems for sustainable energy production.

Longe et al. (2014) tested a renewable energy-sourced microgrid design for a rural area in South Africa. Around 1.4 billion people in the world do not have access to electricity. A whopping 85% of them are rural dwellers who reside mostly in Sub-Saharan Africa. More than half (55%) the rural dwellers in South Africa do not have access to electricity. The Umhlabuyalingana Local Municipality has an electrification rate of 20%, which makes it the least electrified municipality in the world. The study investigated the implementation of a renewable energy source (RES) micro-grid compared to grid extension, and it was used as a case study. The HOMER tool was used to carry out the simulation, optimization, and sensitivity analyses. A photovoltaic (PV) with a battery system was found to be the optimal microgrid combination. The proposed microgrid yielded \$0.378/kWh cost of electricity, 0 kg/person $CO2$ emission, 100% renewable penetration compared to \$0.328/kWh cost of grid electricity, 8.9 kg/person $CO2$ emission from grid extension, and 0% renewable penetration from the national grid. The microgrid was more efficient than the grid. It had a standalone break as the electric distance limit of 34 km was less than the 150-km power line, which was ideally required for Umhlabuyalingana. The microgrid design was a better solution for electrifying the non-electrified areas of Umhlabuyalingana. The study concluded that grid extension was not a preferred solution.

Venkatraman and Khaitan (2015) published their findings on the management of microgrids using a survey of various techniques in achieving reliable and sustainable energy supply. They discussed the usefulness of the applications of microgrid systems using renewable energy resources in the electrification of rural regions in India. The study presented an overview of alternative energy resources and advanced distributed energy resources (DER) technologies and their positive impacts on air quality. It also showed how these technologies substantially reduced environmental pollution by mitigating GHG emissions and how they increased the conservation of valuable resources for future use.

Martinez & Rivier (2016) studied the critical role of microgrid technologies in sustained electricity generation and distribution by presenting a detailed literature review of microgrids along with their distinct features. The paper provides a detailed description of the critical physical components involved in microgrids technologies including generator units, converter units, and the systems used for energy storage. The researchers report the detrimental impacts of the conventional methods of electricity generation using non-renewable resources like fossil fuels. The paper also provides insights into the important issues and challenges encountered in the deployment of microgrids.

In their study, Akinyele & Rayadu (2016) presented their insights and the best practices involved in developing sustainable energy systems for remote communities. The study reports a growing global interest in adopting microgrids for rural electrification in India due to the potential benefits of microgrid systems such as flexibility, reliability, efficiency, and cost-effectiveness. The researchers emphasize the strategies for microgrids' interconnections with the power grid in their study on the centralized control to optimize the functioning of the microgrids. The study also lists the possible alternative solutions for the electrification of remote areas such as microgrid renewable technologies and modular power technology applications such as turbines, hybrids, and microturbines for the development of sustainable energy development.

Schnitzer et al. (2014) focus on seven different research papers to critically review the best microgrid practices to achieve the goal of rural electrification. In this review, the authors emphasize the utility of microgrids applications based on renewable resources as the best alternative energy solution for the electrification of rural communities. The study discusses the control mechanism for microgrid applications with energy storage by focusing on the challenges and the rural communities' need for sustainable energy development.

Louie et al. (2014) discusses the recent developments in microgrid technology by presenting various instances where microgrid applications are successfully implemented across the world. By emphasizing the contribution of major microgrid systems, the study reports that microgrid technologies are the preferred energy applications for the 21st century. The paper reviews the critical contribution of microgrid systems to facilitating a transition to smarter grids for sustainable energy production and offers recommendations for the control of microgrid technologies. The researchers present the important elements of the various applications of microgrids for sustainable energy generation in remote locations.

Williams et al. (2015) evaluate the cost-effectiveness of installing microgrids in Sub-Saharan Africa, South Asia, and Southeast Asia. When it comes to economic and social development, access to electricity is an important factor. The low rates of access in the three locations mentioned above prompted developing nations and international organizations to set high goals regarding the access of electricity. Microgrids are decentralized, cost-effective solutions for locations that are remote from the central grid infrastructure. A shortage of funds from public and donor sources has impeded the realisation of these goals. It has led to a greater participation of the private sector in the electrification process. Since there is an associated risk in carrying out the electrification projects in rural areas and the marginal expected returns on investment, the private sector is not very keen on this ambitious project. The study ends with the anticipation that decentralized microgrid-based projects will ensure that people who stay far from the grid will not have to wait long for electricity and light. Therefore, microgrid projects are not great opportunities for the private sector since there is a risk factor involved along with low returns. Innovations from businesses, carefully designed policies, and incentive programmes from the private sector and the donor community are essential for making rural electrification a grand success.

There are several studies on reforms in the electricity sector. Pollitt (1997) categorizes empirical studies on these reforms into four groups: i) those that use financial and physical indicators; ii) those that look at labour productivity measures or total factor productivity (TFP); iii) those that use frontier methodologies; and iv) those that are based on social cost–benefit analysis of electricity privatization. The first approach is the simplest. Yarrow (1992) develops a counterfactual scenario based on the assumption that the British electricity sector has not been privatized, and then he compares the actual results. To further develop the model, Branston (2000) conducts a counterfactual price analysis on the privatization of the British electricity sector. The result is that the reforms had a minor impact on prices. Duncan & Bollard (1992) analyse the impact of the reforms of the government control of the

Electricity Corporation of New Zealand. Rocha et al. (2007) analyse the return on capital of Brazilian electricity distributors, concluding that the return on equity in Brazil was systematically negative until 2003. Bishop & Thompson (1992) analyse changes in the labour or total factor productivity growth rates caused by the 1983 Energy Act, which sought to limit competition in the electricity industry. Haskel & Syzmanski (1992) examine the impact of the implementation of a divisional management structure in the UK ESI in 1983. Plane (1999), who estimates the total factor productivity of the Côte d'Ivoire Electricity Company (CIE), finds that production efficiency improved due to privatization. Using cross-sectional data for developing countries, Hawdon (1996) finds that privatized firms had higher production efficiency. Berg & Jeong (1991), who analyse the effects of the introduction of incentive regulation in the US, suggest that narrow incentive regulation focused on plant utilization and thermal efficiency does not reduce relative inefficiency. Cullman & Hirshhausen (2008) do a cross-country efficiency analysis of the electricity distribution companies in some East European countries, namely Poland, the Czech Republic, Slovakia, and Hungary. Their results suggest that privatization has had a positive effect on technical efficiency in the four countries. The fourth method measures the impact of privatization on society as a whole. Jones et al. (1990) outline the methodology, while Galal et al. (1994) apply it to 12 instances of privatization. Newbery & Pollitt (1997) apply the methodology to the privatization case of Britain's CEGB. Oliveira et al. (2004) look at the gains and losses of shareholders, board members, fuel suppliers, consultants, equipment suppliers, service-providers, consumers, the government, and regulators created by the British ESI. They conclude that the reforms are overall beneficial, though not for stakeholders. Toba (2007) measures the welfare impacts of the electricity sector reforms in the Philippines. The results show that consumers and investors are net gainers, while the government lost due to loss of revenue and the environment lost due to increased pollution.

Domenech et al. (2014), and Ranaboldo et al. (2014) conducted studies specific to the context of sustainable solutions for electrification through microgrids using solar energy. Domenech et al. (2014) study a community electricity project. Considering micro-scale resource evaluation and social constraints, the study deals with a combination of microgrids and household systems feed by wind, PV, or micro-hydro energies. Rural communities are often isolated from the electrification process, so standardized solutions are provided using the same technologies at all points in time. However, these solutions may not always be relevant to the community and its population. The previous study aimed to offer a technical design of an electrification system for the Alto Peru community (in Cajamarca, Peru). The technology was used in each area based on the micro-scale resource evaluation and the socio-economic requirements of that particular population. The four implemented technologies are: wind microgrids in the highlands, a micro-hydro power plant in the vicinity of a waterfall, a PV microgrid in a cluster of points protected from the wind, and individual PV systems in scattered points with low wind potential. This project successfully brought electricity to 58 households, a health centre, a school, a church, two restaurants, and two shops. It concludes that more training processes will be necessary for future projects to ensure the design and implementation of an electrification system for the population.

Wu et al. (2013) examine the application of microgrid technology in China. Their previous paper also looked at the state-of-the-art technologies used for the implementation of microgrids in the country. The emphasis is on DERs and their influence on the distribution network. The Chinese government funds researches aimed at setting up microgrids in the country. The previous study revealed that every province in China has made advancements in microgrid technology. The application of microgrids in China is supported by several organisations such as the State Grid Corporation of China (SGCC) and China Southern Power Grid (CSPG).

Électricité du Laos (EDL), the public electricity utility of the Lao People's Democratic Republic, has achieved remarkable institutional success over the past two decades with respect to rural electrification. EDL has distributed electricity to an increasing proportion of the Lao population, with improving levels of service consistency and technical efficiency. The expansion of the electricity grid to remote areas and the poorest sections of the Lao population has enabled EDL to build legitimacy for itself in the eyes of its clients and stakeholders. The role of the power sector in the country's development trajectory was envisioned by its first cohort of revolutionary leaders in the 1970s and has been used as a blueprint for sectoral development over the past four decades. The current power sector strategy was developed in the early 1990s in concert with donors' institutional development programmes after the launch of the country's economic and administrative reforms.

Abdilahi et al. (2014) investigate urban centres in Somaliland for the feasibility of renewable energy-based microgrid systems. The ever-increasing and fluctuating diesel prices have an adverse impact on the business climate in these areas. Considering the post-conflict march towards economic development, the study seeks to investigate the possibility of supplying electricity to Hargeisa, Somaliland's major urban centre, from a renewable energy-supplemented hybrid system. The city still lacks a modern electricity grid of its own. Somaliland needs to reduce energy costs, and a feasibility study was conducted to understand how to supply electricity to a sampled residential load. There is only a primary-type electric load that is in line with the present-day electricity consumption in the area. The analysis utilized a software program called Hybrid Optimization Model for Electric Renewables (HOMER). The techno-economic analysis indicated the economic prospect of achieving a 58% renewable energy (RE) penetration and of reducing the cost of energy (COE) by 30%. The total net present cost (NPC) of the stimulated system also dropped by 25% vis-à-vis a current diesel-only microgrid. The hybrid microgrid shows the prospect of a better economic future than the present "business as usual" scenario in Somaliland.

Soyoye & Ayinla (2016) explore sustainable electricity supply in African nations and examine the concept of microgrids. The study posits that the communities in the region should make use of the resources that are available locally. In the African context and for developing nations, Microgrids ensure energy efficiency and electrification for poor communities.

Denholm et al. (2010b) investigate the role of energy storage in the generation of renewable energy. The report examines the role of energy storage in electricity grids and looks at the effects of large-scale variable renewable resource deployment such as solar and wind energy. The common electricity grid and energy storage vary constantly as the demand for electricity keeps changing. The authors also examine the need for energy reserves. Besides, they discuss the impact of variable renewable energy resources, for example, how the resources necessitate several other methods and technologies to reach their full potential. Also examined is the importance of solar and wind resources in the grid. The study discusses concerns about the reliability of the grid and investigates how such resources could facilitate energy storage.

Murthy Balijepalli et al. (2010) also report that electricity costs are justified because the costs for generating electricity in the common grid are on the rise due to the rising costs of procuring fossil fuels. Hence, an economic analysis of the lifespan of such systems should be conducted by performing a cost analysis based on such parameters as equipment reliability, fuel costs, and the future prices of technology. Life cycle assessment (LCA) is performed for the assessment of environmental impacts, revealing that the deployment of microgrid has positive effects on local labour, employment generation, local businesses, and so on.

The increasing usage of renewable energy resources such as wind, solar, and water has led to significant changes in the way electricity is generated and in the traditional concept of electric grid operation using fossil fuels. The use of information communication technology in the energy generation and distribution sector has resulted in smart grid technologies and the development of cost-effective and sustainable power systems. Studies in the field of smart grid technology have paved the way for the development of innovative energy products and services (International Energy Agency, 2015). Many studies have explored the contribution of renewable energy-based smart grids to sustainable energy development, and this section gives an overview of the existing research contributions to the applications of smart grid systems.

Bigerna et al. (2015) examine the socio-economic aspects to understand the feasibility of developing smart grid applications in the long run. They analyse five major parameters—consumer acceptance, privacy issues, costs, cyber safety, and regulatory aspects—in order to understand the viability of deploying energy applications based on smart grid technologies. The report also stresses the importance of cooperation between various stakeholders like governments, private sector, consumers, and environmental agencies in defining the needs of smart grid technologies for rural electrification.

Del Giudice et al. (2015) report the dynamic mechanisms of smart grid technologies and the superiority of smart grid systems over the traditional systems. The study states that smart grid technologies lend flexibility to the energy generation process, thus reducing the loss of energy, and that these technologies enable both energy generators and consumers to optimize energy generation and utilization. The researchers discuss the potential challenges that need to be considered when it comes to deploying power systems based on smart grid technology; these challenges include voltage regulation, grid synchronization, energy storage, and load management.

Eswar (2015) investigates the advancements in the field of smart grid technologies to generate electricity in a reliable and sustainable manner. The researcher also discusses how smart grid systems contribute to achieving cost-effective electricity demand management. The paper gives a detailed account of how proper integration of various resources of energy such as hydro power, wind energy, and solar energy can be achieved using smart grid technologies. The efficiency achieved in the transmission and distribution of electricity is also detailed. According to the paper, some of the significant advantages of deploying smart grid electrification systems are improved supply of electricity, reduced loss of electricity due to the use of time-of-use technology systems and smart meters, effective demand–supply management, and increased efficiency of power generation and distribution.

Wazeer & Singh (2018) address the growing trend of using smart grid technologies based on renewable resources to fulfil the ever-growing global energy needs and electricity demands. The paper focuses on the importance of micro smart grid applications in electrifying rural regions across India. It also offers suggestions and proposals for the effective generation, transmission, and distribution of electricity through the deployment of smart grid systems based on locally available energy resources. The paper highlights the importance of developing robust cyber security systems in improving the efficiency and cost-effectiveness of the rural electrification schemes based on smart grid technologies. The paper states that the use of microgrid systems can substantially improve the reliability of electricity supply, and that incorporating renewable energy resources with microgrid energy systems can mitigate the carbon emission caused by the burning of fossil fuels.

Nigam et al. (2019) review a report on the development and future prospects of smart grid systems from an Indian perspective. The study reviews the progress in the research areas involving smart grid technology and its deployment to meet future energy demands in India. The study also discusses the significant financial implications of the appropriate deployment of smart grid energy applications due to reduced power shortages and improvements in power supply and management. The researchers present an overview of the Indian power market, observing that inadequate power infrastructure, mismanagement of demand, and supply of power are the crucial challenges of rural electrification in India. These challenges can be overcome by the appropriate deployment of applications based on smart grid technology, which can lead to cost reduction and the integration of various electricity generation networks.

The literature review presented above shows that various studies have been conducted in the deployment of microgrids that accommodate different energy generation technologies for better energy management. However, commissioning microgrids and smart grid technologies using renewable resources in the hilly terrains presents huge challenges due to the geographical constraints. The hilly terrains are difficult to access and setting up huge microgrid energy systems involves considerable time and costs compared to the setting up of these technologies in the non-hilly regions. Hilly regions not only pose geographical constraints and challenges, but the extreme weather conditions also make it difficult to work in those regions. Moreover, the service and maintenance of microgrid technologies can be cumbersome in the hilly regions. The availability of appropriate sunny conditions is necessary for establishing a reliable and cost-effective microgrid infrastructure involving solar energy resources. But these constraints were not reported in the past studies on microgrid and smart grid systems, which has led to gaps in knowledge.

Previous studies demonstrated the benefits for developed markets and favourable traditional geographies, but there was no major commentary on the rural markets in Indian hilly terrains (especially in North Bengal).

Research Gaps

- Socio-economic development perspectives on microgrid systems in developing countries are missing.
- There are no references to the measurable benefits of sustainable energy for the rural terrains.
- There is no detailed analysis of the perspective and fitment of renewable energy-based electrification for rural hilly terrains of North Bengal.

2.2 LITERATURE REVIEW THEME 2

The need to move towards renewable energy-based equipment and microgrid systems for socio-economic developments in the rural parts of India

In recent years, climate change and the pressing need for a low-emission electricity generation system have led to the development of sustainable energy systems based on renewable energy resources. This section offers a detailed review of past research in the field of renewable energy-based systems and microgrid technologies in order to understand the need for making the transition from non-renewable energy-based systems to renewable energy systems for rural electrification in India.

Molyneaux et al. (2016) evaluate the various technology options available for rural electrification in India, by providing the advantages and disadvantages of these technologies. According to the study, the electrification strategies for the country’s rural regions are mainly based on three major technologies, namely central grid extensions, microgrids, and solar home electrification. The adoption of central grid extension for rural electrification in India has met with some major constraints, such as unreliability, high costs, regular shortages, losses due to electricity transmission and theft, and location-based challenges. Solar house systems have major disadvantages such as high installation and consumption costs, and limited load capacity (limited to basic heating and lighting). Considering the above limitations, microgrids offer an ideal solution for rural electrification in India as it is more flexible, reliable, and has lower operation and maintenance costs.

In their study, Comello et al. (2017) try to understand the various plans advocated by the government of India to make a transition from traditional power generation systems to environmentally friendly technologies for rural electrification in India. The study reveals that, owing to the increasing energy requirements, particularly in the rural regions, the country needs to harness energy through alternative renewable resources. The over-reliance on fossil fuels like coal, oil, and natural gas to meet energy demands has led to environmental deterioration in the form of increased levels of air and water pollution, depletion of non-renewable resources, and disparity between the supply of and demand for energy.

Agarwal et al. (2014) examine the effects of electrification on socio-economic developments in rural India. The fundamental drivers for adopting renewable energy-based microgrid systems in India are accelerated socio-economic growth, and the fulfilment of increasing energy demands of individual households and the rural population. The paper stresses the importance of utilizing locally available renewable energy resources for providing electricity access to the rural regions, which can help sustain fossil fuels for future generations and mitigate the environmental risks resulting from increasing carbon emissions. The study also states that the government needs to encourage rural households to adopt renewable energy resources for energy production and discourage them from using fossil fuels and firewood for their heating and lighting purposes.

To examine the role of electricity in improving the quality of life of people living in the rural regions, Malakar (2018) conducted a qualitative study in two villages in the Indian state of Andhra Pradesh. According to the findings of the study, the availability of electricity plays a critical role in the socio-economic development of villages by providing the population with economic opportunities and by improving their quality of life. Electricity was not completely available to all the inhabitants of the two villages where the study was conducted, and the study recommends reconsidering the definition of an electrified village. The study concludes that sustainable energy generation using renewable energy resources will not be successful in rural India without proper community engagement and availability of incentives through financial loans and subsidies to encourage the rural population to adopt cleaner energy resources.

The current rate of electrification indicates that on average one million new electricity connections are provided in the country against an annual household growth of 1.85 million, indicating a sluggish rate of electrification in the country. This becomes all the more evident when it comes to rural electrification, as only 78 million rural populations out of a total of 138 million living in rural regions have access to electricity (IRENA, 2016a).

According to a recent study, Germany is witnessing prolific community ownership. Unions play a strong role in encouraging solar energy manufacturing “as a way to promote local growth and local jobs,” and “most solar panels are owned by residences, with more than 90 percent of panels operated by homeowners, cooperatives, and communities, not big energy companies or utilities” (B. K. Sovacool 2012). Similarly, prolific community ownership may be seen among residents of Sikkim and Darjeeling, irrespective of their occupations (Rai, Sharma, & Jha 2017).

Chaurey, Ranganathana, & Mohanty (2014) analyse the rural electrification policy initiatives adopted in India and the challenges and issues related to the electrification of interior villages in the state of Rajasthan. The paper also examines the advantages of utilizing off-grid renewable technologies in these remote and geographically challenged villages. The report states that microgrid systems offer the ideal technology for rural electrification due to its flexibility, reliability, and ease of control. The paper concludes that microgrid applications using renewable energy resources like wind and hydropower provide cost-effective results in accelerating rural electrification.

Patel & Chowdhury (2015), who review the techno-economic challenges faced while implementing microgrids in rural South Africa, report that the reliability of off-grid microgrids is the primary challenge that needs considering when using microgrids for rural electrification. The researchers discuss the significance of utilizing renewable energy resources in addressing the problem of energy shortage in the country, and emphasize the need for sustainable energy generation and distribution.

Samantha (2015), who evaluates the evolving challenges of electrification infrastructure in the rural hinterlands of India, reveals the significant variations in the per-capita consumption of energy in the urban and rural regions of the country. According to the study, per-capita electricity consumption is just 8 kWh in the rural regions of the country, while it is 24 kWh in the urban areas. The study also reports that electricity is mainly used in the agriculture sector in rural India, and that this has resulted in several challenges such as excessive subsidies, demand–supply mismatch, and non-payment of electricity dues by consumers in the rural areas. Gaona et al. (2015) discuss a case study on the significance of microgrid technologies for rural electrification in Colombia, and analyse the possibilities and opportunities of using microgrid technologies in the isolated parts of the country

According to Heynen et al. (2019), the challenges associated with rural electrification in India can be overcome through the implementation of off-grid systems like microgrids using renewable energy resources like solar PV technology and wind energy. The methodology used in the study and other relevant information are available online. Analysing past data on electrification in the rural regions of Maharashtra and Odisha, the study recommends the involvement of the private sector in developing microgrid energy systems using renewable resources (Samanta, 2015a). The study identifies the limitations of using grid extensions for rural electrification and underlines the poor supply of electricity in the remote regions of Maharashtra and Odisha.

Azurza et al. (2012) examine the electrification procedures in rural areas based on renewable resources. When it comes to electricity, urban industrial needs are different from rural needs. There is a need to rethink electrification strategies considering economic, social, and environmental aspects, suggests the study. Microgrids linked with renewed distributed generation will be of great benefit to rural, remote, or sparsely populated areas. The study also discusses the environmental rewards of using renewable energy resources and offers a comparative characterization of rural and urban loads, extended microgrid topologies, and compares available storage techniques. The main steps in designing a new microgrid are also reviewed. The rural electrification process has different load patterns compared to urban loads. Daily and yearly variations are also considered. The rural patterns are smoother. The use of fossil fuels will have severe environmental impacts, warns the study.

Sen et al. (2015) present a case study on complete rural electrification using solar DC microgrids. Grid extension in rural and remote regions is a complex and difficult process. In such cases, mini grids can be used to power local businesses and small households. Under the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) and the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY), India should expand its course of rural electrification using DC microgrids. The previous research shows that DC microgrids are useful in rural regions where grid expansion is not otherwise possible for the next 5–10 years.

Balijepalli et al. (2010) assess the challenges of deploying microgrids in India. Microgrids could offer the long-term solution for energy needs. The earlier study focuses on the encountered and anticipated issues; it also recommends the use of technologies and economics for the deployment of microgrids in India. The current issues, feasible solutions, and conceptualization of efficient and smart microgrids are also analysed. Deferred network expansion, improved voltage profiles, and reduced losses are some of the key advantages of microgrids. This prospective approach integrates various generation technologies into known electricity distribution networks. Thus, microgrids make it evident that the interconnection of various systems has larger benefits. The development and utilization of safe and dependable communication infrastructure and control strategies are the key considerations for the success of microgrids. The smart grid technology will play a vital role in the success of microgrids.

Prasad et al. (2012) talk about the development of a new, smart distributed DC microgrid suitable for high penetration. It is stated to utilize energy from distributed renewable generators. The applications of solar energy and microgrid energy architecture are also assessed. The study focuses on solar energy. An excess of 15% energy can be saved by using the proposed DC power distribution system, whereas inverters cannot save energy. The paper proposes a solar tracking system which will improve the power collection efficiency of a solar panel by 30%. The hybrid DC microgrid is expected to reach new heights in terms of generation, distribution, and use of power. Residential and commercial establishments, as well as sustainable communities, will greatly benefit from this system.

Buragohain (2012) discusses how solar energy impacts rural development in India. Around 25,000 villages are located in remote isolated areas, and hence, the electrification of these regions is not viable through conventional electricity grids. Besides, extension of the electricity grid is not feasible in remote areas. This has led the Ministry of New and Renewable Energy (MNRE) to implement the "Remote Village Electrification Programme" (RVEP) that is aimed at electrifying rural and remote villages in India. The main objective to install home lighting systems in all the Indian states where solar PV technology is used. Moreover, the National Council of Applied Economic Research (NCAER) conducted an evaluative study in some states (Assam, Meghalaya, Jharkhand, Odisha, Madhya Pradesh, and Chhattisgarh). The study reveals that the functioning of the installed systems varies from geographically and seasonally. Moreover, the performance of the systems may decline over years of operation. The research identifies significant improvements in the education of rural children, people's standard of living, etc. The study also gives the insight that the installation of solar systems and microgrids led to a decline in the crime rate.

A report by Indian Merchants' Chamber (2017) examines the use of renewable energy in the rural parts of India. The report states that there is scope for the use of renewable energy resources in the rural regions. This is because renewable energy is clean and affordable for the poor and can be used to meet the basic needs of cooking, lighting, and heating. If these resources are not considered, complete rural electrification will remain a dream.

Mainali (2014b) examines the sustainability of rural energy in developing nations. The study looks at the key issues in the global discussion about sustainable energy access. The various sustainability assessment methods have been designed for rural regions in developing nations and are crucial to the assessment of performance of energy technologies in the rural regions. The methods also track the progress of sustainable energy access efforts among rural households.

Raman et al. (2012) study the opportunities and challenges associated with the installation of solar photovoltaic-based microgrids for rural electrification in India. Rural electrification is important for the development of the nation's economy, which is linked with the improvement in the quality of life. Electrification also leads to improved productivity and education of children.

Though rural, agriculture-dependent areas are considered the backbone of the country's economy, people tend to migrate to urban locations. Rural electrification will decelerate such migration. Around 70% of the Indian population resides in rural areas, which further highlights the need for rural electrification.

Transmission of electricity and the extension of electricity grids to distant areas away from the power generation units have prevented the government from achieving 100% electrification in India. Hilly and remote areas are isolated from the electricity grid, and nearly 18,000 villages lack access to electricity.

Since the cost of electrification in these remote areas is high, microgrid PV systems provide a viable alternative. Microgrid systems are beneficial as they cause no pollution or noise, consume no fuel, lead to low transmission and distribution losses, and have long durability. The production of electrical energy from PV systems helps check the emission of 0.7 kg of $Co2$.

Even the scarcity of land for the installation of solar panels could be overcome using rooftop PV systems. In Kerala, for example, hilly terrain is a reason for the shortage of land, and 31% of the state's population resides in hilly areas. The study concludes that the main hindrances to the implementation of solar PV systems are the high cost and low efficiency. Although the costs of solar PVs have decreased, for a developing country like India, such costs are still very steep. The study recommends R&D to improve the technology.

The above literature review shows that there is an increasing understanding among the developed and developing economies around the world to make a progressive shift towards cleaner energy technologies. Past studies advocate the importance of making a transition towards renewable energy resources, primarily focusing on the increasing carbon emission due to the over-reliance on non-renewable energy resources. The majority of these studies emphasize that developing economies should focus on renewable energy resources to mitigate the effects of environmental pollution caused by the burning of fossil fuels. However, the potential socio-economic benefits coming from the utilization of microgrid systems for rural electrification have remained largely unstudied, particularly in the Indian context.

Research gaps

- These researchers show how the socio-economic indicators such as HDI, GDP, and migration ratio can be evaluated from the perspective of renewable energy-based development.
- There is no outlook on the use of renewable energy for the electrification of hilly regions in India, nor is there any special focus on the evaluation of renewable energy-based rural electrification potential and the related development index for North Bengal and its rural hilly areas.

2.3 LITERATURE REVIEW THEME 3

Patterns of Family Behaviour in Consumption Decisions for Solar Energy-based Equipment and Microgrid Systems in Rural Hilly Terrain of Developing Countries

Solar-based systems are an economically viable alternative for the rural electrification of hilly terrain areas of developing countries, since extending the central grid in such terrain can be quite a cost-intensive and challenging process. This is more so when the homesteads are scattered and the households' electricity demand is low. Hence, the use of renewable sources like solar home systems is the ideal and cost-effective method of electrification. In this section, a detailed literature review of past research studies is presented to help us understand the important factors that determine the behavioural pattern of families in deciding specific solar energy-based equipment and microgrid systems for the electrification needs in the rural hilly regions of the developing countries across the world.

Kabi, Kim & Szulejko (2017) conducted a study to understand the social impact when solar home systems were implemented in the rural regions of Bangladesh. In this study, the questionnaire-based survey was the methodology used. The study was carried out in the rural regions of Bangladesh over a period of six months. The study reported that the comfort and living standards of the inhabitants of rural regions of the country improved significantly with the installation of solar energy-based equipment in their households. The findings of the study showed that the expenses associated with the solar home systems were the major constraint for the rural dwellers and the study recommended down-payment facilities and options like instalments for the purchase of solar energy equipment. These would attract more low-income groups to adopt solar house systems technologies, it observed. The study also pointed out the improvements required in the quality of solar energy-based types of equipment and in the after-sales service to attract the masses to the use of this technology.

Harrison and Adams (2017) carried out a study to understand the affordability of alternative sources of energy systems among the communities in the sub-Saharan African region, using direct survey and questionnaire methodologies. The study was conducted among respondents from African countries that included Kenya, Tanzania, Zambia, Malawi, and Senegal. The study reported that the price of the solar energy-based equipment and the affordability level of the individual families determined the purchasing behaviour of the community in deploying solar house systems for electrification. The study also identified that the availability of financial schemes also exerted a major influence on decisions to buy solar energy-based equipment. The researchers found that dissemination of awareness and proper education with respect to solar power-based energy technologies is considerably low among the population in the interior areas of the sub-Saharan African regions. The study also revealed that the direct marketing strategies adopted by the manufacturers and marketers of the solar energy-based lighting products had exerted a good influence on the purchasing decisions of the rural households for solar products.

Opiyo (2017) conducted a study to evaluate the cost-effectiveness of solar PV-based systems in the electrification of rural areas of sub-Sahara regions and provided insights into consumer preferences for the energy sources. The survey-based study was conducted to understand the reasons for energy choices made in the sub-Saharan Africa community. The findings of the study revealed that most of the population belonging to the sub-Saharan African community had the lowest preference for the national grid because of factors like high-priced connection payments, the unreliable nature of the system, and the corrupt practices by the authorities. The study revealed that solar home systems were utilized only by the rich families of the community and the electrification in most of the community was primarily through PV-based communal grids.

Dharmala (2015) conducted a study to evaluate the various options available for rural electrification in India by evaluating the feasibility of utilizing the polygeneration systems involving local renewable sources for energy generation to match the demand for electricity. By comparing the various renewable sources available in the study area, the findings showed that solar PV and biogas technologies are the preferred resources of energy generation in the village where the study was conducted. A field study and a socio-economic survey were the research methodologies used in this study; the findings revealed that the majority of the population in the village where the study was conducted was enthusiastic about the adoption of solar energy and biomass-based types of equipment for basic lighting and heating purposes. This was because it would improve their children’s education and give them an opportunity to earn additional income.

Khan and Azad (2014) conducted a research study to evaluate the socio-economic impact of the solar home system in the rural regions of Bangladesh. The research study deployed both quantitative and qualitative methods. By conducting individual household surveys and by interviewing shopkeepers in the rural region of Dhaka, the study found that solar house systems played a significant role in the community’s social development, particularly in the sectors of education, household jobs, occupation, and health. The participants in the study revealed that solar energy-based equipment was primarily used by the high-income group families; also, the solar house systems were the most preferred system of electrification implemented in the community in comparison with the other energy source alternatives.

Tong et al. (2015) conducted a two-year study to assess the factors that potentially influenced the adaption of solar-powered lanterns by the population in a village in Kenya. The study identified that the rural community in Kenya prefer kerosene as the fuel of choice for lighting and other purposes, primarily because of its easy availability and lower cost. The study reported that the families in the Kenyan village adopted solar-powered lanterns instead of solar house systems for the purpose of electrification on account of the cost-effectiveness of the solar-powered lanterns and their ease of availability. The findings of the study also revealed that the solar-powered lanterns address the specific lighting needs of the household and are quite affordable to a majority of the families in the upper- and lower-income groups of the Kenyan village.

In order to examine the factors that affect the behaviour of homemakers towards the consumption of solar energy-based equipment, the research by Beatty and Talpade (1994) is considered, wherein the impact of parental employment status on the influence of teens as well as differences in the gender-based perceptions were examined. The motivational aspects that include the use and importance were found to have been the strongest providers of consistent explanations which teenagers perceived across purchase situations. Furthermore, the status of parents also exerted a strong influence on the purchasing behaviour of the family.

A review of the grid-connected versus standalone energy systems for decentralized power was conducted by Kaundinya et al. (2009). Several articles were reviewed and different features of various technological alternatives—which are evident for decentralized power—were examined, wherein the technological, economic, and environmental feasibilities were studied for both standalone and grid-connected systems. These are the decentralized power options presented in the review.

From the literature review above, it can be understood that the cost of the initial investment in establishing solar energy-based equipment is the primary factor that acts as a major barrier towards establishing solar PV systems in the rural electrification process. The electricity generated from solar energy resources are the most expensive, as the upfront investment costs of the solar PV systems are very high compared to the other renewable resources-based electricity generated. Solar home systems come with high maintenance requirements, and solar energy-based equipment requires proper maintenance and regular service by the vendor. Since the maintenance and service costs are quite high, these may not be affordable for the low-income families located in the hilly regions of developing countries. Low-quality components are another major limitation of solar energy-based equipment. These have an impact on the functioning of the system as well as the longevity of the equipment. When components are not locally available, it becomes a major factor influencing the household to opt for solar house systems for their electrification needs. The awareness of the solar-based energy products and the easy availability of the financial schemes—along with the direct marketing strategies adopted by the marketers of the solar products—can exert a significant influence on the purchasing decision of the individual households to buy solar power-based energy equipment such as pico-solar lanterns and solar house systems.

The majority of the research studies that were conducted to understand the decision-making of the rural households in opting for solar-based equipment for their lighting and heating needs discussed the important factors, such as family health, education, and opportunities for additional income and family productivity. However, there are no specific studies demonstrating how these factors exerted a significant influence on the family behavioural pattern to indicate their preferences for solar energy-based equipment and microgrids, particularly in the Indian context. The intended use of electricity is another basic factor that determines familial decision-making in adopting electrification technologies through solar power-based energy equipment and the adoption of microgrid technologies. The purchasing behavioural style and attitudes of the rural household vary from country to country, based on income opportunities, education, and level of awareness vis-à-vis the alternative energy products and technologies among the inhabitants of the rural community.

Research Gaps

- No specific study has demonstrated how these factors exerted a significant influence on the family behavioural pattern to indicate their preference for solar energy-based equipment and microgrids, particularly in the Indian context.

- The rural inhabitants of hilly terrain areas may not have sufficient familial income or may not require electrification from expensive sources.

2.4 LITERATURE REVIEW THEME 4

Study of the Evolution of Rural Electrification and its Related Framework in Different Countries through Solar Power-based Renewable Energy Equipment and Microgrid Systems

Various researches have been conducted to study the evolving nature of rural electrification around the world. These mostly relate to the utilization of advancements in energy generation technologies using renewable sources, particularly solar energy. This section presents the literature review of recent researches into the solar power-based energy equipment and microgrid systems adopted in different countries.

Bhattacharya and Palin (2016) conducted a research study to evaluate the possibilities of enhancing the accessibility to electricity by deploying micro-grid energy technologies in the developing countries of the South Asian region. The study was based on the multi-disciplinary review of the mini- and microgrid electrification measures prevalent in the less developed South Asian nations viz. India, Bangladesh, Nepal, and Sri Lanka. The report indicated that most of the unelectrified global population live in South Asian and African regions, and that electrification measures in these regions cannot be achieved merely through grid extension. The study recommended integrating renewable energy-based technologies with microgrid technologies to achieve the target rate of electrification in these developing countries.

Urpelainen (2014) conducted a research study to understand the importance of integrating grid extension and the mini- and microgrid technologies to electrify the rural communities of India. The study revealed that the national grid alone is not sufficient to provide reliable electricity that can match the electricity needs of the country’s rural regions. Hence, the study recommended that solar power based on renewable energy systems be deployed to electrify these regions. The study also indicated the necessity of taking into consideration the socioeconomic costs involved in the deployment of off-grid energy technologies in the remote and poverty-stricken rural regions of the country.

IRENA (2016a) presented an energy report related to the electrification of both urban and rural regions of India. It reported that the increasing urbanization of the country has led to an exponential increase in the energy demand for industrialization purposes. The report indicated that the country's reliance on fossil fuels for energy production has significantly caused environmental pollution in all regions where industrial activities are highly concentrated. The report also indicated that in order to move the country to an environmentally friendly energy system, the Government of India (GOI) has adopted various initiatives and strategies for increasing renewable energy generation. With accelerating urbanization in India, the demand for electrification is continuously increasing in its urban regions, but it is important for the country to achieve 100 per cent electrification in the rural regions to speed up socio-economic progress.

Grimm et al. (2016) conducted a research study to evaluate the usefulness of solar energy-based pico-photovoltaic kits as the low-cost alternative for cost-intensive grid extension to electrify the rural communities of Rwanda. The randomized controlled study revealed that the low-cost solar kits are the first step in the energy ladder in the rural electrification process of the country, reporting a significant positive influence that these low-cost solar kits made in the overall domestic productivity, education, and public health of the community. The study also indicated that affordability would be a principal barrier for the adoption of the solar energy-based energy equipment. It recommended that the authorities should adopt strategies like subsidies and financial support to promote the low-cost kits among the poorest sections of the community in Rwanda.

Harrison et al. (2017) reported that after the use of pico-solar light, the children in an African community were able to extend their studies well into the night, thereby generating significant positive effects in the academic performance of the community's children. The study compared the UN modern energy benchmark and reported that the low-cost pico-PV equipment would not be sufficient to achieve the UN-recommended standards. The study found that the rural population in many developing countries do not prefer solar power-based energy technologies as the initial investments involved in establishing the infrastructure are high.

Hazelton et al. (2014) reported that the deployment of microgrid systems causes significant improvements in the livelihood of not only the individual family but in those of the members of the entire community. The researchers studied the prospective benefits of using PV microgrid systems for electrifying rural areas as well as the various challenges and risks connected to the deployment of microgrids for electrifying the rural community. The study reported compatibility issues of the solar power-based energy technologies and community integration challenges as the major impediments in the deployment of photovoltaic mini-grids for rural electrification.

Litzow et al. (2017) conducted a detailed study of the electrification programmes adopted in the rural regions of Bhutan to understand the influence of electrification measures in improving the social outcomes of the rural population like productivity, education, and public health. Quasi-experimental research methodologies and a sensitivity analysis were used to evaluate the influence of electrification measures on the quality of life of the population under study. The researchers conducted a cost-benefit analysis to study the investments by the Bhutan government for rural electrification and reported that the electrification measures are insufficient in bringing about a significant improvement in the major social outcomes.

Harrison and Adams (2017) conducted a research study using direct survey and questionnaire methodologies to assess the affordability of off-grid energy access in the rural regions of Africa. The report indicated that less than one-third of the population belonging to sub-Saharan Africa have to access electricity through grid-based energy technologies. The majority of the families in these regions prefer solar power-based energy technologies for lighting and heating in comparison with other alternative energy sources. This is primarily because solar energy-based lighting equipment can be used anywhere, unlike other renewable energy sources like biomass and wind power.

Murthy (2012) examined the integration of micro-grids with renewable energy in the Indian scenario. The previous research reviewed the Indian energy scene, wherein the challenges and solutions to these were attempted. On a conceptual basis, it was showed that micro-grids play a major role in the energy sector's evolution for the future, but the modes vary, as in the case of developed nations. Renewable energy is deemed to play an important role in India wherein the level of penetration will be about 20 per cent in both off grid and grid-fed modes. The previous paper presented the microgrid system with generalized renewable energy fed to provide access for reliable power supply. An India-centric approach is, therefore, necessary.

Longe et al. (2014) further examined the design for renewable energy sources in the rural regions of South Africa. The study showed that more than 1.4 billion people living in the world do not have access to electricity, with 85 per cent of these estimated dwellers in the rural region; most of such people live in sub-Saharan Africa. In South Africa, more than 50 per cent of rural dwellers lack access to electricity.

The Umhlabuyalingana local municipality is one of the five municipalities in the jurisdiction of Umkhanyakude district municipality, situated in the north-eastern part of KwaZulu-Natal province in South Africa. The Umhlabuyalingana local municipality is identified as the least electrified municipality in the entire nation, in which the rate of electrification is found to be around 20 per cent. The previous study considered this as the case region wherein the implementation of a Renewable Energy Sources (RES) micro-grid compared to grid extension was examined. HOMER software was deployed for the simulation, sensitivity analyses, and optimization.

The study identified that photovoltaic (PV) systems with better integration is an optimal solution and a microgrid combination for the proposed microgrid, which might yield \$0.378/kWh cost of electricity, 0 kg/person CO_2 emission, and 100 per cent renewable penetration when compared to \$0.328/kWh cost of grid electricity, 8.9 kg/person CO_2 emission from grid extension, and 0 per cent renewable penetration from the national grid. It was further revealed that the microgrid had a standalone breakeven electric distance limit of 34 km less than the 150 km transmission powerline required for

Umhlabuyalingana. The design for the microgrid was proposed as a better solution to ensuring electricity access in non-electrified areas of Umhlabuyalingana local municipality compared to grid extension.

The costs of deployment, maintenance, operation, and the economic policies that enhance the installation of solar energy systems have been discussed by Devabhaktuni et al. (2013). The demand for energy all over the world has grown beyond the limits of what can be installed. It is desirable to improve energy security and reliability; alternative energy sources need to be investigated as well.

Among the renewable sources of energy, solar energy is the most promising option since it is extensively available. In terms of cost, solar energy attains more competitive levels compared to other energy sources. It may be able to sustain the lives of millions of underprivileged people in the developing countries. The economies and environments of developing countries will also benefit from solar energy systems. Many international, governmental, and non-governmental organizations have made considerable improvements, including the funding and development of projects of renewable energy systems, for developed and developing countries. These changes make more places, which were earlier uninhabitable, liveable. An increase in the installation of solar PV systems will benefit ecosystems, developing societies, and the solar energy market.

From this literature review, it can be understood that most of the research studies conducted on rural electrification in the past concentrated on the off-grid energy generation technologies for the socioeconomic development of the whole region. No major study has been conducted yet on the evolution of microgrid technologies and solar energy-based energy equipment, particularly in the hilly terrain areas of an Indian rural region and on how these rural electrification technologies impact the quality of life of rural inhabitants of the hilly terrain areas of rural India. The process of establishing microgrids in the hilly regions is quite challenging when compared to establishing electrification infrastructure in the plains; this significantly increases the costs involved in the deployment of microgrid technologies in the hilly terrain. The increased costs of generating electricity increase the electricity charges for the consumers, which may not be affordable for inhabitants of the hilly regions of North Bengal. The conceptual framework and models from developed or open countries have to be validated in regulated markets, mostly controlled by the government; the evolution of these to become a fully developed efficient framework has not yet been tested for Indian rural conditions.

Research Gaps

- A comprehensive efficient framework for rural electrification for India could not be found during the secondary data research and studies
- A detailed strong framework for renewable energy equipment and microgrid system-based grid connected electrification is not available for the Indian subcontinent
- The implications of renewable energy equipment and microgrid system-based rural electrification framework in the rural hilly terrain of North Bengal have not been articulated in detail

2.5 LITERATURE REVIEW THEME 5

Policies of the Government of India/Ministry of Power (MOP) and Schemes for Rural Electrification, Energy Security, and Solar Microgrid Power Adaptation

India has been one of the largest markets for electricity in the world, in comparison with the power systems of the EU, China, Russia, and the US. The national grid in the country is one of the largest synchronous grids in the world. Over a span of time, the government has focused on catching up with the strong growth in the demand for electricity, with millions of additional consumers every year. The Indian system for electricity now seems to have surplus power and a strong adequacy ratio after years of scarcity. In particular, the renewable energy capacity and thermal power, including that from the private sector, account for almost 50 per cent of the total power capacity already installed.

The government has also been working to strengthen the financial health of the country's power sector. Reforms of distribution companies like DISCOM, which have long been overdue, finally seem to be taking proper shape. Further fostered by the Ujjwal DISCOM Assurance Yojana (UDAY), the scheme focuses on decreasing the debt ratio. Furthermore, for avoiding the continuous bailouts required from the Indian government by the DISCOMs, the GOI further announced a package with the intention of strengthening the UDAY scheme with the introduction of typical conditions for the government loans to the power sector by implementation of new policies. Currently, with the introduction of renewable energy in the sector, it has led to an era of dynamism. This has fuelled further efforts to reduce barriers in maintaining and investing the momentum for distribution in the energy sector, such as solar photovoltaics (PV) (IEA, 2020).

The electricity sector can broadly be divided into three major sub-sectors: transmission, generation, and distribution. First comes the generation of electricity, which includes the process of production of electric power by the use of various energy sources. The high-voltage power produced is further carried to the distribution sub-stations from the power generation plants through the transmission grids. In the third segment, the power is finally transferred from the sub-stations to each consumer through a web of distribution networks. Until 1975, all these segments were bundled along with the state-operated electricity departments and boards. In the early 1990s, the segment of power generation was opened up to the private sector. In the late 1990s, some states like Haryana and Orissa began the process of reconstruction of the electricity department by segregating the three segments. Furthermore, the regulatory commissions came to be established by 1998 for regulating the power tariffs at both the central and state levels.

A central law was created for regulating the electricity sector. This Act came to be known as The Electricity Act, 2003. This Act injected several changes into the sector, such as:

- Streamlining the state electrical energy boards,
- Giving additional powers regulators,
- Establishing an Appellate Tribunal,
- Providing for rivalry in distribution and transmission,
- Introducing authority trading as an approved activity, and
- Eliminating cross-subsidies in the sector (Draft Electricity Bill, 2018).

Furthermore, the Electricity (Amendment) Act, 2018 ('Draft Amendments'), which was proposed by the Ministry of Power for the purpose of amending the Electricity Act, 2003 ('the Act'), aimed to keep up with the pace of changes in the dynamics of the market, which can further enhance the capacity of renewable sources as well as challenge the provision of quality in the supply of electric power. Furthermore, this paper explains the vast changes that were introduced in the 2018 amendment, which acts as a torch-bearing Act for the power sector and has had a huge impact on the infrastructural changes. The Draft Amendments also require comments from stakeholders and the industry prior to being placed in Parliament.

The major changes in the Draft Amendments seem to propose the case of power cuts, the reasons of which can majorly be attributed to these, apart from the technical issue. The draft proposed the levy of suitable penalties on the companies involved in distribution and further propose to credit these into the account of particular consumers. The other major change that has been proposed would be the benefit of the reduction of tariffs, and once the assets have been completely depreciated, those would mandatorily be passed on to the consumers. Characteristically, these paybacks are kept back by the corporations involved in the generation, so that there is no reduction in overall tariffs. Hence, it would be fascinating to observe what advances the power industry make with reference to this projected alteration.

The Draft Amendment proposes 24x7 supply of electricity as an obligation over the DISCOMs, non-compliance of which could cause the State Electricity Regulatory Commission to impose penalties. The commission can not only penalize but can even revoke the licence(s) of the DISCOM(s), depending upon the severity of the offence.

The overall proposals by the Draft Amendments are as follows:

a) Time-bound lessening of CSS i.e., cross-subsidies, and
b) CSS at its maximum could be 20 per cent of wheeling costs.

These provisions are a part of the prevailing Act and include the provisions with respect to the reductions of CSS. However, as evident, these were watered down much later than these should have. Furthermore, the proposal that the CSS at its maximum could be 20 per cent of wheeling costs signifies that the implementation would drastically reduce CSS. Similarly, the provisions made for the 'additional surcharge' could be proposed to be deleted, as it would also have a major impact. In recent times, the states seem to use an additionally elevated surcharge as an instrument to dampen open access (Link Legal India Law Service, 2018).

Various researches have been conducted in relation to energy security and the implementation of solar and microgrid energy systems for pollution control and to fulfil energy demands. Past researches have also critically examined the major electrification Acts, policies, and regulations enacted by the Government of India at various periods. This section reviews some of the important researches conducted on these topics in recent years.

Heynen et al. (2019) conducted a research study to understand the progress made in the electrification activities of the government by investigating the policies and measures taken by the Government of India towards rural electrification. The study reported that the Saubhagya Scheme, launched by the Government of India in 2017, is an ambitious scheme to achieve universal household electrification by providing electricity access to 25 million rural families that have been denied electricity. Further, Samantha (2015) presented a research paper that studied the infrastructure established for the rural electrification of India. It outlined the major rural electrification schemes adopted by the government at various periods. The noted rural electrification schemes detailed in this paper include Pradhan Mantri Gramodaya Yojana (PMGY), Kutir Jyoti Program (KJP), Minimum Needs Programme (MNP), Accelerated Rural Electrification Programme (AREP), Rural Electricity Supply Technology Mission (REST), and Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY). Josey and Sreekumar (2015) investigated the progress made in the Indian power sector by investigating important policies and schemes initiated by the Ministry of Power. The report indicated that the main objectives of the past rural electrification schemes like the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) are to provide free accessibility to electricity to rural families below the poverty line (BPL); this scheme, between 2005 and 2014, provided free electricity connections to 2.16 crore BPL households. Again, Surdeo (2017) presented a research paper that reported the evolution of the power sector in

India to understand the major regulations in the rural electrification and the impacts of government-initiated reforms in the generation, transmission, and distribution of electricity. The paper indicated that significant progress was made in rural electrification after the Ministry of Power launched the Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY) in December 2014, the implementation of which is closely monitored through Gram Vidyut Abhiyantas (GVA).

Also, Veluchamy et al. (2018) presented a research paper that investigated the major policies and reforms carried out in the power distribution sector in India, including the important policies relating to rural electrification. Through a SWOT analysis, the paper presented the implications of the Energy Act of 2003 and the findings indicated that the irrational subsidies for agricultural use have increased the losses of state power utilities, thereby halting the progress made in achieving complete rural electrification. Furthermore, Nihalur (2018) conducted a research study to investigate the various reforms initiated by the Government of India in recent years and their effects on the progress in electrification made in the rural regions of the country.

The study reported that considerable progress has been made in village electrification after the implementation of the Saubhagya Universal Household Electrification scheme in 2017. Also, Princeton University (2014) presented a research paper that examined the contribution of the microgrid energy system for the fulfilment of energy demand in the rural electrification of India. The paper reported the various small-scale microgrid electricity projects that were successfully commissioned in the Indian rural regions, which includes the Gram Oorja solar-powered microgrid project, Mera Goa Power Project (using solar photovoltaic technology), and the Sagar Islands microgrid power project in the Sundarbans region.

Energy Forum (2017) presented a report on off-grid renewable energy-based electricity systems and the policies undertaken by the Government of India to provide clean energy access to rural households of the country. The report indicated that the Indian government, through its National Solar Mission policy, has set an ambitious target to provide 20 million solar lighting systems in rural communities across the country by 2022, to mitigate air pollution threats caused by the burning of kerosene and wood-based fuels. Garg et al. (2017) presented a policy brief on the prevailing power sector in India by investigating the energy security for the rural population including the Above Poverty Line (APL), Below Poverty line (BPL), and poor people living in the rural regions of the country. The report has recommended the kerosene subsidy reforms and stressed the necessity to encourage the use of solar lighting alternatives among the APL and BPL sections of rural India. Arunanchalam et al. (2015) presented the research paper that invested in energy security in India by analysing the key opportunities, pressing challenges, and the policy regulations of the Government of India. The paper has discussed important policies like the Integrated Energy Policy (IEP) and the Energy Conservation Act that were adopted to ensure energy security for the rural communities and recommended that the energy security problems can be mitigated by adopting a decentralized distribution–generation approach.

The above literature review indicates that considerable progress has been made in rural electrification in the last few years through the implementation of various power sector policies and schemes. However, the existing literature has not provided sufficient knowledge as to how much real progress have been made in the electrification of rural households in the hilly terrain of North Bengal through the policies and schemes introduced in the power sector and their influence on the energy security of APL, BPL, and poor families living in the region under study. The present study intends to cover the research gaps identified in the review of past researches conducted on this subject.

Research Gaps

- There is no strong evidence as regards the progress made in the electrification of rural households belonging to the hilly terrain areas of North Bengal.
- The existing literature has not provided sufficient knowledge on policies and schemes introduced in the power sector and their influence on the energy security of APL, BPL, and poor families living in the hilly terrain areas of North Bengal.

Below are the key gaps identified from the Literature review based on the five major themes of Literature Review:

Themes	Research Gaps
Theme 1 – The status and perspective of the world's smart Grid and Micro Grid systems for sustainable energy in socioeconomic development, which provide the direction of movement and key learnings	Benefits demonstrated for developed markets and favourable traditional geographies, but no major commentary/analysis provided on Indian hilly terrain in rural markets (especially in North Bengal)
Theme 2 – The variables/factors which affected the homemakers' relative influence on family decisions for socioeconomic development in the rural areas of developing countries	Although the consumer socialization theory recognizes that family behavioural aspects play an important role in family socialization of homemakers, its effect on the homemakers' relative influence is still indecisive
Theme 3 – The need to move towards renewable energy-based equipment and microgrid systems for ensuring better socio-economic conditions in rural India	Key socioeconomic development parameters perspectives like HDI, GDP contribution, migration ratio, etc. are not evaluated explicitly in the light of renewable energy-based rural electrification aspects for the rural hilly terrain of North Bengal, India
Theme 4 – Framework study for the evolution of rural electrification in developed countries through solar power-based renewable energy equipment and microgrid systems	The conceptual framework and models of evolution from a developed open market to a regulated market controlled by the government and from the latter to a fully developed efficient framework has not been tested for Indian rural conditions in any literature.
Theme 5 – The theoretical underpinnings of rural electrification through solar power-based renewable energy equipment as part of microgrid systems	Though theories of adoption and diffusion of technologies abound, there is a lack of guiding principles with regard to the adoption and diffusion of utility products like solar-based equipment as part of microgrid systems.

Also, below are the key variables, factors, and sub-variables identified through the Literature Review:

Figure 2.1: Highlights of the Key Variables Identified Initially

Based on a further detailed analysis and relevance study from the case studies and by charting out the established rural electrification frameworks from developed/developing nations, the following variables have been finalized from the perspective of the Literature Review:

Table 2.1: Key Variables Identified from Literature Review

SL NO	Universal Variables
1	To have affordably priced electricity services
2	Assuring equitable access to electricity services to citizens
3	Stable, predictable and transparent price policy
4	Promoting trade in electricity & related products and technologies
5	Encourage and enhance electricity trading within different states & utilities of India
6	Adaptation and investment in latest technologies
7	To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation
8	To have better tools to estimate the demand potential and capacity planning
9	To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors
10	Concessional State funding & Financial Incentives for Rural Electrification & Renewable Microgrids
11	Stable Fiscal Regimes in Governing Contracts
12	To maximize exploitation of locally abundant available renewable energy resources for each of the regions
13	Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players
14	Resource Sharing & Shared Services Approach
15	Reducing risk through JV/ PPP Model in Rural Electrification project development
16	To have a secured and uninterrupted supply of electricity

2.6 THEORETICAL UNDERPINNINGS

The underpinning theories—such as the Theory of Diffusion of Innovation, Theory of Adoption, Perceived Attributes Theory, and other relevant theories—identified through the literature review—will be examined in this section in relation to the identified themes. The figure below represents the Main Base Theory and Underpinning Theories.

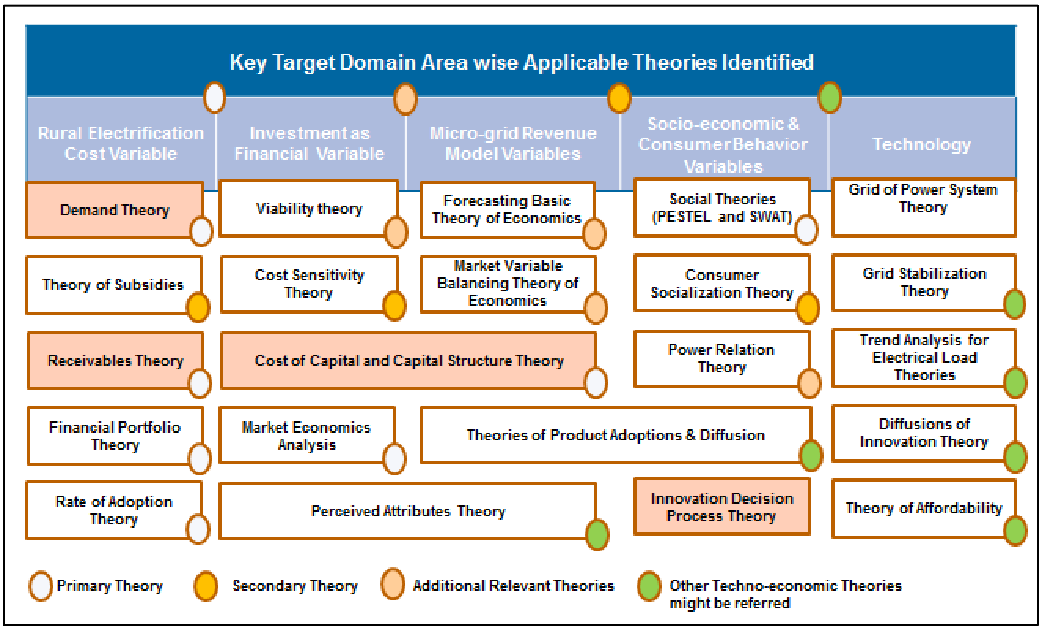


Figure 2.2: Highlights of the Main Base Theory and Underpinning Theories

2.6.1 DEMAND THEORY

Demand theory is a theory about the relationship between consumer demand for goods and services and their prices. Demand theory forms the basis for the demand curve, which relates consumer desire to the amount of goods available. There is an inverse relationship between the price of a good and the demand for it. Below are the depictions of the Law of Demand:

- As prices fall, we see an expansion of demand.
- If price rises, there will be a contraction of demand.

Ceteris Paribus Assumption: Many factors affect demand. When drawing a demand curve, economists assume that all factors are held constant except one—the price of the product itself. Ceteris paribus allows us to isolate the effect of one variable on another variable. The Demand Curve shows the relationship between the price of an item and the quantity demanded over a period of time. There are two reasons why more is demanded as price falls:

1. **The Income Effect:** There is an income effect when the price of a good falls because the consumer can maintain the same consumption for less expenditure. Provided that the good is a normal one, some of the resultant increase in real income is used to buy more of this product.
2. **The Substitution Effect:** There is a substitution effect when the price of a good falls because the product is now relatively cheaper than an alternative item and some consumers switch their spending from the alternative good or service.

From the review of literature in the Identified Theme 4, it is evident that no major study has been conducted on the evolution of microgrid technologies and solar energy-based energy equipment, particularly in the hilly terrain areas of Indian rural regions, and how these rural electrification technologies have impacted the quality of life of rural inhabitants living in the treacherous terrain of rural India. The lack of adequate cost-effective, high-quality electricity supply through the National Grid system has impacted the economic and social growth of the hilly rural terrain of North Bengal, which warrants local solutions in the form of renewable energy-based equipment as part of microgrid solutions for rural electrification. Establishing microgrids in the hilly regions is quite challenging compared to establishing electrification infrastructure in the plains, which significantly increases the costs involved in the deployment of microgrid technologies in the hilly terrain. The increased costs of generating electricity raise the electricity charges for the consumers, which may not be affordable for inhabitants of the hilly terrain of North Bengal. Hence, demand theory has been adopted to examine the relationship between consumer demand for goods and services and their prices.

2.6.2 PERCEIVED ATTRIBUTES THEORY

The Perceived Attributes Theory (Rogers 1995) says there are five attributes upon which an innovation is judged: that it can be tried out (trialability), that results can be observed (observability), that it has an advantage over other innovations or the present circumstance (relative advantage), that it is not overly complex to learn or use (complexity), and that it fits in or is compatible with the circumstances into which it will be adopted (compatibility) (Palit & Bandyopadhyay, 2017).

2.6.3 GRID STABILIZATION THEORY

According to the Grid Stabilization Theory, energy storage can be instrumental for emergency preparedness of an ecosystem because of its ability to provide backup power as well as grid stabilization services for any terrain, while it could also be proved effective for an isolated off-grid operational ecosystem as well.

2.6.4 CONSUMER SOCIALIZATION THEORY

The Consumer Socialization Theory by Beatty and Talpade (1994) recognizes that family behavioural aspects play an important role in the family socialization of homemakers, and the effect of this on the relative influence of homemakers is still indecisive. The Consumer Socialization Theory is also silent on the relative influence of the homemakers and household members in the family behavioural aspect on adapting solar energy-based equipment and microgrids as options for sustainable energy in development across rural areas. The Consumer Socialization Theory is silent on the homemakers' role in affecting the consumption decision-making areas for socio-economic conditions. From the review of literature in Identified Theme 3, it is evident that the rural inhabitants of the hilly terrain may not have sufficient familial income, or they may not require electrification from expensive sources. Hence, the Consumer Socialization Theory recognizes that family behavioural aspects play a key role in family socialization. It is also indecisive as regards homemakers' relative influence on family decisions apart from the behavioural aspects of family socialization.

2.6.5 THEORY OF PRODUCT ADOPTION AND DIFFUSION

From the review of literature in Identified Themes 1 and 2, no perspective could be obtained regarding the use of renewable energy-based electrification in the hilly regions of India and no special focus could be found on the evaluation of the potential of renewable energy-based rural electrification and related development index for North Bengal and its rural hilly areas. Also, the analysis of the perspective and fitment of renewable energy-based electrification for the rural hilly terrain of North Bengal are not articulated in detail. The Theory of Product Adoption and Diffusion has a key role to play in the purview of the socioeconomic preferences to accept the renewable solar energy-based infrastructure and related products from the consumers' perspective. The adoption theory has a simple objective: To observe new product adoptions and new product diffusion in the market to understand how and why as well as to what extent a new product is adopted by individuals or organizations. It can also be called the Theory of Product Adoption (Rogers 1976).

According to the adoption theory, a new product that is being launched in the market should have previous empirical data pointing towards the possible success of a product. The market test is a possible tool for testing the Adoption Theory from the perspective of the current renewable energy-based rural electrification framework evolution initiative. Below are the key assumptions of the Adoption Theory:

i. The Adoption Theory assumes that multiple factors influence the customer's decision.
ii. These factors might include the consumers' knowledge and awareness of the product, his/her acceptance of innovation as well as his/her experience of buying such products.
iii. The researcher, therefore, gathers more information so that he/she can influence purchasers to buy the product and can thereby analyse the results of faster product penetration into the market.
iv. Overall, the diffusion of innovation is a part of the adoption theory, where the diffusion of a new and innovative product or even normal product is studied. It is observed that the products are always picked up first by innovators, then by the early adopters, the early majority, the late majority, and, finally, the laggards.

In order to study the rural electrification framework of the developed nations and to adopt it for Indian rural hilly terrain, as in the rural areas of North Bengal, the Theory of Adoption and Theory of Diffusion of Innovations will play a major role. The diffusion of innovations is a theory that seeks to explain how, why, and at what rate new ideas and technology spread.

Everett Rogers, a professor of Communication Studies, popularized the theory in his book *Diffusion of Innovations*. This book, first published in 1962, logged its fifth edition in 2003. According to Rogers, diffusion is the process by which an innovation is communicated over time among the participants in a social system. The origins of the Diffusion of Innovations Theory are varied. These span several disciplines.

According to Rogers, there are four main elements that impact the spread of a new idea: the innovation itself, communication channels, time, and a social system. This process relies much on human capital. The innovation must be widely adopted in order to be self-sustaining. Within the rate of adoption, at some point, an innovation reaches critical mass. The categories of adopters are innovators, early adopters, the early majority, the late majority, and laggards. Diffusion manifests itself in different ways. It is highly subject to the type of adopters and the innovation-decision process. The criterion for the categorization of the adopters is innovativeness, which is the degree to which an individual adopts a new idea. The Theory of Diffusion of Innovation would explore key areas like Relative Advantage, Compatibility, Complexity, Trialability and Observability, etc.

Overall, the diffusion of innovation is part of the Adoption Theory, which studies the diffusion of a new and innovative product, or even a normal product. It has been observed that the products are always picked up first by innovators, then by early adopters, the early majority, the late majority, and, finally, laggards. An overall study of these theories indicated that the research would also include the analysis of how the rural electrification framework and the related variables from the developed countries are being adopted by the households in Indian rural hilly terrain and the populations of these geographies. No such study has been found yet that is related to such objectives in India's rural hilly terrain, especially in North Bengal. The 'top-down' and 'bottom-up' models of adoption/diffusion provide a directional perspective on the process. Innovation typically involves broad aspects of curriculum and instruction and might encompass a wide range of technologies and practices. Micro-level theories focus on the individual adopters and a specific innovation or product rather than on large-scale change (V.H. Carr. Jr. 1996).

2.7 PREVIOUS STUDIES ON THEORETICAL UNDERPINNINGS AND DEVELOPMENT APPROACH OF AN EFFICIENT RURAL ELECTRIFICATION FRAMEWORK

Hirmer and Cruickshank (2014) presented a research paper on rural electrification with the aim to develop a theoretical framework by applying value-theory concepts in the process of the electrification of villages. The research paper indicated some of the important perceived values of rural electrification. These include the availability of electricity per family, electricity cost, savings, income, time savings, supply-level consistency, and the real intended utilization of the electricity. The researchers suggested that the application of value-theory concepts in rural electrification can provide a reliable tool to objectively evaluate the success of the energy generating systems deployed.

UN ESCAP (2014) presented a report on rural electrification by proposing a new conceptual framework to promote economic progress in the rural regions of the Asia-Pacific region. The new framework—the 5P model—provides a unique approach to electrification using renewable energy resources (including wind and solar energy) by involving the public and private sectors. The new framework has placed emphasis on developing the rural enterprises by nurturing small and big entrepreneurs' participation and initiatives with the important objective of accelerating rural electrification and achieving the socioeconomic development of the rural community. The development of the framework was based on the 300 households of Lao PDR, and provide a detailed calculation of the necessary investments required for the rural electrification project to exhibit the feasibility and viability of deploying similar projects to offer reliable and affordable electricity access to the rural communities of the Asia-Pacific region (UN ESCAP, 2014).

PWC (2016)—in its 'Electricity beyond the Grid' report—provides an approach that explores the opportunities available out of the larger centralized grid for the electrification of rural communities. The report provides insights into the various challenges of deploying grid infrastructure in challenging geographical locations like hilly terrain and the need for adopting an integrated approach involving various stakeholders for rural electrification. The report reiterated the significance of embracing off-grid solutions, which are at present not given much importance in the major national energy policies of developing countries, to accelerate the process of electrification in the remote communities of such countries. The important recommendations of the report include the creation of a conducive atmosphere to promote off-grid energy solutions in rural regions by establishing sufficient fund mechanisms for encouraging innovations and the development of off-grid energy technologies.

Rudnick et al. (2014) presented a report that detailed the global approaches followed in the rural electrification through the rural electrification energy policies adopted in three countries with different levels of socioeconomic growth—namely the United States, India, and Zambia. In the Indian context, the report indicated that the major challenges faced by the energy sector of the country are primarily caused by the burgeoning population growth, the exponential growth of industrialization, and the imbalance in the demand and supply levels of electricity, specifically in the rural regions of the country. In the case of a sub-Saharan country—Zambia—the report indicated that the critical issues that hamper the progress of rural electrification in the country include insufficient funding and non-availability of sustainable renewable energy-based energy generation models.

To achieve economic growth that is consistent in both urban and regions of India, Kale (2014) recommended that the energy generation technologies based on solar and wind energy should be made accessible to the majority of the rural population living in the interior regions of the country. The report recommended that in order to mitigate the challenges encountered in the rural electrification of the country, the government should create a separate ministry for rural energy development and develop energy policies that focus on the effective engagement of all stakeholders of the rural communities, encouraging private sector participation.

The review of the literature described above in respect of the prevailing conceptual frameworks on rural electrification shows that the past researches in this subject focused mainly on the economic aspects of rural electrification.

However, these frameworks mention little of the important requirements of the rural communities involved. Besides, the theoretical approaches discussed above are generalized concepts, or are country-specific. While the application of value-theory based frameworks for rural electrification might be suitable for regions where there is a relatively high number of inhabitants, their expected value addition needs differ completely from those of the typical rural population living in the hilly regions of an Indian state.

Several previous researchers have examined the need for developing an efficient rural electrification framework in the rural regions of developing nations. In this respect, a research by Cook (2013) was examined, which revealed several implications that underlie the development of a better rural electrification framework. For the poor masses living in the rural regions of developing nations, only poor infrastructural development is delivered, which has various reasons.

Rural electrification schemes by governments of the developing nations do not provide access to poor people, especially those living in regions denied electricity access. According to Estache and Estache (2007), there are three aspects that need to be considered in this regard. Firstly, instruments are necessary for the provision of electricity-based services by service operators.

Secondly, there is a need for instruments developed by governments of developing nations to reduce the costs of connection, while the availability of land for setting up the renewable energy-based ecosystem needs to be evaluated in and around the target geography as well as government intervention would be required to make the necessary lands available for setting up such infrastructure. Also, critical natural and geographical factors like earthquakes and floods have to be considered while planning for such renewable energy infrastructure. The government has to take up appropriate preventive and corrective actions to protect such infrastructure, subject to detailed analysis of the geographical impacts as well as the impacts of possible natural calamities to set up such infrastructure (Benjamin McLellan, 2012). Also, the government should provide subsidies to the poor in respect of their payment plans (Wei et al. 2002).

Thirdly, there should be a range of suppliers who can provide users of electricity the choice of opting for the services that are low in cost. However, in the Asian context—as stated by Bhattacharyya (2007)—such reforms take place at a slow pace.

However, Numminen and Lund (2017) developed a framework for developing nations, wherein the name of the research title itself denotes proving innovative solutions to developing nations—'*Frugal energy innovations for developing countries—a framework*'. The concept identified by the previous researchers is for building a framework for alleviating global energy poverty in a sustainable manner. Numminen and Lund (2017) researched on the development of affordable energy products and services for people living in emerging nations wherein the framework developed was based mostly on the utilization of renewable energy resources. The previous study employed a two-stage-based analysis wherein the various technological innovations that are used by low-income consumers are examined.

It has been identified that low-income consumers utilize technologies like fuel-efficient biomass cooking stoves, small-scale PV systems, and pico-grids, as these technologies are highly affordable.

Considering the aforementioned criteria, as stated by Numminen and Lund (2017), it is important to examine researches that provide ample evidence for the design of sustainable Off-Grid Rural Electrification Projects. The World Bank (2008) revealed the principles and practices behind such projects. According to the report, the selection of an off-grid electrification system or an extension of the grid system is based on the distance from the grid. For rural and mountainous regions, microgrid and off-grid solutions are the most appropriate.

However, the decision to use individual systems and a mini-grid is associated with factors like resource availability, the income level of users, and the availability of equipment. The World Bank (2008) further revealed that the decision to use individual systems and a mini-grid is also associated with the load use. For a productive load, a mini-grid is used, whereas for household purposes, individual systems are suitable. However, the options specified are generally based on the combination of various technologies, such as renewable energy technologies, solar home systems, wind home systems, pico-hydro, and so on. Hence, there is a need to examine the feasibility and suitability of installing such systems.

2.8 KEY ENABLERS AND RELATED VARIABLES/FACTORS FOR SUSTAINABLE RURAL ELECTRIFICATION

Rural electrification and the related Governance Frameworks—as an effective means of improving living conditions—have attained prominence over the last two decades. This growth has been fuelled mainly by socioeconomic and political imperatives, aimed at improving rural livelihoods and technological innovation. The rural electrification framework puts in place a set of relevant policies and regulatory measures necessary for developing and implementing sustainable electrification systems in the rural regions. The policy framework details the financial and non-financial parameters associated with the projects, ways, and means of harnessing renewable and non-renewable resources available in the specific rural region and the various stakeholders involved in rural electrification. Different countries adopt various policies, project proposals, and regulations relevant to the specific rural region based on the needs of the intended beneficiaries and the overall objectives of the rural electrification schemes. A rural electrification framework that has been properly laid out provides a clear-cut structure of the important activities that need to be undertaken to maximize the efficiency and cost-effectiveness of the projects, thereby facilitating the overall socioeconomic development of the targeted rural community (UN ESCAP, 2014).

A study by Sinha and Kandpal [105] has compared the charges of supplying electricity by extending the grid system as against the cost of supplying power from sources that may be decentralized for rural India. This study also considers the cost for extension of the grid in terms of the investments as mentioned in Bernal-Agustin and Dufo-Lopez [9]. These investments tend to have performed the elevation of a grid-connected solar PV system in the Spanish case. The environmental and economic benefits that a PV system can provide are projected in the studies based on the payback period as well as the net present value of the project. The initial costs of a PV system—such as the cost of the inverter and the generator, installation charges and so on—are also considered in the paper, along with the subsidy that would be available to investors. The total cash flow generated by the project annually is currently estimated by considering both income and expenditure. Furthermore, income is generated by selling the power generated to the grid, or by reducing the purchased electricity through the auto-consumption of the generated electricity via the photovoltaic systems. As analysed by Chakraborty and Chakraborty [17] in a case of PV systems of solar energy for the Sagar Dweep island in India, the study took considerations of grid extensions and PV systems as alternative systems, which could be optional from environmental and economic perspectives. It shows the cost-effectiveness of the grid systems over long distances as against PV systems. Other studies have included the consideration for the optimization of plant sizes and the cost of biomass that would be used in Western Canada along with the optimal mix needed for generation of energy in Indian rural applications.

In contrast, Gulli (2006) seems to use the method of social-cost benefit analysis in order to carry out a comparison of small and centralized electricity generation and distribution (Bhattacharyya, 2012b). Moreover, the study places emphasis on four dimensions for ensuring the sustainability of rural electrification, namely economic, socio-cultural, environmental, and institutional.

Institutional Sustainability

Institutional sustainability tends to measure the effectiveness and extent of governance and the other institutions involved in enabling the systems for achieving the set goals in dimensions through the performance of functions related to the production, management, distribution, implementation, regulation, monitoring, and so on (Sharma & Balachandra, 2015). Institutional sustainability also demands a level of durability, service standards, and technicality along with the benefits of coherence provided by the laws (Ilskog & Kjellstrom, 2008) and regulations (Sharma & Balachandra, 2015). The failures noted in the electrification of rural areas have been attributed to the lack of legal systems in respect of the standards, laws, and regulations (Reddy, 2015), or possibly the typical absence of appropriate standards (García & Bartolomé, 2010). Furthermore, quite a number of studies seem to underscore the fact that sustainable institutions must contain the ability of adaption (Dunmade, 2002) to the population's future needs and demands (Retnanestri, 2007).

In his study, White (2013) discussed the consequences that may arise on account of the discontinuity of the policies by the use of a case study. Feed-in tariffs were introduced in Ontario, Canada, in 2009, which resulted in a humungous uptake of that programme. By 2010, the subsidies were drastically reduced, which further resulted in the RES community losing the assurance to facilitate the fact that the government would present unfailing support to the segment. Again, in Norway, a sizeable biodiesel plant was established by the Ministry of the Environment over a span of few weeks, prior to the government's announcement of the major changes in the bio-energy policies. The results seem to show unexpected negative impacts that the policy changes can have on the investments and their uncertainty. Moreover, the study also highlighted the essence of institutions required for rural electrification (Schillebeeckx et al., 2012; Chaurey & Kandpal, 2010).

Economic Sustainability

Economic sustainability holds the key to the present and dynamic strength of the economic structure and the national electricity systems, which are calculated via the thematic construct of supply, security, production, and end use (Sharma & Balachandra, 2015). In the process of electrification, the solution of economic sustainability needs to ensure the affordability and funding of systems. These could include the operations, initial investments, and maintenance over the lifetime (Wimmler et al., 2015; Bhattacharyya, 2012a).

For the energy sector, there are other significant indicators that reflect the economic sustainability of electrification solutions. These are the cost-effectiveness and dependability of delivery (Sharma & Balachandra, 2015). Furthermore, as energy utilization is connected with earnings, pains arising from rural electrification can be predicted to contribute to the returns of its users (Cook, 2011).

Environmental Sustainability

This assesses the contributions an electrical system can make to environmental standards by the measurement of the impact on the atmosphere, water, land, and possible transitions (Sharma & Balachandra, 2015). Environmental sustainability along with electrification in villages in various countries is connected with various Sustainable Development Goals (SDGs) (Nations, U. 2016). This further requires an awareness on the part of civil society regarding environmental issues, as its support is essential for the enforcement of regulations (Demirtas, 2013).

Sociocultural Sustainability

This is related to the specific opportunities required for fulfilling the potential. Essentially, it constitutes the Sustainable Development Goals (SDGs). Although sustainability at the socio-cultural level has complexity in its dynamics among the individuals and the society as regards the diversity, quality of life, equity, social cohesion, etc., these are essential for good governance (Day et al., 2016). This kind of sustainability requires considerations of equity among different communities in an area. The electrification in rural areas and the decisions for it would depend on the need for access and the priorities over the provision of electricity to the households (Axelsson et al., 2013). Moreover, there would be need to pay attention to the accuracy of the technology applied in a specific condition, depending on the area of implementation (Hirmer & Cruickshank, 2014) along with the level of social acceptability that would imply a need for a participatory approach for the community.

2.9 SUMMARY OF LITERATURE REVIEW

Various studies were examined to assess the feasibility of solar energy systems connected to an isolated microgrid, which functions to electrify specific regions mentioned in the previous literature. Studies based on the international context of the utilization of microgrids were analysed and researchers' perceptions were acquired. Studies by (Domenech et al., 2014; Ranaboldo et al., 2014) examined the feasibility of rural electrification through the use of microgrids powered by renewable energy resources. The sources of power, as stated in the previous studies, were wind and solar energy combined.

Furthermore, the effectiveness of the implementation of microgrids in the rural areas of sub-Saharan Africa, South Asia, and Southeast Asia was assessed (Williams et al., 2015); the results of the study concluded that decentralized supply of power helped power rural homes in the selected areas of the study. Additional studies in the Indian context proved the feasibility of enabling microgrids in the rural areas of India (Balijepalli et al., 2010a; Prasad et al., 2012; Kumar Singh & Ravi Teja, 2015; Buragohain, 2012).

Although previous researches in the context of rural electrification have successfully revealed the potential of decentralization in power supply and the use of renewable energy sources (wind and solar energy) to power microgrids, previous literature lacks in the specifics of the feasibility of using only solar-based energy solution through microgrids. While many researchers have examined a combination of renewable energy resources to power the microgrid, lacunae exist in the knowledge of the utilization of solar energy systems as the only source to power microgrids. In addition, no prior research has proved the feasibility of implementing solar energy-based solutions as a power source to the microgrid in hilly regions of India, which are isolated from electricity access. The need for electricity is ever increasing. Although 100 per cent electrification of the nation is one of the key visions of the Union Government of India, many rural areas of India still have no access to electricity at present. Some villages are situated far from the regular electricity grid; certain hilly regions are difficult to be electrified. At such a juncture, the researcher considered the possible ways of electrifying the rural and hilly areas of India. Decentralized micro-electricity grids were found to be a viable option.

An efficient framework for rural electrification in the hilly terrain of North Bengal—which used the solar energy-based equipment as part of the microgrid system—was not found through the literature review and secondary data research. Also, since pollution is a burning issue, the use of renewable energy resources, especially the use of solar energy to power the decentralized microgrid is an environmentally friendly choice, considering the increasing focus on balancing climate conditions across the world.

The existing literature in the context of the study revealed the absence of a feasibility study on the electrification of rural hilly regions of North Bengal in India through solar energy equipment as part of microgrid systems. This statement discerns the presence of two gaps: Firstly, no study has been conducted to examine the feasibility of rural electrification in the hilly regions of North Bengal. Nor has any efficient framework for rural electrification been found for the rural hilly terrain of North Bengal. Secondly, though wind energy is considered a viable option to power microgrids in hilly regions, no study has been conducted till date to assess the potential of solar energy systems within the same scenario and neither any framework or detailed analysis is found for rural electrification through solar energy equipment as part of microgrid systems. It is especially missing for the rural hilly terrain of India's North Bengal.

In this respect, considering the aforementioned researches and reports on the development of a framework for rural electrification, it has been observed that a similar rural electrification framework for the hilly terrain of North Bengal in India is not available. Accordingly, such a framework can be conceptualized, when the relevant key variables and enablers for that framework through a quantitative study of the local population and the perceptions of experts in the Energy and Utilities (E&U) sector (pertaining to the geographical location of North Bengal) on that proposed framework are acquired. Also, the underpinning theories like the Theory of Diffusion of Innovation, Theory of Adoption, Consumer Socialization Theory, Perceived Attributes Theory and other relevant theories identified through the literature review will be examined in that context. The study of the overall stakeholders, their socio-economic and technical aspects, and the identified key variables to develop the proposed rural electrification framework along with the analysis of the results of these studies would play the role of an enabler for further enriching the underpinning theories like Demand Theory, Theory of Adoption and Diffusion, and Consumer Socialization Theory. Furthermore, the framework proposed below is validated from the perspective of the input variables (adopted through the literature review of the similar frameworks from other developed/developing countries), in the light of theories like the Consumer Socialization Theory in order to analyse the influence of households on consumption decision for the solar energy equipment-based microgrid solutions.

CHAPTER- 3

RESEARCH PROBLEM

This section will consider the research problem and related research questions to derive the final research objectives, based on the study of the secondary research documentation and the Literature Review. Some of the gaps have been identified through the process. However, because of time and financial constraints and on account of restricted access to the target scope areas, it was not possible to cover all the gaps identified in the Literature Review, in relation to the present scope of the study, the research problems, and the objectives.

According to the World Energy Outlook (2013) of the International Energy Agency (IEA), more than 1.2 million people worldwide did not have access to electricity. Almost all of them live in developing countries (1,257,000 out of 1,258,000). The IEA reports that just 65.1 per cent of rural areas in developing countries had access to electricity whereas the rural electrification rate of transition economies and OECD countries was 99.7 per cent (Maximo Torero, November 2014). While electricity by itself may not be able to create all the conditions for economic growth, it is obviously essential for basic human needs and economic activity (IEA, 2013). In theory, access to electricity can improve socioeconomic conditions in developing countries through its impact on the key components of poverty, namely health, education, income, and the environment (Kanagawa and Nakata, 2008). As far as the rural areas are concerned, Khandker, Barnes and Samad (2009) claim that the lack of access to energy—more precisely, to electricity—is one of the major hurdles to economic development. Chaurey, Ranganathan and Mohanty (2004) argue for a strong correlation between rural poverty and access to electricity; this is because power is a prerequisite for productive activities. In addition to improving productivity by giving access to more efficient means of production, access to an electrical grid and better power services could also lead to household time savings and allow them to work more hours by increasing their access to markets (Bernard and Torero, 2011).

In the three aspects of generation, transmission, and distribution, West Bengal has an efficient public governing system. It is endowed with rich mineral resources which includes coal. Coal is expected to dominate the Indian electricity generation sector for a long time in the future as well. According to the Load-Generation Balance Report by the Central Electricity Authority, West Bengal will face an energy shortage of only 1 per cent (PWC, 2014). Though North-eastern India and West Bengal have surplus power, they are not able to meet their domestic requirements on account of the inadequate grid supply provisions. It is said that West Bengal provides unrestricted supply of power to its consumers; however, there is a relatively low percentage of households in the region that have access to electricity (Forum of Regulators, 2014). In the eastern region of India, West Bengal has an installed capacity (in MW) of a total of 10,063.84 MW (Thermal—8683.83; Hydro—1248.30; RES—131.7;) and has the highest installed capacity in the entire eastern India (Central Electricity Authority, 2016). In this context, it is evident that revenue maximization, increasing sales and profitability for power supply, and supply of sustainable energy through the available renewable sources are some of the important business challenges. Having affordable power with a high degree of sustainability to enhance lifestyles and higher education, generating employment, and new sources of income are the key issues in the area of demand. Revenue deficit, low profitability, poor energy supply operations in the rural areas, etc. are the major problems faced by the energy suppliers. Renewable energy sources like solar power are underused because of the inadequate grid infrastructure in the rural and hilly areas of the state.

On the other hand, electrical power supply is also highly essential for socioeconomic development since it is a major infrastructure. Regional disparity is a ubiquitous feature of developing countries like India. According to the Economic Survey 2000–01 of the Ministry of Finance, New Delhi, Government of India (2001), the eastern state of West Bengal remained one of the top states of India in respect of Net State Domestic Product (NSDP).

However, the rural hilly terrain of North Bengal has not seen significant socioeconomic development over the past few decades. Instead, there are major problems like the lack of development in the terrain, the poor financial conditions, a backward lifestyle, and emigration of the inhabitants (Sharma, 2014).

Although research has shown that access to electricity can have positive impacts upon rural economic development, solar home lighting kits alone are not enough to bridge the poverty gap. The Indian government has seen community microgrid installations as a way to accelerate economic activity; it strongly encourages microgrid and mini-grid developers and local officials to consider using electricity to offer not only power, but also internet access, medical and educational services, potable water, and skills and training. Ministries and departments can accelerate economic activity linked to microgrids by establishing clear poverty reduction goals that create rural economic development through better access to healthcare, education, and jobs.

In this context, the lack of adequate cost-effective, high-quality electricity supply through the National Grid system affects the economic and social growth of the hilly rural terrain of North Bengal, which warrants local solutions in the forms of renewable energy-based equipment as part of microgrid solutions for rural electrification.

3.1 RESEARCH PROBLEM

The secondary documentation studies and literature review shows that an efficient framework for rural electrification through the solar energy equipment-based microgrid systems in the hilly terrain of North Bengal is largely not available. Therefore, the research aims to study the socioeconomic aspects of using solar energy-based electrification in the rural hilly terrain of Bengal through microgrids. Furthermore, the research would attempt to ***develop a comprehensive framework for rural electrification, primarily focusing on the hilly terrain of North Bengal, using renewable energy sources like solar energy equipment as part of microgrid systems*** in its combined form. This is based on the main base theories like the Theory of Product Adoptions and Diffusion, Consumer Socialization Theory, and Demand Theory.

The theory of Product Adoption and Diffusion or the Product Adoption Theory (Rogers 1976) has a key role to play in the purview of socioeconomic preferences to accept the framework for renewable solar energy-based infrastructure and related products from the consumers' perspective. The adoption theory has a simple objective: To observe new product adoptions and new product diffusion in the market to understand how and why as well as to the extent to which a new product or model is adopted by individuals or organizations.

The Consumer Socialization Theory by Beatty and Talpade (1994) recognizes that family behavioural aspects play an important role in the family socialization of homemakers; however, the effect of the same on homemakers' relative influence is still indecisive. From the review of literature, it is evident that rural inhabitants of the hilly areas may not have sufficient familial income or may not need/prefer electrification from costly power supply sources. This requires the investigation and study of aspects of techno-commercial feasibility of the solar microgrid-based rural electrification model.

3.2 RESEARCH QUESTIONS

1. What are the enablers for rural electrification through solar energy-based equipment as part of microgrid systems in the rural hilly terrain of India's North Bengal?
2. What are the key variables/factors influencing the decisions of households to adopt solar energy-based equipment and microgrid systems for rural electrification in the rural hilly terrain of North Bengal?
3. What would be a suitable framework for successful rural electrification through solar energy-based equipment as part of microgrid systems in the rural hilly terrain of India's North Bengal (based on learnings from developed countries)?

3.3 RESEARCH OBJECTIVES

- To identify the key enablers and related variables/factors for the electrification of the rural hilly terrain of India's North Bengal through solar energy-based equipment as part of microgrid systems

- To develop an efficient framework for sustainable rural electrification through solar energy-based equipment as part of microgrid systems in the rural hilly terrain of India's North Bengal.

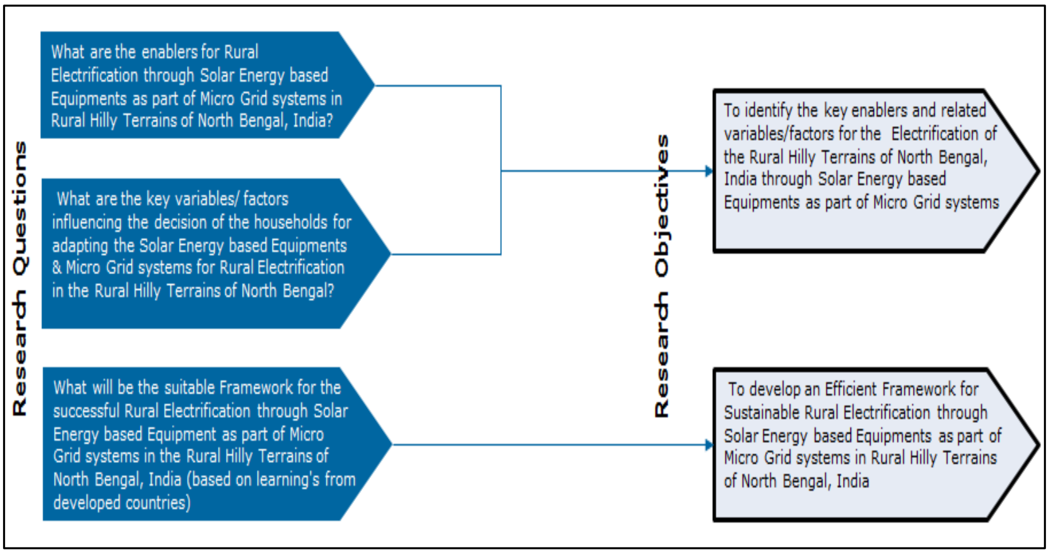


Figure 3.1: Diagram depicting how research objectives are derived from research questions

CHAPTER- 4
RESEARCH METHODOLOGY

4.1 THEORETICAL FRAMEWORK

An overview of the key variables and sub-variables identified through the secondary document study and literature review for the requirements of the current research work on a possible rural electrification framework through solar energy equipment as part of a microgrid system follows. With the aim of examining the socioeconomic feasibility and adoption of an efficient rural electrification framework (from the perspective of developed countries) in the implementation of a solar energy equipment-based microgrid, several previous researches were analysed. For instance, a study by Azurza et al. (2012) assessed the feasibility of rural electrification using renewable resources, which took into consideration the economic, social, and environmental aspects of such deployment. The study discerned that the generation of energy through renewable resources and their linkages with the decentralized microgrid is an ideal option to electrify rural and remote villages with sparse populations. The paper presented the different aspects of economic, social, and environmental feasibility. The economic advantage of using microgrids linked to renewable resources is the independency from fossil fuel use. However, the high installation costs and investment requirements act as a serious disadvantage. Similar to the study by Balijepalli et al. (2010a), the previous paper reports that such costs could be justified, given the ever-increasing costs of electricity generated in the common electricity grid, since the prices of fossil fuels are increasing every day. Economic analyses in this respect are essential, considering the lifespan of such systems, which could be conducted by analysing the costs of parameters in the future—such as the reliability of equipment, costs of fuel, and price of technology in the future. Environmental impacts are assessed using the Life Cycle Assessment (LCA). The social impacts of microgrid deployment have effects on the local labour management, increase in employment, local business profit generation, and so on.

Williams et al. (2015) further discerned the economic advantages of deploying microgrids in the rural areas of developing countries. The previous study identified microgrids as having the potential to mitigate losses incurred during the transmission/distribution of electricity, which is evident from the centralized electricity grid. The cost of delivering electricity across the regions covered by the centralized grids often exceeds that in decentralized solutions, which can be attributed to delivery and transmission losses. Since the demand for electricity in rural areas is lower than that in the urban regions, the losses incurred could not be justified. Decentralized solutions are identified as the viable option in electrifying rural and remote areas of developing countries. Yet another economic advantage in the implementation of microgrid solutions is that these decentralized grids can be integrated into the central grid upon expansion. Studies by Blum et al. (2013) and Szabo et al. (2011) also elucidated the cost-effectiveness of decentralized solutions, which are associated with the prevention of transmission/delivery losses.

A study by Sen et al. (2015) focused on the various socioeconomic and even technical aspects of a DC microgrid to check its viability. The study is aided by survey reports on it in various villages of India. The paper also tried to integrate the scheme introduced for rural electrification with a DC micro grid and attempted to analyse whether a DC microgrid is a sustainable option for rural electrification. The Rajiv Gandhi Grameen Vidyutikaran Yojana scheme (RGGVY), which is trying to implement the same thing, says that renewable microgrids can be implemented in a totally unelectrified village or villages having access to a weak grid where the power supply is unreliable and lasts less than six hours. The total energy required under this scheme for a rural household is 1 kWh/day. This includes the basic lighting provided to the house along with the livelihood activities. According to the new Remote Village Electrification Programme (RVEP) scheme drafted in March 2012 for rural electrification, every household is eligible for a maximum of 58 W connections (2 light points of 9 W each and 40 W socket). Though DC grids might be a solution to the RGGVY scheme of rural electrification, but on taking the RVEP scheme into consideration, the limited capacity of this DC microgrid raises a question as to its viability and sustainability. DC microgrids are very successful in hamlets where the number of households is very low and there is no chance of grid extension in the upcoming five to 10 years on account of its geographical location.

A study by Bhattacharyya (2012b) revealed that a large set of the rural electrification literature focuses on techno-economic factors, which are often technology- and country-specific. The purpose of this paper was to review alternative methodologies used for off-grid electrification projects to identify the features of each methodological approach and present their strengths and weaknesses. The paper reviewed a large volume of relevant literature covering techno-economic feasibility studies, analytical works highlighting methodological applications, and practice-oriented literature. The review identified five methodological options, namely the worksheet-based tools, optimization tools, multi-criteria decision-making (MCDM) tools, system-based participatory tools, and hybrid approaches. The paper recommended a hybrid approach that combines two or more options to take advantage of the strengths and weaknesses of different options. This was in line with the findings of Schillebeeckx et al. (2012); they carried out a large literature review and found that the majority of research within the field of rural electrification can be categorized under the following five headings: country-based approach; local potential; technology policy; institutional issues; and drivers of success. The latter was limited to a small number of case study sites. The study provided an overview of the technological, institutional, and viability lenses, and elaborated on the user-centric lens in greater detail. For energy policy and practice, the study combined the four lenses to develop a business model framework that policymakers, practitioners, and investors could use to assess RE projects or design future rural electrification strategies.

All the studies discussed in the context of the analysis of the socioeconomic feasibility of the implementation of solar-powered microgrids provide the basis for choosing the appropriate indicators of energy sustainability. The dimensions selected in this regard are: social, economic, legal and regulatory issues, and techno-commercial penetration, which impact prosumer behaviour. An analysis of these dimensions is considered necessary for analysing the future of the implementation of microgrids in the rural hilly terrain of India's West Bengal state. The figure below presents the theoretical framework for the study:

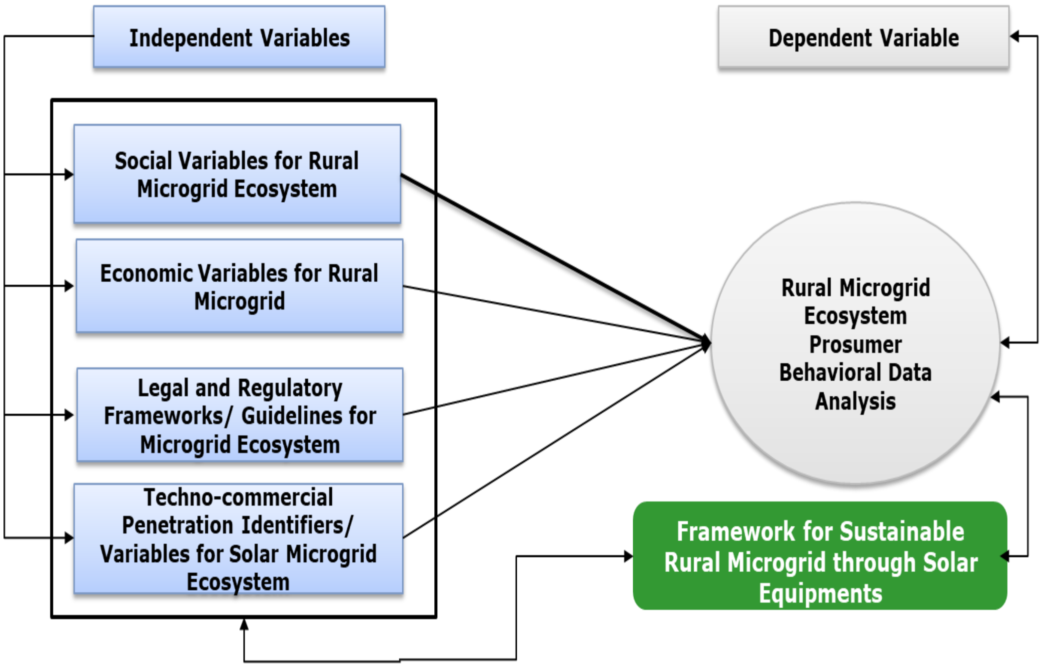
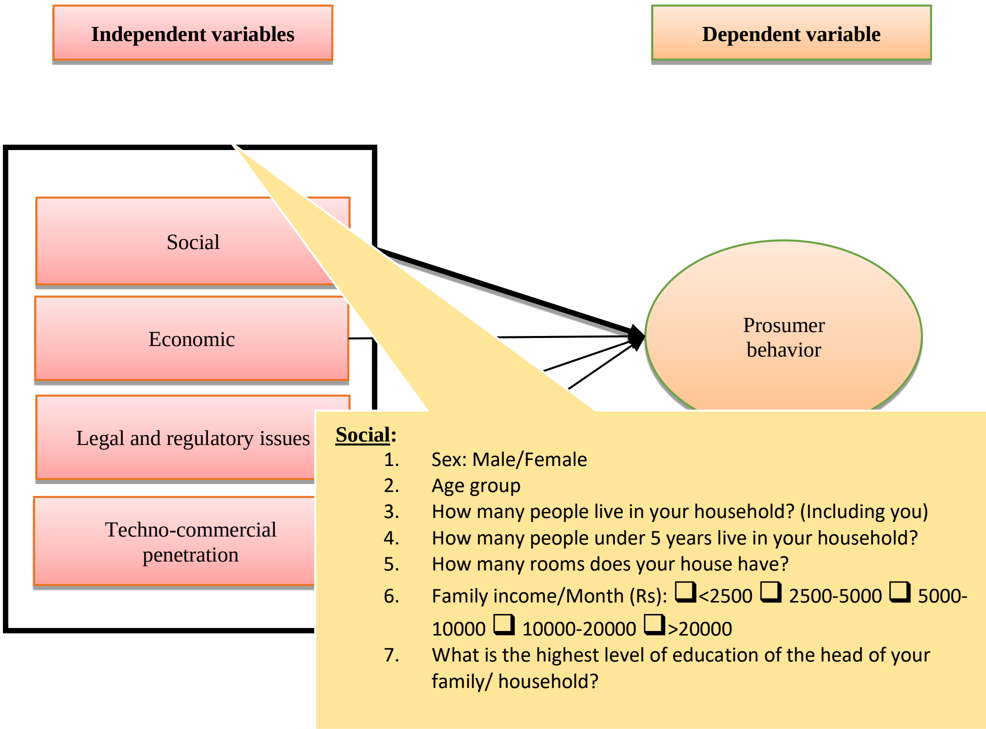
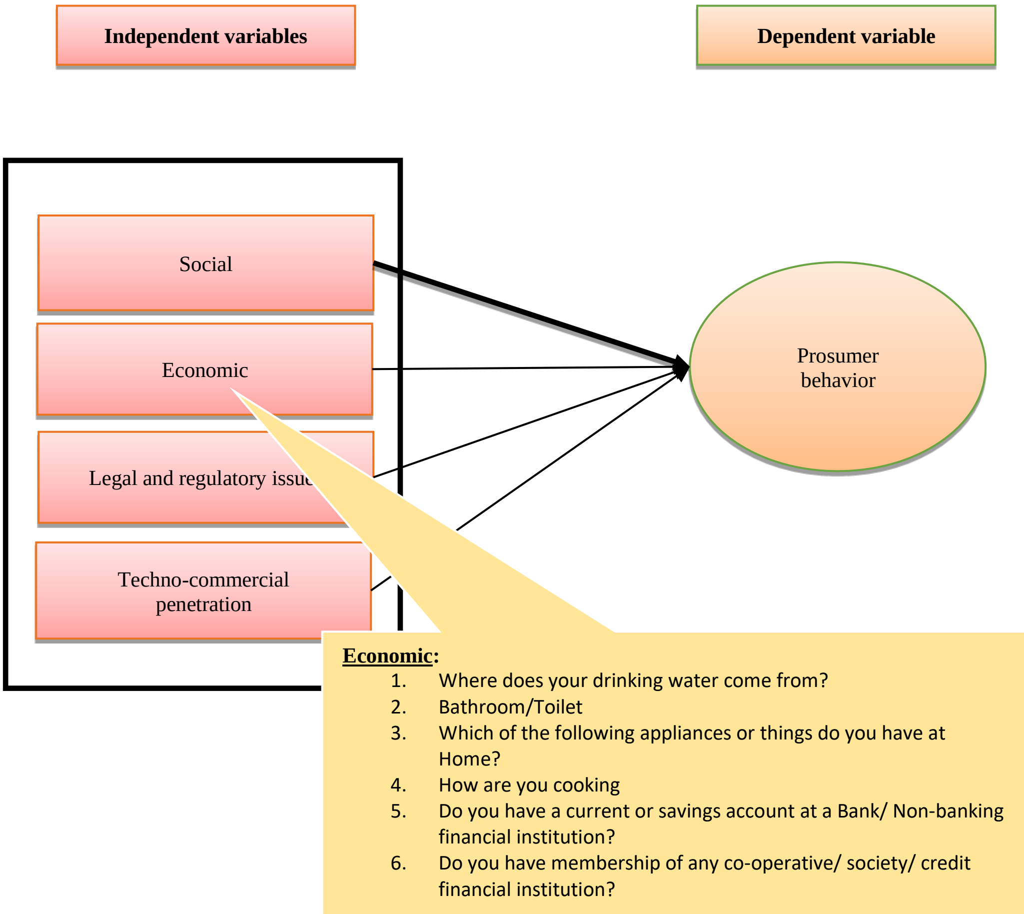


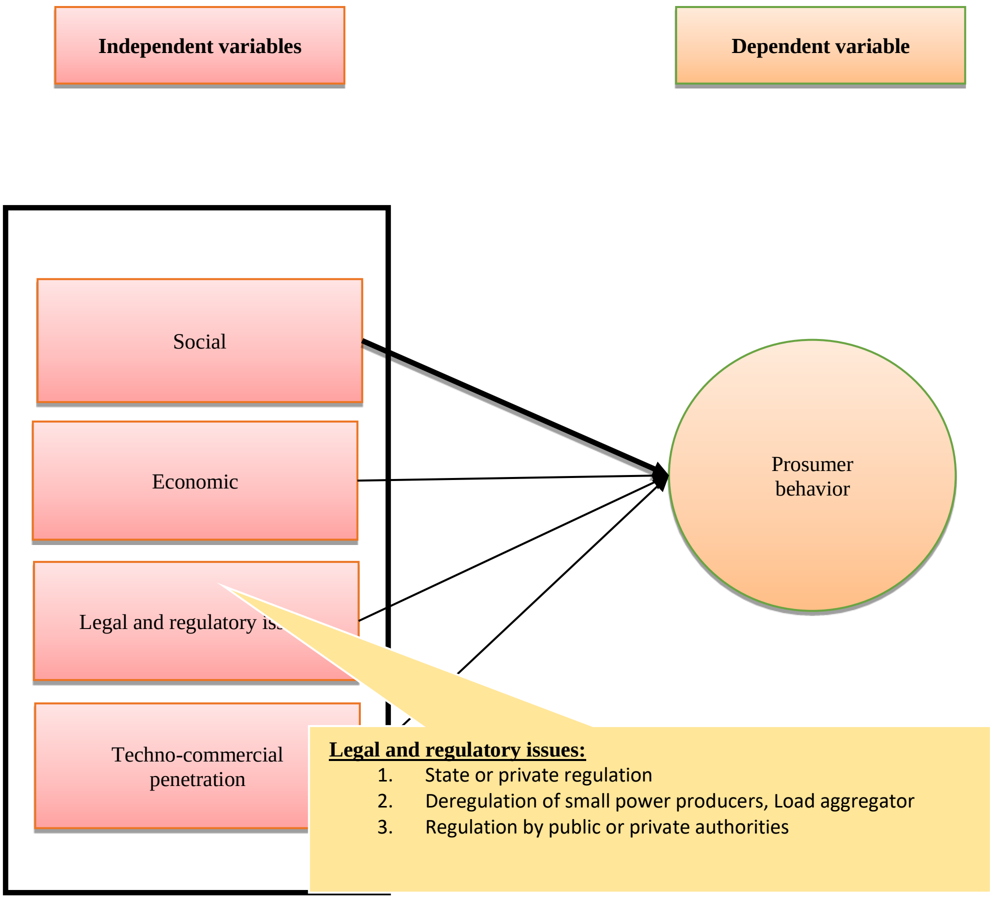
Figure 4.1: High level theoretical framework for the research work

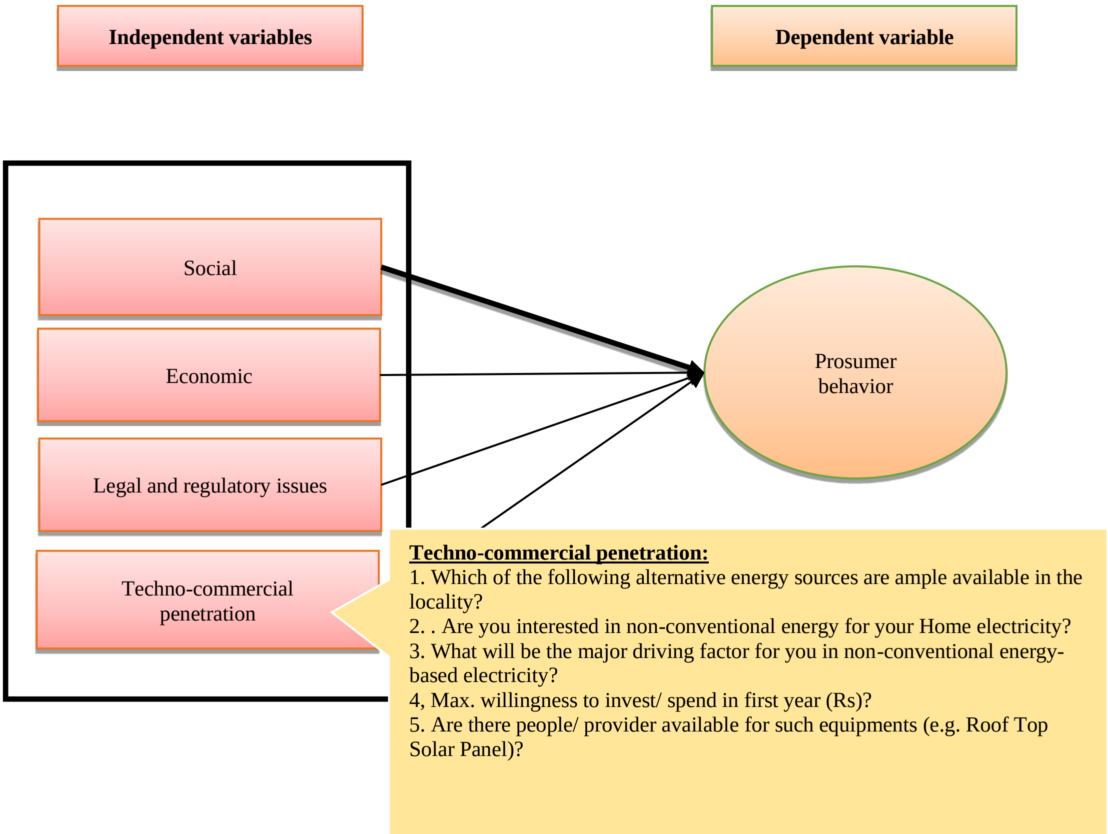
In order to elaborate how the independent and dependent variables will be analysed through a sample survey as well as how the correlation will be established, the diagrams below depict these for each of the key independent variables:

1. How many people live in your household?
2. What is the highest level of education in your household?
3. Do you have a current or savings account at a bank in the locality?
4. Is non-conventional energy a driving factor in non-conventional energy-based electricity?
5. Do you have access to affordable electricity?
6. Is there any electrification benefit for you, such as a rural electricity subsidy or as a government electrification scheme benefit, as a BPL family?
7. Are you willing to pay an amount for reliable electricity supply at your home?


Independent variables
Dependent variable
Social
Economic
Legal and regulatory issues
Techno-commercial penetration
Prosumer behavior
Social:
1. Sex: Male/Female
2. Age group
3. How many people live in your household? (Including you)
4. How many people under 5 years live in your household?
5. How many rooms does your house have?
6. Family income/Month (Rs): ❑<2500 ❑ 2500-5000 ❑ 5000-10000 ❑ 10000-20000 ❑>20000
7. What is the highest level of education of the head of your family/ household?


Independent variables
Dependent variable
Social
Economic
Legal and regulatory issu
Techno-commercial penetration
Prosumer behavior
Economic:
1. Where does your drinking water come from?
2. Bathroom/Toilet
3. Which of the following appliances or things do you have at Home?
4. How are you cooking
5. Do you have a current or savings account at a Bank/ Non-banking financial institution?
6. Do you have membership of any co-operative/ society/ credit financial institution?


Independent variables
Dependent variable
Social
Economic
Legal and regulatory
Techno-commercial penetration
Prosumer behavior
Legal and regulatory issues:
1. State or private regulation
2. Deregulation of small power producers, Load aggregator
3. Regulation by public or private authorities


Independent variables
Dependent variable
Social
Economic
Legal and regulatory issues
Techno-commercial penetration
Prosumer behavior
Techno-commercial penetration:
1. Which of the following alternative energy sources are ample available in the locality?
2. . Are you interested in non-conventional energy for your Home electricity?
3. What will be the major driving factor for you in non-conventional energy-based electricity?
4, Max. willingness to invest/ spend in first year (Rs)?
5. Are there people/ provider available for such equipments (e.g. Roof Top Solar Panel)?

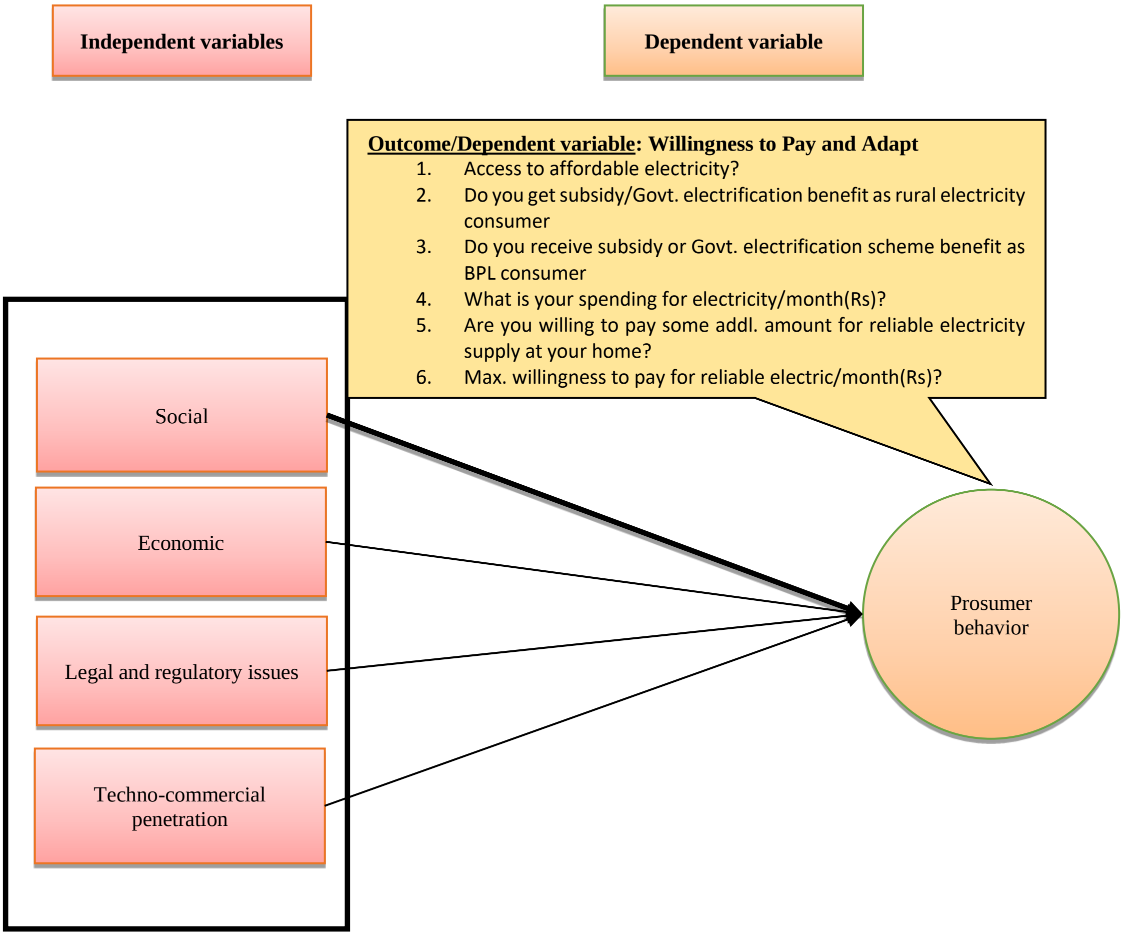


Figure 4.2: Theoretical Framework for the Study

4.2 RESEARCH DESIGN

A Research Design is defined as the process or plan of the research, which offers a strategic framework for collecting data for the study. Also, it acts as a link between the research questions and the execution of the research strategy. The Research Design also directs one to deliver outcomes that are refereed to be reliable (Schumacher, 2001). Research Designs are of different categories; they can be classified into two major categories viz. Exploratory and Conclusive research designs. Generally, exploratory researches are qualitative in nature and conclusive researches are quantitative in nature. Conclusive research can be further subdivided into descriptive and causal research (Seth Ginsburg, 2011).

Exploratory research—also known as qualitative research—has been adopted in researches in order to develop the researcher's initial thoughts and understanding, and to offer a way for further researches (Churchill & Iacobucci, 2005). This kind of study is required when there is a need for the researcher to recognize the problems, and when that problem needs to be defined accurately. Also, this type of study is unstructured and highly flexible (Aaker et. al. 2007). Furthermore, an exploratory study can be conducted with the help of a literature survey and ideas from peers. On the other hand, descriptive research is structured, and is of a fixed format. This is opposed to exploratory research (Churchill & Iacobucci, 2005). For the survey, if the study employs a longitudinal or cross-sectional design, this design type is suitable. Information collected from the sample population is only in a cross-sectional design at one point in time. However, in a longitudinal design, it is at different points of time (Kinnear & Taylor, 1996, Churchill & Iacobucci, 2005 & Seth Geinsburg, 2011). As this research aims to understand the experiences of the individuals and determine the relationship between the variables selected for the study, an explanatory sequential mixed methodology has been selected for the study.

The Research Design specifies the details of the procedures necessary for obtaining the information required to structure and/or solve a research problem (**Malhotra & Dash, 2011**). The research design must be chosen based on the philosophical assumptions (worldview) and the strategy of inquiry. This is influenced by the end objective that has to be accomplished and the research questions at hand. Softer issues like researchers' experience and the audience of the research report also often considered in the Research Design.

The philosophical assumptions/worldview can be of four types:

Postpositivism—works towards something more definitive, i.e., where the cause will lead to an outcome. In Postpositivism, data is also reduced into smaller sets of data or ideas. In this approach, the researcher starts with the concept and collects data which either disapproves of the concept or accepts the concept. Hence, with this approach, the researcher needs to apply quantitative techniques or methods.

Constructivism—also known as social constructivism. Social constructivism emphasizes the social contexts of learning, and that knowledge is mutually built and constructed. The researcher tries to convert their experiences into theory and concepts, which are very wide. The central idea of social constructivism is that human learning is constructed, and knowledge is constructed through social interaction and is a shared rather than an individual experience (**Vygotsky, 1978**). The idea is to capture all the varied and complex views to build in the theory rather than narrow the data, as was the case in Postpositivism. The view of the participant becomes more important in such study. This approach helps develop a theory or a concept.

Advocacy or Participatory—Everyday practices, which have long since established themselves as a subject of inquiry, introduce their own perspective, namely the way in which people deal with the existential challenges of everyday life. The participatory research processes enable researchers to step back cognitively from familiar routines, forms of interaction, and power relationships in order to fundamentally question and rethink established interpretations of situations and strategies. This philosophical view believes that Constructivism does not help address the issues of the lower end of the society. An advocacy/participatory worldview holds that research inquiry needs to be intertwined with politics and a political agenda. Hence, the research contains an action agenda for reform that may change the lives of the participants, the institutions in which individuals work or live, and the researcher's life. Moreover, specific issues need to be addressed that speak to important social issues of the day viz. empowerment, inequality, oppression, domination, suppression, and alienation. The researcher often begins with one of these issues as the focal point of the study. This research also assumes that the inquirer will proceed collaboratively so as not to further marginalize the participants as a result of the inquiry. In this sense, the participants may help design questions, collect data, analyse information, or reap the rewards of the research. Advocacy research provides a voice for these participants, raising their consciousness or advancing an agenda for change to improve their lives. It becomes a united voice for reform and change. This approach basically works better for qualitative research, but quantitative research can also be used here.

Pragmatism—Pragmatism research philosophy considers concepts to be relevant only if they support action. Pragmatists recognize that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture, and that there may be multiple realities (**Saunders, M., Lewis, P. & Thornhill, A., 2012**). Unlike in Postpositivism, where actions lead to results, the pragmatism worldview works based on certain actions and situations that exist. This uses all, or most, of the approaches that are available to understand the problem and seek solutions. As discussed, this approach takes up an issue, with the problem to solutions being associated with situations **(Pattan, M., 1990).**

There are many forms of this philosophy. However, for many, pragmatism as a worldview arises out of actions, situations, and consequences rather than antecedent conditions (as in Postpositivism). Instead of focusing on methods, researchers emphasize the research problem and use all approaches available to understand the problem (**Rossman, & Wilson, 1985).** Pragmatism is not committed to any single system of philosophy and reality. This applies to the mixed methods research, in which inquirers draw liberally from both quantitative and qualitative assumptions when they engage in their research.

The researcher not only selects a qualitative, quantitative, or mixed methods study to conduct his/her research, the inquirer also decides on a type of study within these three choices. Research Designs are types of inquiry within qualitative, quantitative, and mixed methods approaches that provide specific direction for procedures in a research design. Others have called them *strategies of inquiry* (**Denzin & Lincoln, 2011**). The designs available to the researcher have grown over the years as computer technology has advanced the methods of data analysis and the ability of humans to analyse complex models, and as individuals have articulated new procedures for conducting social science research. For the current research work, we have decided to adapt the mixed methods for the study, as described below:

Mixed methods entail combining or integrating qualitative and quantitative research and data in a research study. Qualitative data tend to be open-ended without predetermined responses while quantitative data usually include closed-ended responses, such as those found on questionnaires or in psychological instruments (**Creswell, John, W., 2014).**

The mixing of different methods originated in 1959, when Campbell and Fisk used multi-methods to study the validity of psychological traits. This prompted others to mix methods, and soon approaches associated with field methods, such as observations and interviews (qualitative data), were combined with traditional surveys (**Sieber, 1973**). Recognizing that all methods have limitations, researchers felt that biases inherent in any single method could neutralize or cancel the biases of other methods. Triangulation of data sources—a means for seeking convergence across qualitative and quantitative methods—was born (**Jick, 1979**). By the early 1990s, the idea of mixing moved from seeking convergence to actually integrating or connecting the quantitative and qualitative data. For example, the results from one method can help identify participants to study or raise questions to ask for the other method (**Tashakkori & Teddlie, 1998**). Alternatively, the qualitative and quantitative data can be merged into one large database, or the results can be used side by side to reinforce each other.

Three general strategies of mixed methods are described below:

1. **Sequential mixed methods** procedures are those in which the researcher seeks to elaborate on, or expand, the findings of one method with another method. This may entail beginning with a qualitative interview for exploratory purposes and following it up with a quantitative, survey method with a large sample, so that the researcher can generalize results to a population. Alternatively, the study may begin with a quantitative method in which a theory or concept is tested, followed by a qualitative method involving detailed exploration with a few cases or individuals.
2. **Concurrent mixed methods** procedures are those in which the researcher converges or merges quantitative and qualitative data in order to provide a comprehensive analysis of the research problem. In this design, the investigator collects both forms of data at the same time and then integrates the information in the interpretation of the overall results. Also, in this design, the researcher may embed one smaller form of data within another larger data collection in order to analyse different types of questions (the qualitative addresses the process while the quantitative one the outcomes).

3. **Transformative mixed methods** procedures are those in which the researcher uses a theoretical lens as an overarching perspective within a design that contains both quantitative and qualitative data. This lens provides a framework for topics of interest, methods for collecting data, and outcomes or changes anticipated by the study. Within this lens could be a data collection method that involves a sequential or a concurrent approach.

The research design flow has been identified below for the proposed study:

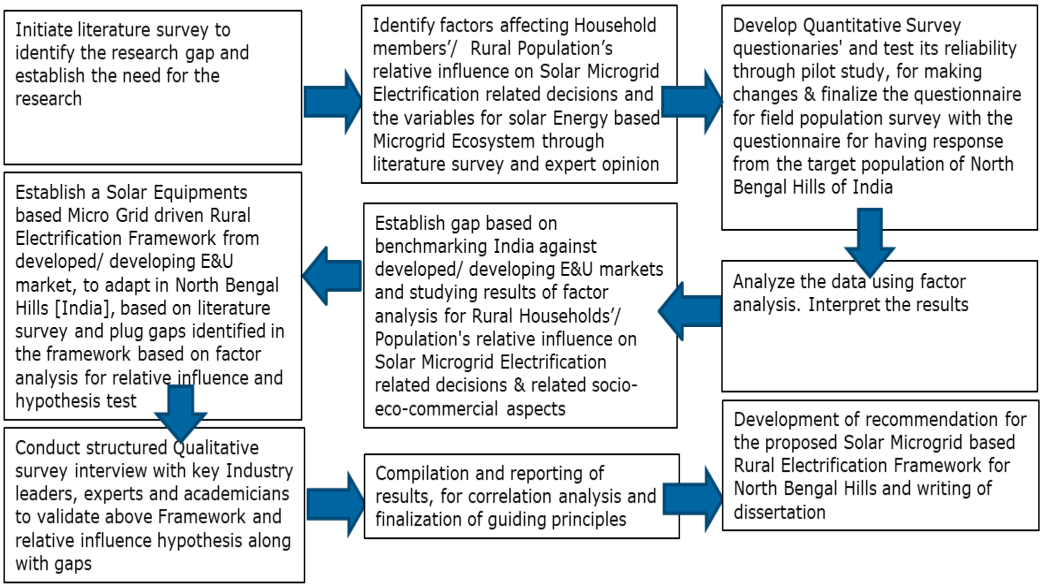


Figure 4.3: Research design flow overview

Based on the overall strategy that we have evaluated; we have decided to go in for the mixed methods to conduct the research with the flow delineated below:

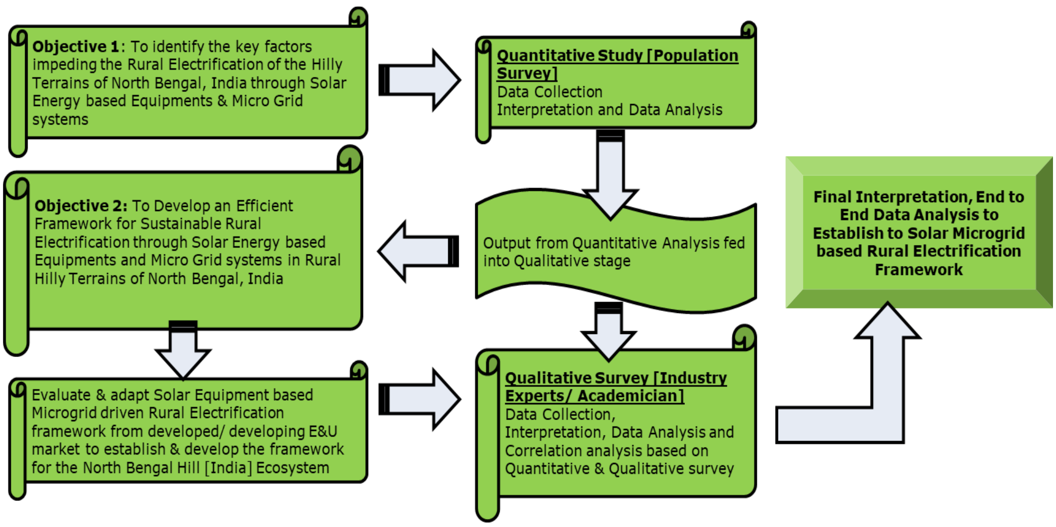


Figure 4.4: Research flow overview

Below are the key justifications for adopting this mixed methods-based research design:

- Developing a framework for solar equipment-based microgrid-driven rural electrification in the Indian situation [to be precise, in the hilly terrain of North Bengal] requires a global view [taking into account the developed/developing E&U market], which is a pragmatic stand, as it uses all possible approaches to explore and research the problem.
- An attempt to identify variables using only a qualitative method would have led to personal bias on account of the limited number of experts. Also, in using a single methodology, the conceptual lens would have to be developed only with the help of a literature survey and the personal experience of the researcher, resulting in the **possibility of bias.**
- Developing a framework for solar microgrid-based rural electrification in the Indian scenario requires ***studying emerging approaches*** **and *a textual analysis*** *using closed and open-ended questions with experts***.** This can be done only with qualitative methods like a framework analysis for first identifying a conceptual lens for developed/developing E&U markets and then using grounded theory for creating the framework for Indian conditions.

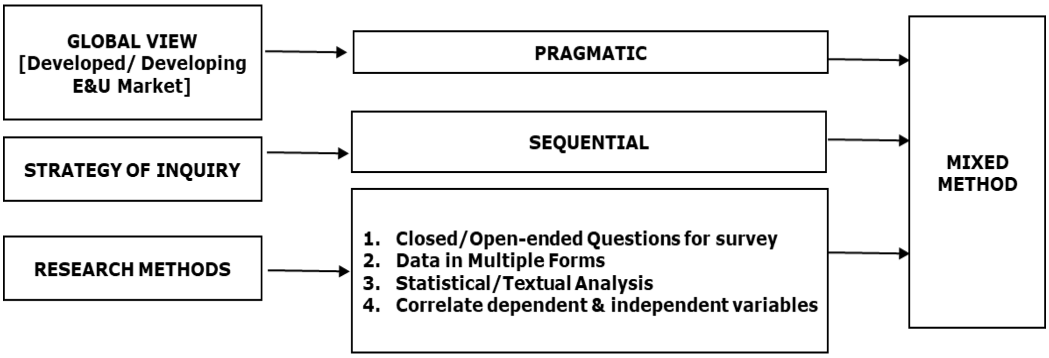


Figure 4.5: Derivation of mixed method approach for research flow

4.3 RESEARCH PHILOSOPHY

A research philosophy is defined as *a belief about the ways in which data about a phenomenon should be collected, analysed, and used*. Traditionally, there has been a significant debate on the choice between research philosophies of positivist or interpretivist approaches, and among the research methods of quantitative or qualitative analyses. Accordingly, ‘interpretive researchers assume that access to reality (given or socially constructed) is only through social constructions such as language, consciousness, shared meanings, and instruments. The development of the interpretivist philosophy is based on the critique of positivism in the social sciences. Accordingly, this philosophy emphasizes qualitative analysis over quantitative analysis. The interpretivist approach is based on a naturalistic approach of data collection like interviews and observations. Secondary data research is also popular with the philosophy of interpretivism. In this type of studies, meanings usually emerge towards the end of the research process.

Positivism depends on quantifiable observations that lead to statistical analysis. It has been noted that ‘as a philosophy, positivism is in accordance with the empiricist view that knowledge stems from human experience. It has an atomistic, ontological view of the world as comprising discrete, observable elements and events that interact in an observable, determined and regular manner’. Crowther and Lancaster (2008) argue that as a general rule, positivist studies usually adopt a deductive approach; in contrast, an inductive research approach is usually associated with a philosophy of phenomenology. Moreover, positivism relates to the viewpoint that the researcher needs to concentrate on facts, whereas phenomenology concentrates on the meaning and has a provision for human interest. According to the research philosophy of pragmatism, the research question is the most important determinant of the research philosophy. Pragmatics can combine both positivist and interpretivist positions within the scope of a single research in accordance with the nature of the research question. Hence, this research intends to adopt pragmatism as the study aims to focus on facts and also integrates human interest into a study.

4.4 RESEARCH APPROACH

Generally, there are three kinds of research approaches—namely inductive, deductive, and abductive (Kennedy, 2018), A deductive approach involves using existing theories to develop a hypothesis, which is usually tested by the subsequent collection of quantitative data (Wilson, (2010). In an inductive approach, in contrast, a phenomenon is first observed and then interpreted, and the empirical data collected is then used to develop theories (Feeney and Heit (2007). Again, the abductive approach involves a combination of developed theories and empirical findings, an approach that enables the researcher to understand and interpret both the existing theories and observations. The relevance of hypotheses to the study is the main point of distinction between the deductive and inductive approaches. The deductive approach tests the validity of assumptions (or theories/hypotheses) in hand whereas the inductive approach contributes to the emergence of new theories and generalizations. Abductive research, on the other hand, starts with 'surprising facts' or 'puzzles'; the research process is devoted to their explanation.

Abductive reasoning—also referred to as the abductive approach—is set to address weaknesses associated with the deductive and inductive approaches. Specifically, deductive reasoning has been criticized for the lack of clarity in terms of how to select the theory to be tested by formulating hypotheses. Inductive reasoning, on the other hand, has been criticized because 'no amount of empirical data will necessarily enable theory-building'. Abductive reasoning, as a third alternative, overcomes these weaknesses by adopting a pragmatist perspective. Since this research will adopt a mixed methodology, the abductive approach will be more suitable for the study.

4.5 RESEARCH METHOD

Kemper, Springfield and Teddlie (2003) define the mixed methods design as an approach that includes both qualitative and quantitative data collection and analysis on parallel lines (concurrent mixed methods design, in which two types of data are collected and analysed in sequential form). Bazely (2003) defines this method as the use of mixed data (numerical and text) and alternative tools (statistics and analysis) but applies the same method. It is a type of research in which a researcher uses the qualitative research paradigm for one phase of a study and a quantitative research paradigm for another phase of the study. The qualitative research provides insights and understanding of the problem setting while quantitative research seeks to quantify the data and typically applies some form of statistical analysis. Whenever a new research problem is addressed, quantitative research must be preceded by appropriate qualitative research. In this thesis, both these research methods have been employed in different degrees. 'To identify the key socioeconomic and techno-commercial factors impeding the rural electrification of the rural hilly terrain of North Bengal, India, through solar energy-based equipment and microgrid systems', this study attempts to conduct a quantitative survey method using a possible 7-point Likert scale for ranking the related variables. Following the quantitative survey, the present research will attempt to conduct qualitative interviews based on Objective 2, which states: 'To develop an efficient framework for sustainable rural electrification through solar energy-based equipment and microgrid systems for the rural hilly terrain of North Bengal, India'. These interviews have been conducted with experts in the E&U sector in North Bengal and all associated key stakeholder experts.

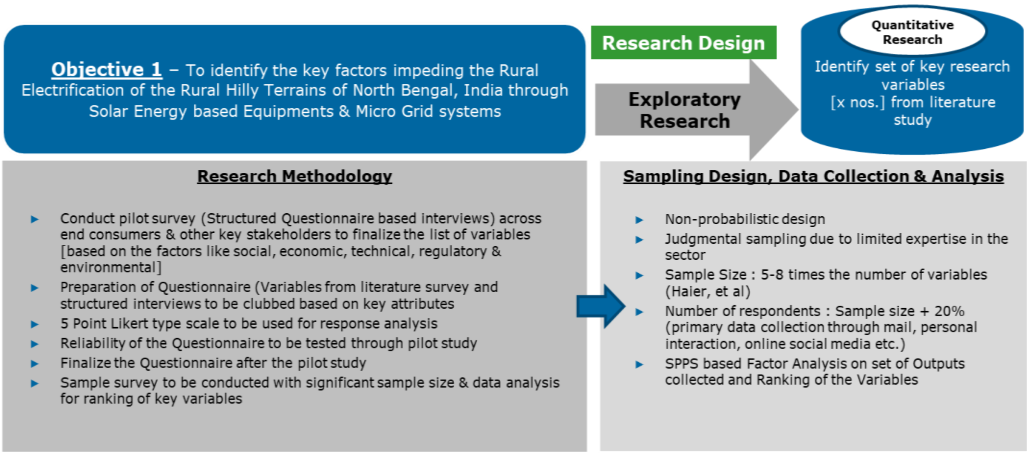


Figure 4.6: Summary of High-Level Research Methodology [Objective 1]

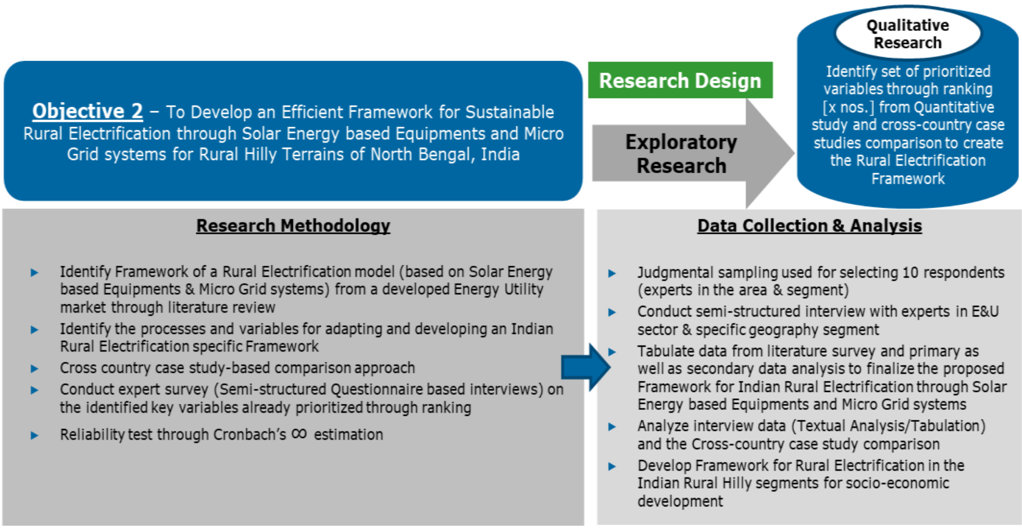


Figure 4.7: Summary of High-Level Research Methodology [Objective 2]

4.6 SAMPLING

Various sampling techniques, such as probability sampling or non-probability, are available to derive the number of participants which might reflect a true and unbiased representation of the entire population. Random sampling, a probability sampling technique, is a choice whereby the chance for selecting every unit is known (Tayie, 2005). Probability sampling technique is further classified into stratified sampling, clustered sampling systematic sampling, and simple random sampling. Similarly, in non-random sampling, a non-probability technique, there is no probability of determining the samples being selected; it is also difficult to inspect any sampling errors. This technique is also classified into judgmental sampling, quota sampling, convenience sampling, and snowball sampling.

The present study deploys the stratified random sampling technique, especially the multistage sampling method. This technique tries to confine the possible samples to those which are 'less extreme', thereby ensuring that all parts of the population are represented in the sample to enhance the efficiency. The error in the estimation is to be decreased. The population of N units is divided into disjoint groups of N1, N2,..Nh,..NL, respectively, in stratified sampling. These sub-groups or strata, as they are called when taken together, constitute the entire population where N1+N2+…NL=N. A sample of the predetermined size is drawn independently from each stratum. A stratified sample is formed by the collection of sample pieces from different strata. If a simple random sample selection technique is used in each stratum, the eventually formed sample is called a stratified random sample.

Reasons for Stratification

- Each subdivision is a stratum. The stratification is done to obtain precision for some subdivisions of the population. Each stratum is treated as a 'population' because sampling is done independently in each stratum. For instance, estimates will be required in terms of province, income group, occupation, and age group, among others, in household surveys. In business surveys, it is done by the Standard Industrial Classification (SIC).

- For the sake of administrative convenience, stratification can enable the survey organization to control the distribution of fieldwork among its regional offices.
- At times, different parts of a population may need different sampling procedures. In the context of human populations, people who live in institutions like hotels and hospitals are kept in a different stratum from people who live in ordinary houses. Separate sampling schemes will be required in the case of household surveys in rural and urban areas. The population density will differ in these two areas.
- Stratification may yield a gain in terms of the precision of the estimates which depends on the type of stratification. If a heterogeneous population can be divided into subpopulations (strata) using prior information about the population, each substratum may internally be homogeneous. If each homogeneous stratum is characteristic under consideration, a precise estimate with smaller variances can be derived from a small sample in that particular stratum. These estimates can be combined to get a precise estimate for the entire population.
- In the present study, three main household groups will be identified for sampling by stratifying the overall sample:
- Rural households with SHS (Group 1),
- Rural households without SHS in two villages with SHS dissemination (Group 2)
- Rural households without SHS in the villages without SHS dissemination (Group 3).

North Bengal hilly regions, especially the new Kalimpong district [erstwhile Kalimpong subdivision of Darjeeling district] and nearby localities of Darjeeling district which are adjacent to Jalpaiguri district, are not economically developed as they have the per capita GDP of approx. USD 1100–1200 [2017 census], which is even less than that of the state of West Bengal that has around USD 1500 (2017) per capita GDP [approx. 1700–1800 USD in 2018–19]. The region's slow economic growth could be dated back to the 1960s: the trading through Jelep La pass [as part of erstwhile Silk Route via Tibet] was permanently closed as a result of the Chinese annexation of Tibet [1959] and the subsequent Sino–Indian war [1962].

The district town of Kalimpong, along with the adjacent areas, recorded a population of 49,403 [circa 10,000 families, Census 2011] with the population density of 40.70/sq. km, while the overall district, covered mostly with Sino Himalayan Subtropical & Temperate Forests, recorded a population of approx. 1.32 lakh [Census 2011]. Lack of energy security and unavailability of uninterrupted quality electricity supply is one of the major factors that has slowed down the socio-economic growth of the overall region. The state of West Bengal has RE potential of more than circa 19 GWp out of which solar energy alone accounts for more than 16.8 GWp (88%), while North Bengal, together with Purulia, Bankura, and Midnapur districts, has been identified to have more than circa 80% solar power potential (Deloitte, 2017). As part of the overall MNRE target, West Bengal has aimed to achieve 8% of its overall electricity consumption from solar energy out of which Rooftop Solar PV schemes of North Bengal would play a significant role. In this study, 439 samples leverage local support and administrative patronage, while approx. 23% of the collected sample data could not be used due to ambiguity and an erroneous trend in the response data, hostile approach of the interviewed persons, and data quality and consistency issues. The remaining [approx. n1=337] samples with good-quality, consistent data were leveraged for tabulation, further tool-based data analysis, and deduction of inference-related activities.

The initial questionnaire for this sample survey was created based on the discussion and mutual agreement with the research supervisors and several industry experts. These were further fine-tuned and revised based on the initial sample survey results with approx. 20–25 interviews in order to prepare the final questionnaire with mostly close-ended questions with multiple response options and Likert scale-measuring options. Another set of qualitative survey questionnaires, comprising both close & open-ended questions, was created through multiple iterations with several subject matter experts, industry specialists, and research supervisors to run those questionnaires through around 20–25 relevant stakeholders and specialists [actual sample n2 = 21], which comprise policymakers, academicians, industry leaders, SMEs, etc. in order to pursue qualitative data analysis for the proposed microgrid framework for the target geography of the rural hilly regions of North Bengal.

4.7 DATA COLLECTION TOOLS

Data collection in the proposed study imparts the use of primary data. The proposed study will utilize a mixture of both qualitative and quantitative research methodologies. In the quantitative approach, the reactions of many respondents were collected and measured using statistical techniques. The sample size is selected using appropriate sampling techniques, and the statistically analysed data could even fit a large population with a certain limit of error. In contrast, qualitative approaches are used to identify the research context by understanding the results of the respondents. The responses of the respondents are captured in their own words and their experiences are collected in detail. While quantitative approaches are standardized with a relatively large sample size, qualitative approaches detail the information collected from a small number of people (Patton, 1990).

Secondary Data Collection Method: The data is based on available materials published in newspapers, all peer-reviewed refereed journals, journals with huge, internationally recognized databases for research such as EBSCO and Emerald, government universities, reputed organizations like CII, and industry magazines released by IHS, Ernst & Young, and PwC for discussion on energy security.

Data Analysis: The raw data collected was processed to obtain valuable and knowledgeable information using appropriate analytical techniques such as factor analysis. The SPSS software was used for the factor analysis.

In this study, primary data was collected using approaches such as questionnaires, household surveys, and interviews from an adequate sample of the overall population. The sample for the study was drawn based on the multistage drill down approach, where the target geography would be sequentially divided from the circle and division levels to reach up to the specific village-level population for drawing the final sample. The sample size was proposed to be a minimum of 5–8 times or may be 10 times of the identified related key variables from the secondary documentation research on the similar rural energy framework and other relevant perspectives. Qualitative interviews were conducted with the involvement of key stakeholders, including experts from the areas of rural electrification, solar PV areas, solar home systems (SHS), administrative-economic-financial-social sectors etc., wherein information was acquired regarding the experts' knowledge of the socio-economic impacts of solar electricity. In addition, household surveys and short individual interviews were conducted with shopkeepers and owners of small-scale businesses in selected North Bengal villages.

4.8 RESEARCH METHODOLOGIES ADAPTED FOR QUANTITATIVE & QUALITATIVE STUDIES

The technical feasibility evaluation was completed in two parts. First, general information on existing microgrids and microgrid technology was collected and evaluated. Second, a high-level design for a potential microgrid for the study area was developed. This conceptual design included inputs from industry experts, academicians, and key electric utility stakeholders in the state along with the knowledge of the study team.

A microgrid is a contained energy system capable of balancing captive supply and demand resources to maintain reliability. In fact, microgrids have the following key elements and features:

- Defined by function, not size
- Incorporates multiple distributed technologies
- Maximizes reliability and efficiency
- Can include other utilities—steam, hot water, chilled water, network connectivity
- Can function in 'islanded mode' disconnected from larger utility grid

By creating a conceptual design that the study team and outside experts believed could be constructed and would operate successfully, technical feasibility was confirmed with the understanding that an actual constructed system might differ to a certain extent from the details of the proposed framework model. Based on the research and literature review, the study team determined that a microgrid in the study area of North Bengal hilly regions would be feasible to construct and operate.

As per the latest tariff table of WBSEDCL, the state-owned power distribution agency of West Bengal, the minimum per unit electricity rate in North Bengal hilly regions would be circa INR 4.89/ KwH, whereas for a little bit higher quantum of monthly consumption the per unit rate would vary within a range of INR 7.33–8.92/ KwH. Accordingly, the traditional national grid-based power supply is not quite affordable for the majority of the poor rural population—this fact was reflected in our sample survey for the quantitative study. Moreover, the quality of power supply and reliability is also not adequate for the rural communities of North Bengal hills. As part of the ambitious RE policy of the Union Government of India, the recent expansion of solar power has been significant across the country, including the ultra-mega power plants (UMPP) in Solar PV as well as co-generation provisions. According to recent trends in large solar programme execution reverse auctions of the Solar Energy Corporation of India (SECI), the lowest quoted tariff by several players was in the range of INR 2.48–2.49/ KwH (circa. $0.0349/ KwH). Accordingly, it is evident that with significant government subsidies and capital investment for solar energy equipment set-ups as well as different incentives within UDAY schemes, solar energy/RE-based localized microgrid electrification would become more easily affordable, accessible, and commercially feasible for the rural population in North Bengal hilly regions—this could ensure both short-term and long-term socio-economic growth of the region. The table below shows the recent solar energy tariff trends in India:

SECI: 750 MW Solar Projects in Rajasthan — MERCOM india research

Auction Results for 750 MW Solar Projects, Rajasthan

Bidder/Developer	Capacity	Quoted Bids/Tariff		% Over Winning Bid
	MW	(₹/kWh)	($/kWh)	
Fortum Solar	250	2.48	0.0349	-
Palimarwar Solar House (LNB Group)	40	2.48	0.0349	0.00%
ACME Solar	250	2.48	0.0349	0.00%
Sitara Solar Energy (UPC Renewables)	100	2.48	0.0349	0.00%
ReNew Power	110 (360)*	2.49	0.0351	0.40%
Azure Power	100	2.50	0.0352	0.81%
Mahindra Susten	200	2.51	0.0353	1.21%
Rays Power Infra	120	2.52	0.0355	1.61%
Green Infra Wind Energy (Sembcorp)	200	2.56	0.0360	3.23%

*ReNew Power bid for 360 MW but won only 110 MW — Note: $1 = ₹71.02

SECI — Source: Mercom India Research

Figure 4.8: Recent decreasing solar energy tariff trend in India

Factor Analysis for Quantitative Study of Socio-economic & Techno-commercial Policy Aspects:

As the research study aims to identify the factors for RE microgrid-based rural electrification, factor analysis using principal components analysis and varimax rotation was applied to the responses to extract the most important factors. Factor analysis is a multivariate statistical technique that can help the researcher to reduce the number of variables or parameters to a manageable number; it provides simplicity after reducing variables. For long studies with large blocks of Matrix Likert scale questions, the number of variables can become really unwieldy. Simplifying the data using factor analysis helps to clarify the results and focus on them. A factor explains the correlations among a set of given variables, and factor analysis examines the whole set of interdependent relationships for data reduction and summarization (Malhotra & Dash, 2009). Hence, the factor analysis technique was applied to reduce the list of 25 factors to a smaller set of underlying factors that are significant in understanding the reasons for the success or failure of the distributed RE microgrid-based rural electrification practices. Factor analysis denotes a class of procedures primarily used for data reduction and summarization. In this research, a large number of variables have emerged from the literature survey and the questionnaire method. These factors may be correlated and must be reduced to a manageable level. Relationships among the sets of many interrelated variables are examined and represented in terms of a few underlying factors.

Mathematically, factor analysis is similar to multiple regression analysis: Each variable is expressed as a linear combination of the underlying factors. The amount of variance that a variable share with all other variables included in the analysis is referred to as communality. The covariation among the variables is described in terms of a small number of common factors plus a unique factor for each variable. These factors are not overtly observed. If the variables are standardized, the factor model may be represented as the following:

$$Xi = Ai1Fi + Ai2F2 + Ai3F3 + ... + AimFm + ViUi$$

where *Xi* = the *i*-th standardized variable

Aij = the standardized multiple regression coefficient of variable *i* on common factor *j*

F = common factor

Vi = the standardized regression coefficient of variable *i* on unique factor *i*

Ui = the unique factor for variable *i*

m = the number of common factors

The unique factors are correlated with each other as well as with the common factors. The common factors themselves can be expressed as linear combinations of the observed variables

$$Fi = Wi1X1 + Wi2X2 + Wi3X3 + ... + WikXk$$

where Fi = estimate of the i-th factor

Wi = the weight or factor score coefficient

k = the number of variables

It is possible to select weights or factor score coefficients in such a way that the first factor explains the largest portion of the total variance. Then, a second set of weights can be selected so that the second factor accounts for most of the residual variance, subject to being uncorrelated with the first factor. The same principle could be applied to the selection of additional weights for additional factors. Thus, the factors can be estimated in such a way that their factor scores, unlike the values of the original variables, are not correlated. Furthermore, the first factor accounts for the highest variance in the data, the second factor for the second highest, and so on.

The concept map for factor analysis, as provided by Malhotra and Dash, is shown in the figure below (**Malhotra & Dash, 2010**):

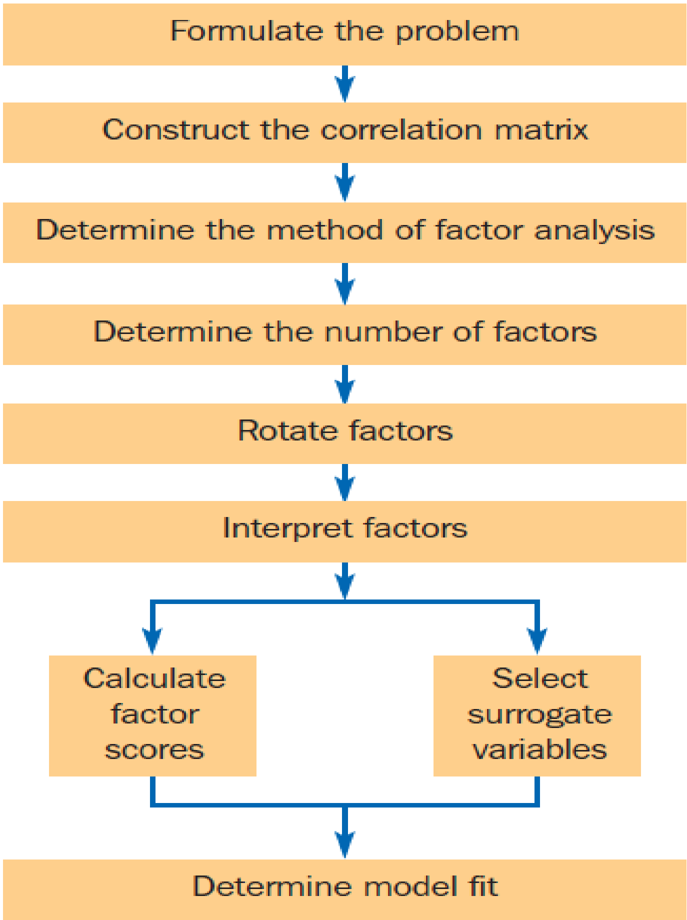


Figure 4.9: Factor Analysis Concept Map (Malhotra & Dash, 2010)

Below is the qualitative method adapted for analysing the study with the grounded theory approach:

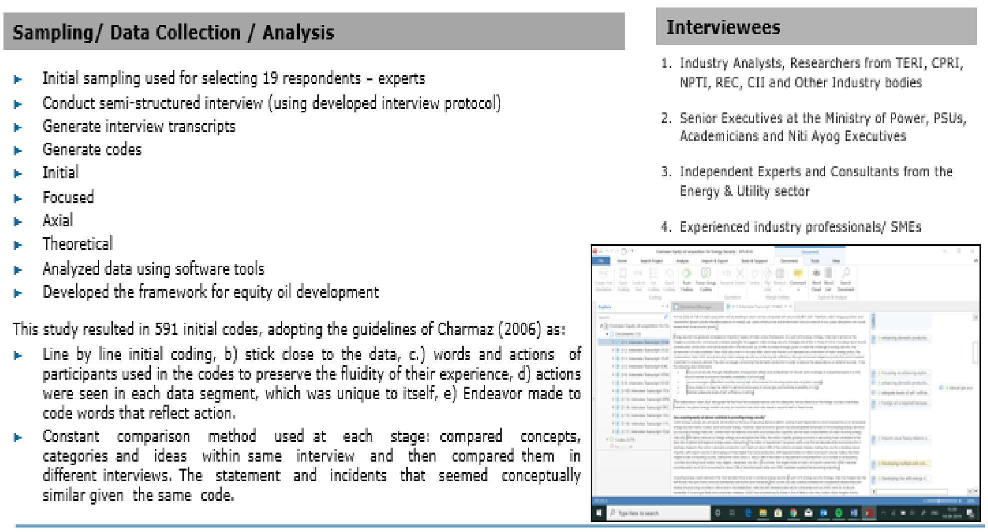


Figure 4.10: Qualitative analysis method overview

Discussion on Data Output Analysis:

Literature surveys were carried out as explained in the previous section of this thesis. These surveys provided a list of 20 variables that have been outlined below. Textual analysis was used to prepare the list of universal variables.

1. To have affordably priced electricity services
2. To assure equitable access to electricity services to all citizens
3. To have a stable, predictable, and transparent price policy
4. To promote trade in electricity and related products and technologies
5. To promote electricity trading in different states of India
6. To promote adaptation and investment in latest technologies
7. To ensure healthy relations between the Union Govt. and State Govts. for effective collaboration and cooperation
8. To have better tools to estimate the demand potential and capacity planning
9. To provide financial incentives for investment in rural electrification and renewable energy microgrids by utilities/investors
10. Concessional state funding and financial incentives for rural electrification and renewable microgrids
11. Stable fiscal regimes in governing contracts
12. To maximize the exploitation of locally abundant available renewable energy resources for each of the regions
13. Maximize the strategic tie-up between state utilities and IPPs/ FIIs/Pvt. sector players
14. Resource sharing & shared services approach
15. Reducing the risk through the JV/ PPP model in rural electrification project development
16. To have secured and uninterrupted supply of electricity
17. Demand sensitivity- and availability-based tariffing
18. Payback period for institutional investors
19. Human Development Index of target rural electrification geographies
20. Solar energy potential and cost baseline

Furthermore, semi-structured interviews were conducted using judgmental sampling with 21 experts in the energy and utilities segment, while the interview protocol included the following key questions to the experts. The experts were briefed that the interview was part of the academic work on finding factors for the implementation of a solar microgrid-based rural electrification framework to ensure energy security for rural India. The industry veterans and experts were also informed that by identifying the factors, the purpose would be to develop a framework for solar-power microgrid-based rural electrification in the Indian perspective, especially within the perimeter of the hilly regions of India.

1. What factors enable or impede solar microgrid-based rural electrification in developed or developing nations globally?
2. What factors enable or impede solar microgrid-based rural electrification in Indian conditions and contexts?
3. What factors enable or impede solar microgrid-based rural electrification and are related to the government power policy and the rural electrification model?
4. What factors enable or impede solar microgrid-based rural electrification and are related to the regulatory interventions and electricity sector reform?
5. What factors enable or impede solar microgrid-based rural electrification and are related to the development of competitive skill sets, knowledge, and technology transfer from external entities or overseas bodies?

In addition to the above-mentioned points, intervening questions were asked in relation to the topic as they can act as an aid to our discussion. The discussion is captured in the summary form as key points emerge from the deliberation. Each semi-structured interview lasted 20–30 minutes. The factors identified through the literature review and obtained from the semi-structured interview process were combined to have the number of variables around 25. These variables were converted into a questionnaire.

Designing a questionnaire with mostly close-ended questions and carrying out a pilot survey for testing the reliability of the questionnaire by developing questions that respondents can and will answer is likely to yield the desired information. However, it can be tricky as two apparently similar ways of posing a question may provide different types of information. Any questionnaire has three specific objectives. First, it must translate the information needed into a set of specific questions that the respondents can and will answer. Second, a questionnaire must uplift, motivate, and encourage the respondent to become involved, to cooperate, and to complete the task. And third, a questionnaire should minimize the response error. Since there are no scientific principles that guarantee an optimal or ideal questionnaire, questionnaire designing is a skill acquired through experience. The first step in questionnaire designing is to specify the information needed—this is also the first step in the research design process. It is also vital to have a clear idea of the target respondents. The characteristics of the respondent group have a great influence on questionnaire designing. The pilot survey was done to check the reliability of the questionnaire. The survey was done on 30 respondents.

Pilot study outputs would be tested by measuring Cronbach's alpha, which was developed by Lee Cronbach in 1951. This measure is used for testing reliability/validity and internal consistency. Cronbach's alpha is a number between 0 and 1. Internal consistency checks whether all variables are related to each other so that they can measure the same concept. Any value of 0.60 and 0.70 demonstrates a lower level of acceptability (Haier, Black, Anderson, & Tatham, 1998). If the value of alpha is high (>0.90), it may suggest redundancies and demonstrates that the test length should be shortened (Mohsen and Tavakol, 2011). ***Cronbach's alpha score for our pilot survey is 0.8, demonstrating that the questionnaire is reliable, valid, and have internal consistency.***

4.8.1 QUANTITATIVE HOUSEHOLD SURVEY

For Objective 1, which seeks 'to identify the key factors impeding the rural electrification of the rural hilly terrains of North Bengal, India, through solar energy-based equipment and microgrid systems', the proposed research is done through the quantitative survey method using a seven-point Likert scale for ranking the related variables. Household surveys were conducted for this purpose. Quantitative information was acquired from both SHS users and nonusers. Household-level data was collected through a household survey conducted in villages with ongoing SHS dissemination (‘SHS villages’) and non-electrified villages. Detailed quantitative information is obtained through the collection of information from the mixture of mostly structured close-ended and a few open-ended questions in the questionnaire. Data reliability and validity would be checked through possible testing methods like Cronbach’s ∞ estimation and KMO test etc.

4.8.2 QUALITATIVE INTERVIEWS

Following the quantitative survey, the present research attempts to conduct qualitative interviews based on Objective 2, which seeks ‘to develop an efficient framework for sustainable rural electrification through solar energy-based equipment and microgrid systems for the rural hilly terrains of North Bengal, India’. This interview is conducted with experts in the field of the E&U sector in North Bengal and all the associated key stakeholding experts for this proposed framework and its implementation perspective, wherein a semi-structured (mix of structured, semi-structured, and open-ended questions) questionnaire is provided to the experts. The questions for such semi-structured interviews were based on the key variables identified and ranked through quantitative research, as well as the information received through secondary research for similar case histories in other countries. Following the interviews and qualitative study, the perceptions acquired from the participants is analysed and an efficient framework is developed for the electrification of North Bengal rural regions. The experts answer the questionnaires in two or more rounds. For all the interviews to be conducted, including the household survey and the qualitative interviews with the expert stakeholders, the projection technique would be used to analyse the interviewees in an analytical way, while the SPSS tool would be used as the tool of analysis for the interviews and related outputs.

4.9 DATA ANALYSIS METHODS FOR QUANTITATIVE AND QUALITATIVE STUDIES

In this study, the analysis of quantitative data, including factor analysis, is carried out using the SPSS software, while the analysis of qualitative data is carried out using the Wordaizer software. SPSS is a dedicated windows-based program that is used to analyse collected data and depict them through graphs and tables; it could handle very large amounts of data and perform analysis on formats such as text. In general, SPSS is widely used in social sciences and business disciplines; it is very often updated. In the present study, the answers to open questions were assigned to coded groups, enabling further quantitative analysis. After applying the respective weight factors to different household groups, statistical analysis was performed. Also, to evolve with the proposed efficient framework for the solar energy equipment based microgrid-driven rural electrification system, thematic content analysis was used to analyse the expert stakeholders' interview data with the help of the Wordaizer software. Based on this analysis, the key cornerstones of the proposed framework are defined and accordingly the detailed constructs and variables/sub-variables are elaborated.

Factor analysis involves grouping similar variables into dimensions. This process is used to identify latent variables or constructs. The purpose of factor analysis is to reduce many individual variables into a fewer number of dimensions. Factor analysis can be used to simplify data, such as reducing the number of variables in regression models. When there is more than one independent variable, the collection of all pair-wise correlations is succinctly represented in the matrix form. In regression analysis, the purpose of examining these correlations is two-fold—to find outliers and to identify collinearity. In the case of outliers, there should be major differences between the parametric measure, the Pearson correlation coefficient, and the nonparametric measure, and the Spearman rank correlation coefficient. In the case of collinearity, high pair-wise correlations could be indicators of collinearity problems. A matrix of correlations between the variables could be the basis for the analytical process. The variables ought to be correlated for factor analysis to be meaningful. In practice, this is usually the case. However, factor analysis may not work in case of a smaller degree of correlation. We also expect that variables that are highly correlated with each other would highly correlate with the same factor or factors. Formal statistics are available for testing the appropriateness of the factor model. The sphericity test of Bartlett can test the null hypothesis stating that the variables are uncorrelated in the population. To put it another way, the population correlation matrix happens to be an identity matrix. In an identity matrix, all the diagonal terms are 1 and all off-diagonal terms are 0. The correlation matrix exhibiting the simple correlations r between variable pairs was included in the analysis, as shown in table below. The diagonal elements, which are all 1, were omitted. The correlation matrix between the variables actually formed the basis for analysis.

Table 4.1: Correlation matrix view

To have affordably priced electricity services	1	0.151	0.502	-0.84	0.295	0.591	0.378	0.067	0.064	0.266	-0.312	0.421	0.352	-0.749	-0.026	-0.352	0.095	-0.117
To assure equitable access to electricity services to all citizens	0.151	1	0.211	-0.337	0.033	0.161	0.121	0.058	0.084	0.192	-0.101	0.178	0.145	-0.246	0.089	-0.133	0.38	0.173
To have stable, predictable, and transparent price policy	0.502	0.211	1	-0.683	0.451	0.38	0.21	0.354	0.365	0.096	-0.469	0.642	0.686	-0.43	-0.187	-0.379	0.186	-0.129
To promote trade in electricity & related products and Technologies	-0.84	-0.337	-0.683	1	-0.213	-0.568	-0.44	-0.222	-0.237	-0.468	0.557	-0.546	-0.468	0.756	0.097	0.54	-0.326	0.082
To promote electricity trading within different states of India	0.295	0.033	0.451	-0.213	1	0.164	0.017	0.026	-0.023	-0.145	-0.099	0.139	0.411	-0.169	-0.391	0.218	0.042	0.117
To promote adaptation and investment in latest technologies	0.591	0.161	0.38	-0.568	0.164	1	0.795	0.454	0.442	0.246	-0.134	-0.027	0.352	-0.668	0.06	-0.29	0.135	-0.048
To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation	0.378	0.121	0.21	-0.44	0.017	0.795	1	0.773	0.762	0.513	-0.412	-0.147	0.093	-0.578	0.002	-0.461	0.1	-0.234
To have better tools to estimate the demand potential and capacity planning	0.067	0.058	0.354	-0.222	0.026	0.454	0.773	1	0.985	0.366	-0.457	-0.003	0.16	-0.417	-0.139	-0.385	0.045	-0.369
To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors	0.064	0.084	0.365	-0.237	-0.023	0.442	0.762	0.985	1	0.383	-0.458	-0.015	0.194	-0.422	-0.084	-0.414	0.075	-0.372
Concessional State funding & Financial Incentives for Rural Electrification & Renewable Micrograds	0.266	0.192	0.096	-0.468	-0.145	0.246	0.513	0.366	0.383	1	-0.474	0.092	-0.205	-0.423	0.024	-0.369	0.182	-0.319
Stable Fiscal Regimes in Governing Contracts	-0.312	-0.101	-0.469	0.557	-0.099	-0.134	-0.412	-0.457	-0.458	-0.474	1	-0.24	-0.292	0.388	0.372	0.813	-0.068	0.474
To maximise exploitation of locally abundant available renewable energy resources for each of the regions	0.421	0.178	0.642	-0.546	0.139	-0.027	-0.147	-0.003	-0.015	0.092	-0.24	1	0.291	-0.165	-0.037	-0.191	0.157	-0.059
Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players	0.352	0.145	0.686	-0.468	0.411	0.352	0.093	0.16	0.194	-0.205	-0.292	0.291	1	-0.352	-0.056	-0.2	0.128	-0.016
Resource Sharing & Shared Services Approach	-0.749	-0.246	-0.43	0.756	-0.169	-0.668	-0.578	-0.417	-0.422	-0.423	0.388	-0.165	-0.352	1	0.108	0.389	-0.219	0.191
Reducing risk through JV/ PPP Model in Rural Electrification project development	-0.026	0.089	-0.187	0.097	-0.391	0.06	0.002	-0.139	-0.084	0.024	0.372	-0.037	-0.056	0.108	1	0.203	0.114	0.159
To have a secured and uninterrupted supply of electricity	-0.352	-0.133	-0.379	0.54	0.218	-0.29	-0.461	-0.385	-0.414	-0.369	0.813	-0.191	-0.2	0.389	0.203	1	-0.108	0.408
Decentralisation and small scale Grid-connected/ Off-grid Ecosystems	0.095	0.38	0.186	-0.326	0.042	0.135	0.1	0.045	0.075	0.182	-0.068	0.157	0.128	-0.219	0.114	-0.108	1	0.379
Research and Development	-0.117	0.173	-0.129	0.082	0.117	-0.048	-0.234	-0.369	-0.372	-0.319	0.474	-0.059	-0.016	0.191	0.159	0.408	0.379	1
Promoting electricity conservation by people and industry		0.003	0	0	0	0	0	0.108	0.122	0	0	0	0	0	0.318	0	0.041	0.016
To encourage low electrical energy intensity	0.003		0	0	0.272	0.002	0.013	0.142	0.061	0	0.032	0.001	0.004	0	0.051	0.007	0	0.001
To achieve Knowledge and Technology Transfer	0	0		0	0	0	0	0	0	0.04	0	0	0	0	0	0	0	0.009
Why No Bank/ NBFC A/c or MFI Membership?	0	0	0		0	0	0	0	0	0	0	0	0	0	0.038	0	0	0.067
What is/are the major source(s) of income for your family?	0	0.272	0	0		0.001	0.378	0.32	0.337	0.004	0.034	0.005	0	0.001	0	0	0.221	0.016
Do you have any Home-based Business	0	0.002	0	0	0.001		0	0	0	0	0.007	0.312	0	0	0.138	0	0.007	0.191
What is the best description of your home-based business?	0	0.013	0	0	0.378	0		0	0	0	0	0.003	0.044	0	0.484	0	0.034	0
If your home-based business in Agro-sector, do you have farmland for irrigation?	0.108	0.142	0	0	0.32	0	0		0	0	0	0.48	0.002	0	0.005	0	0.206	0
If you have farmland for irrigation, define the Quantum (Hectares)	0.122	0.061	0	0	0.337	0	0	0		0	0	0.39	0	0	0.062	0	0.086	0
Are you looking for addl./ new source of income (e.g. non-conventional electricity)?	0	0	0.04	0	0.004	0	0	0	0		0	0.047	0	0	0.333	0	0	0
Do you have access to affordable electricity?	0	0.032	0	0	0.034	0.007	0	0	0	0		0	0	0	0	0	0.107	0
Do you get subsidy/Govt. electrification benefit as rural electricity consumer	0	0.001	0	0	0.005	0.312	0.003	0.48	0.39	0.047	0		0	0.001	0.247	0	0.002	0.14
Do you receive subsidy or Govt. electrification scheme benefit as BPL consumer?	0	0.004	0	0	0	0	0.044	0.002	0	0	0	0		0	0.151	0	0.009	0.388
What is your spending for electricity/month(Rs)?	0	0	0	0	0.001	0	0	0	0	0	0	0.001	0		0.024	0	0	0
Are you willing to pay some addl. amount for reliable electricity supply at your home?	0.318	0.051	0	0.038	0	0.138	0.484	0.005	0.062	0.333	0	0.247	0.151	0.024		0	0.018	0.002
Reasons for not willing to pay for reliable electricity supply	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0		0.024	0
Does Electric network/ grid power line exist in your locality	0.041	0	0	0	0.221	0.007	0.034	0.206	0.086	0	0.107	0.002	0.009	0	0.018	0.024		0
Power cut/ Blackouts/ Outage Per Day (Summer) - in Hours	0.016	0.001	0.009	0.067	0.016	0.191	0	0	0	0	0	0.14	0.388	0	0.002	0	0	

It is important to check whether the variables in the population are uncorrelated with each other. This is stated as the null hypothesis where the variables are independent or simply uncorrelated with each other. Bartlett's test output provides this confirmation. It is equally important to test the adequacy of the sample collected. An index called the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy examines the appropriateness of factor analysis. High values (between 0.5 and 1.0) signal the appropriateness of factor analysis, while any values below 0.5 indicate that factor analysis is not likely to be suitable for the collected sample.

KMO and Bartlett's Test:

Table 4.2: KMO and Bartlett's Test highlights

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.823
Bartlett's Test of Sphericity	Approx. Chi-Square	3794.604
	df	210
	Sig.	.000

Below is the KMO Table:

Table 4.3: KMO Table interpretation

KMO Score	Interpretation
0.9+	Perfect
0.8 – 0.89	Great
0.7 – 0.79	Good
0.5 – 0.69	Mediocre
<0.5	Unacceptable

Since the value of KMO is 0.823—i.e., greater than 0.5—it is acceptable according to Kaiser. If the value was below this level, we should go back to the drawing board and either collect more data or think of more variables to be included in the analysis (Hutcheson & Sofroniou, 1999) The value of the significance level (.000) in the above-mentioned table demonstrates that there is some relationship between the variables collected.

Since we have established above that factor analysis is appropriate for analysing the collected data, a suitable method must be selected. The various methods of factor analysis are differentiated by the approach used to find out the weights or factor score coefficients. There are two basic approaches to factor analysis: principal components analysis (PCA) and common factor analysis (CFA). However, these two approaches are very similar in many ways—they come across as different varieties of the same analysis rather than two different methods. Both are data reduction techniques and spot the variance in variables in a smaller set. These two methods are usually run-in statistical software following the same procedure and even the output looks quite similar. The steps to run these two methods are extraction, interpretation, rotation, and choosing the number of factors or components. However, there is a fundamental difference between them despite all these similarities: PCA is a linear combination of variables, while CFA is a model to measure a latent variable.

In PCA, the approach towards reduction of data pertains to creating one or more index variables from a larger set of measured variables. A linear combination (basically a weighted average) of a set of variables is created to achieve this. The created index variables are called components. The use of PCA involves optimality: the optimal number of components, the optimal choice of measured variables for each component, and the optimal weight.

CFA, on the other hand, approaches data reduction differently; it is a model that performs the measurement of a latent variable, which cannot be directly measured with a single variable (think: intelligence, social anxiety, soil health). This approach is perceived through the relationships that it enables in a set of Y variables—for example, we may not measure social anxiety directly but can measure whether its degree is high or low with a set of variables such as 'I am uncomfortable in large groups' and 'I get nervous talking with strangers'. High social anxiety prompts people to give similar types of high responses to these variables, while low social anxiety prompts people to give similar types of low responses to these variables.

PCA considers the total variance in data. The correlation matrix's diagonal comprises unities, while the full variance is brought into the factor matrix. The recommendation of PCA takes place when the primary concern is to find out the minimum number of factors that account for the maximum variance in data for their use in subsequent multivariate analyses. These factors are called principal components.

CFA estimates factors only on the basis of the common variance. Communalities are inserted in the correlation matrix's diagonal. This method is suitable when the primary concern involves the identification of the underlying dimensions and the common variance is found to be interesting. Principal axis factoring is another name of this method. CFA analyses only the reliable common variance of data, while principal components analyse all variances that may happen in the data. CFA deals with an underlying hypothetical process or construct, but it is not so in PCA that tends to increase factor loadings, especially in a study with a small number of variables and/or low-estimated communality. PCA is used to extract the factors.

Although it is possible to compute as many principal components as variables, but it does not summarize the information nor reveal any underlying structure. A smaller number of factors should be extracted in order to summarize the information that is in the original variables. The question is: how many? The concerns in applications of factor analysis in determining the number of factors are necessary to account adequately for the commonality among the indicators in a set. This concern received considerable attention from quantitative methodologists in the 1950s and 1960s (Cattell, 1966; Guttman). Despite the attention, a half century later, it remains a topic of considerable debate (Hayduk & Glaser, 2000; Herting &Costner, 2000). Researchers have suggested multiple procedures to determine the number of factors. Some of them are a priori determination and approaches based on eigenvalues, scree plot, percentage of variance accounted for, split-half reliability, and significance tests.

A priori determination: Owing to prior knowledge, the researcher sometimes is aware of the number of factors to be expected and therefore can specify the number of factors to be extracted beforehand. However, the extraction of factors stops after the extraction of the desired number of factors. The user is allowed by most computer programs to specify the number of factors and this results in an easy implementation of this approach.

Determination based on eigenvalues: Only factors with eigenvalues greater than 1.0 are retained in this approach. The model does not include other factors. An eigenvalue represents the variance amount associated with a factor. Therefore, there is inclusion of only factors with a variance greater than 1.0. Factors with a variance less than 1.0 are no better than a single variable because each variable has a variance of 1.0 due to standardization. In case the number of variables happens to be less than 20, a conservative number of factors could be seen with this specific approach.

Determination based on scree plot: A scree plot refers to a plot of the eigenvalues against the number of factors in order of extraction. The plot's shape is used to determine the number of factors. Typically, a distinct break between the steep slope of factors is seen in case of the plot, with large eigenvalues and a gradual trailing off that are associated with the rest of the factors. This gradual trailing off is the scree Plot. It has been indicated by experimental evidence that the point at which the scree begins actually denotes the true number of factors. The number of factors determined by a scree plot will, in general, happens to be one or a few more than the number determined by the eigenvalue criterion.

Determination based on percentage of variance: This approach determines the number of factors extracted so that a satisfactory level can be reached with the cumulative percentage of the variance extracted by the factors. The satisfactory level of variance is depending on the problem. It has been recommended that the factors extracted should account for at least 60% of the variance.

Determination based on split-half reliability: In this approach, the sample is split in half, and factor analysis is performed on each half. Here only factors with a high correspondence of factor loadings across the two subsamples are retained.

Determination based on significance tests: It is possible to determine the statistical significance of the separate eigenvalues and to retain only the statistically significant ones. However, in case of with large samples (size greater than 200), many factors could be statistically significant, even though many of these actually account for only a small proportion of the total variance. We have selected the method based on the percentage of variance.

Malhotra & Dash (2010) recommend that if we use the percentage of variance method, at least 60 percentage of the variance should be accounted by the extracted factors. The percentage of variance is the cumulative percentage of variance.

Factor analysis – total variance explained (Extraction method: principal component analysis)

Table 4.4: Determination of Number of Factors

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.154	34.187	34.187	6.154	34.187	34.187	3.198	17.768	17.768
2	2.716	15.086	49.273	2.716	15.086	49.273	3.019	16.773	34.541
3	1.907	10.597	59.87	1.907	10.597	59.87	2.766	15.366	49.907
4	1.61	8.947	68.817	1.61	8.947	68.817	2.512	13.956	63.863
5	1.284	7.132	75.949	1.284	7.132	75.949	1.751	9.729	73.592
6	1.058	5.878	81.827						
7	0.788	4.379	86.206						
8	0.662	3.68	89.886						
9	0.515	2.862	92.749						
10	0.414	2.298	95.046						
11	0.304	1.686	96.733						
12	0.257	1.426	98.159						
13	0.143	0.792	98.951						
14	0.078	0.436	99.387						
15	0.062	0.345	99.732						
16	0.027	0.149	99.881						
17	0.018	0.084	99.964						
18	0.008	0.036	100						
19	0.015	0.081	99.964						
20	0.006	0.0321	100						
21	0.012	0.078	99.964						
22	0.005	0.028	100						
23	0.025	0.144	99.881						
24	0.011	0.02	99.964						
25	0.004	0.025	100						

Eigen values approach was used for determining the number of factors. In this case, Eigen values greater than 1.0 are exhibited the factors retained. These were considered significant as exhibited in the study. Every factor is associated with a certain amount of variance referred to as an Eigen value. Hence, all the factors included have a variance greater than 1.0. Owing to standardization, each variable possesses 1.0 variance. Therefore, the factor that exhibits any variance less than 1.0 is as good as a single variable. The percentage of the total variance was attributed to each factor. In the above-mentioned Table of Factor Analysis (PCA), we see that the eigenvalue greater than 1.0 (default option) results in five factors being extracted. The scree plot associated with this analysis is given in the figure below. Right from the scree plot, a distinct break can be seen at five factors. Finally, the cumulative percentage of the variance accounted for shows that the five factors account for 73.5 % of the variance and that there is marginal gain in going to six factors. Therefore, the five factors appear to be reasonable in this situation.

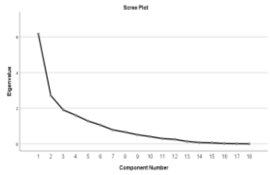


Figure 4.11: Scree Plot view for determination of number of factors

Determination Based on Percentage of Variance: It could be seen in where the number of factors extracted was determined, thereby enabling the cumulative percentage of variance extracted by factors to reach a satisfactory level. According to the result, a total of five factors accounted for 73.5% of the total variance. The factors extracted, taken together, should account for more than 60% of the total variance **(Malhotra, 2009)**.

Communalities

Communalities indicate the amount of variance in each variable that has been accounted for. Initial communalities are estimates of variance in each variable accounted for by all components or factors. For principal components extraction, this is always equal to 1.0 for correlation analysis. Extraction communalities are estimates of variance in each variable accounted for by the components. The communalities in this table are all high, which indicates that the extracted components represent the variables well (as per the KMO Table). If any communalities are very low in case of principal components extraction, we may need to extract another component.

Table 4.5: Communalities: extraction method – principal component analysis

SL No	List of Items	Initial	Extraction
1	To have affordably priced electricity services	1	0.517
2	To assure equitable access to electricity services to all citizens	1	0.641
3	To have stable, predictable, and transparent price policy	1	0.689
4	To promote trade in electricity & related products and technologies	1	0.672
5	To promote electricity trading within different states of India	1	0.593
6	To promote adaptation and investment in latest technologies	1	0.582
7	To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation	1	0.559
8	To have better tools to estimate the demand potential and capacity planning	1	0.681
9	To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors	1	0.564
10	Concessional State funding & Financial Incentives for Rural Electrification & Renewable Microgrids	1	0.611
11	Stable Fiscal Regimes in Governing Contracts	1	0.757
12	To maximise exploitation of locally abundant available renewable energy resources for each of the regions	1	0.633
13	Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players	1	0.676
14	Resource Sharing & Shared Services Approach	1	0.679
15	Reducing risk through JV/ PPP Model in Rural Electrification project development	1	0.707
16	To have a secured and uninterrupted supply of Electricity	1	0.601
17	Decentralisation and small scale Grid-connected/ Off-grid Ecosystems	1	0.506
18	Research and Development	1	0.819
19	Promoting electricity conservation by people and industry	1	0.526
20	To encourage low electrical energy intensity	1	0.661
21	To achieve Knowledge and Technology Transfer	1	0.711
22	Human Development Index	1	0.557
23	Higher pay-back period and challenges in ROI are major detractors for Rural Electrification & Renewable Energy in India	1	0.658
24	Per Capita income & Social Development can be increased through Distributed Renewable Grid Model	1	0.608
25	Scalability of Rural Economy and Financial Inclusion through Co-operative based Prosumer model in Distributed Solar MicroGrid Approach in Rural Electrification	1	0.524

The 'Extraction sums of squared loadings' table shows the variances that are associated with the factors retained. These are same as those under Initial eigenvalues. This is always the case in principal components analysis. The determination of the percentage variance accounted for by a factor is carried out by dividing the associated eigenvalue by the total number of factors (or variables) and multiplying by 100.

Rotation of Factors

Factors are rotated in a way that they become easier to interpret. Rotation makes it easier to explain or predict different items as much as possible by different underlying factors, and each factor explains more than one item. The Rotated Factor Matrix table boosts the understanding the results of the analysis.

The un-rotated or initial factor matrix displays the relationship between the factors and individual variables. The factors, however, were correlated with many variables—this makes these difficult to interpret. Hence, each variable was rotated with the help of the varimax rotation method with Kaiser normalization (Malhotra & Dash, 2010) in order to transform the factor matrix into a simple as well as easily interpretable matrix. The varimax rotation method reduced the number of variables with high loadings on preferably one factor, which makes it easier to understand these. The rotation converged in six iterations.

Table 4.6: Rotated component matrix: extraction method – principal components analysis (Rotation method: varimax with Kaiser normalization)

List of Items	Component				
	1	2	3	4	5
To have affordably priced electricity services	0.734	0.293	0.067	0.059	-0.084
To assure equitable access to electricity services to all citizens	0.793	0.202	0.106	0.068	-0.057
To have stable, predictable, and transparent price policy	0.79	0.095	0.011	0.165	0.103
To promote trade in electricity & related products and technologies	0.733	0.197	0.116	0.052	-0.006
To promote electricity trading within different states of India	0.628	0.406	0.072	-0.041	-0.124
To promote adaptation and investment in latest technologies	0.614	0.476	0.268	-0.013	0.079
To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation	0.454	0.56	0.42	-0.047	-0.121
To have better tools to estimate the demand potential and capacity planning	0.448	0.53	0.38	-0.008	-0.085
To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors	0.32	0.729	0.198	0.019	0.044
Concessional State funding & Financial Incentives for Rural Electrification & Renewable Microgrids	0.069	0.759	-0.075	0.025	0.116
Stable Fiscal Regimes in Governing Contracts	0.079	0.656	-0.273	-0.428	0.344
To maximise exploitation of locally abundant available renewable energy resources for each of the regions	0.354	0.44	0.67	0.008	0.154
Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players	0.324	0.158	0.737	0	-0.073
Resource Sharing & Shared Services Approach	0.142	0.034	0.71	0.004	-0.012
Reducing risk through JV/ PPP Model in Rural Electrification project development	0.297	-0.003	0.786	0.025	-0.019
To have a secured and uninterrupted supply of Electricity	0.364	0.375	0.58	-0.085	-0.076
Decentralization and small-scale Grid-connected/ Off-grid Ecosystems	0.054	0.048	0.466	0.589	0.303
Research and Development	0.104	-0.108	-0.092	0.525	-0.006
Promoting electricity conservation by people and industry	-0.005	0.489	0.451	0.556	0.071
To encourage low electrical energy intensity	-0.04	0.35	0.235	0.616	-0.017
To achieve Knowledge and Technology Transfer	-0.1	0.054	0.026	0.597	0.028
Human Development Index	0.297	-0.003	-0.019	0.025	0.486
Higher pay-back period and challenges in ROI are major detractors for Rural Electrification & Renewable Energy in India	0.324	0.158	-0.073	0	0.537
Per Capita income & Social Development can be increased through Distributed Renewable Grid Model	-0.121	0.56	0.42	-0.047	0.454
Scalability of Rural Economy and Financial Inclusion through Co-operative based Prosumer model in Distributed Solar MicroGrid Approach in Rural Electrification	0.054	0.048	0.466	0.303	0.529

Factor Interpretation and Labelling

Once the solution is reached, we try and name each of the five factors. Each of the factors extracted needs to be provided a name. To ensure that each factor identified by factor analysis has only one dimension and that each attribute loads on only one factor, items with factor loadings less than 0.50 and any item loading on more than one factor with a loading score equal to or greater than 0.40 on each factor were eliminated from the analysis. Simple correlations between the variables and factors were reflected via factor loadings. None of the 25 items was required to be dropped due to low factor loadings (below 0.50), poor reliability, or high loadings on more than one dimension. Accordingly, factor analysis has been conducted considering the 25 variables.

Each variable has a loading number on the factor—for example, equitable electricity access and a stable-predictable-transparent pricing policy have higher loadings of 0.705 and 0.733, respectively, compared to other variables. The significance of this factor originates from the fact that a long-term stable policy framework, which is transparent and predictable, shall enhance the energy equity investment in the high capital-intensive energy utilities industry. Among other variables, promoting bilateral trade scores the next highest loadings. Hence, the name provided to the factor is 'Long-term stable policy promoting bilateral trade relations. Following the principle, each factor has been named in the table below. Analysis of the below Table shows the groupings of the variables under each factor with respect to their factor loadings and the corresponding naming of the five factors.

Table 4.7: Overview of the Five Factors determined through analysis

List of Items	Component					Factor Name
	1	2	3	4	5	
To have affordably priced electricity services	0.734					Long term stable policy and promoting electricity distribution & trading best practices
To assure equitable access to electricity services to all citizens	0.793					
To have stable, predictable, and transparent price policy	0.79					
To promote trade in electricity & related products and Technologies	0.733					
To promote electricity trading within different states of India	0.628					
To promote adaptation and investment in latest technologies	0.614					
To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation		0.56				Concessional Government funding and financial incentives for Rural Electrification & Renewable Energy Microgrids
To have better tools to estimate the demand potential and capacity planning		0.53				
To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors		0.729				
Concessional State funding & Financial Incentives for Rural Electrification & Renewable Microgrids		0.759				
Stable Regulatory Regimes in Governing Contracts		0.656				
To maximise exploitation of locally abundant available renewable energy resources for each of the regions			0.67			Resource sharing & Shared Services Approach as well as Risk optimization through JV/ PPP Model adaptation
Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players			0.737			
Resource Sharing & Shared Services Approach			0.71			
Reducing risk through JV/ PPP Model in Rural Electrification project development			0.786			
To have a secured and uninterrupted supply of electricity			0.58			
Decentralisation and small scale Grid-connected/ Off-grid Ecosystems				0.589		Decentralization to secure uninterrupted high-quality supply of Electricity for Energy Security
Research and Development				0.525		
Promoting electricity conservation by people and industry				0.556		
To encourage low electrical energy intensity				0.616		
To achieve Knowledge and Technology Transfer				0.597		
Human Development Index					0.486	Promoting energy efficiency, Electricity conservation, knowledge and technology transfer
Higher pay-back period and challenges in ROI are major detractors for Rural Electrification & Renewable Energy in India					0.537	
Per Capita income & Social Development can be increased through Distributed Renewable Grid Model					0.454	
Scalability of Rural Economy and Financial Inclusion through Co-operative based Prosumer model in Distributed Solar MicroGrid Approach in Rural Electrification					0.529	

The five factors are extracted out of the factor analysis based on the factor loadings. They are discussed in detail on their applicability for the creation of a framework for the distributed RE microgrid-based rural electrification in India, especially for remote rural hilly terrain areas of the country. The factors are also depicted in the pictorial form below:

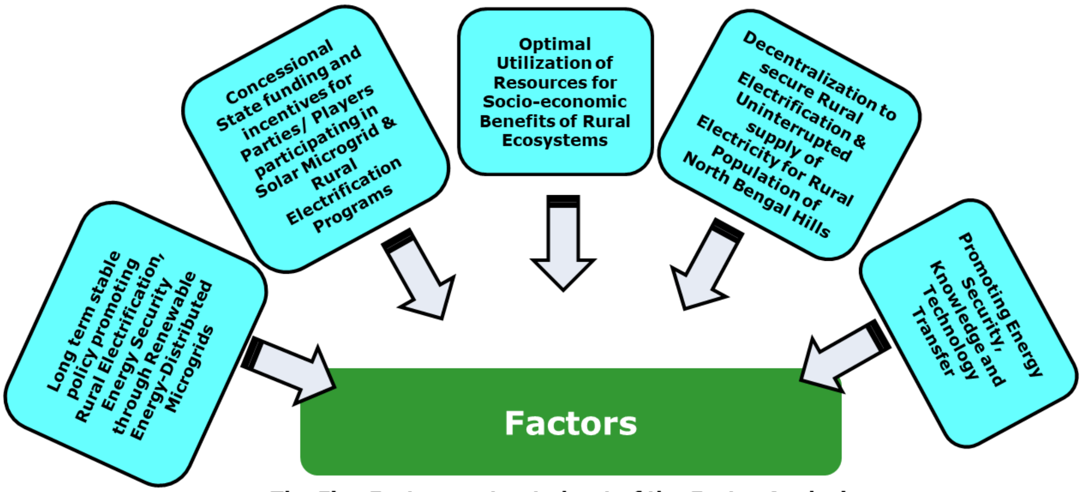


Figure 4.12: Consolidated view of the Five Factors extracted

Factor 1: Long-term stable policy promoting rural electrification and energy security through renewable energy-distributed microgrids:

The national electrical power wheeling and distribution, rural electrification, renewable energy implementation, and electricity trade governance system are often diverse and disjointed in India. In particular, there are gaps in the policies defined by the Union government with regard to public and private utilities. Even the Federal structure of the nation is a bit disjointed because of the differences among the different state governments and the central government. The role of governments in formulating long-term policies in electrical energy sourcing, rural electrification, and distribution of electrical energy within various poor and distant communities of the nation assumes greater significance as National Power Policy is an integral part of the economic policy of the nation. Economic transformation has to be supported by transformation of the energy sector. Stable policies for sustainable energy supplies promote economic growth, as the growth of energy, which is a vast sector in itself, can directly influence the overall growth of the economy. The adoption of a multi-stakeholder electrical energy ecosystem calls for a well-planned model with a robust institutional mechanism for long-term renewable energy microgrid-based rural electrification framework implementation. The factor also defines the importance of developing an effective electricity trading policy to enhance India's energy security perspective.

Factor 2. Concessional state funding and incentives for parties/ players participating in solar microgrid and rural electrification programmes:

Concessional loans from state-controlled agencies and targeted tax incentives for new renewable energy entrants and potential rural electrification investors are appealing because they respond to a number of interests: (i) to support growing the financial agency's own sustainability profile and growing its overall business penetration into the vast untapped potential of the Indian electricity sector; (ii) utility-backed loans and international investments advance the government's goals of enhancing access to electrical energy and increases foreign exchange investments in the country; and (iii) to help enhance electrical energy assets to establish diverse, long-term supply chains. The loan structures are relatively flexible, and since the main lenders are policy-driven financial institutions or foreign investors, the cost of their capital is partially controlled by the state apart from the corresponding markets. Moreover, state loans are political in nature and therefore could allow for deferred repayment schedules when needed for the greater interest of country-wide rural electrification and development missions, depending on the political and diplomatic situation.

Factor 3: Optimal utilization of resources for socio-economic benefits of rural ecosystems:

Investors join hands to gain through leveraging a combination of capabilities from the participant stakeholders and public and/or private utility firms. Energy utility companies tend to avoid extensive exposure to any speculative rural electrification and/or renewable energy investment, or investing in a new region or unproven technology. Rural electrification and/or renewable energy microgrid projects can be too big for a single company, especially for a state-run utility or a new entrant private player, to finance on its own for a vast country like India, both in terms of access to funding and cost exposure in the event of overrun. Accordingly, the renewable energy distributed microgrid-based rural electrification programmes are either taken up as multiple small disperse programmes in several geographies and electricity zones/ districts, especially in the remote hilly regions of India, or for a pan-India renewable energy microgrid execution, or/and a rural electrification programme through several joint venturing of large utilities, and/or investment/ infrastructure firms are required. Another reason for joint venturing is that owners of proprietary technology may restrict or limit access to such projects. Also, the consortium approach could be the preferred mechanism for Indian state-controlled companies pursuing renewable energy and/or rural electrification programmes, as it increases financial strength and bargaining power, enables companies to leverage complementary skills and provides them access to superior technologies, and ensures better linkages across the value chain. It is, in fact, a more pragmatic proposition for the specific energy source-rich geography from the techno-commercial feasibility perspective regarding the rural electrification and/or renewable energy electrification drive, since it provides a holistic turnkey solution for the overall socio-economic development of the respective geography or community in the near future. For example, in case of the rural hilly regions of North Bengal, solar energy sources are ample, which results in an encouragement factor for potential investors or electrification players from the techno-commercial perspective.

Factor 4: Decentralization to secure rural electrification & uninterrupted supply of electricity for rural population of North Bengal hills:

High capital investment dependencies for the initial electrification infrastructure set-up and restrictive access to traditional energy sources necessitates a raging debate as to whether the energy pathways could be developed in a more decentralised manner, thereby leveraging the locally abundant available energy sources through a microgrid ecosystem with the help of neighbouring rural communities or village co-operative societies. Irrespective of whether the past global practice of large generation plants with capital-intensive transmission infrastructures can now be better done with low-cost renewable energy-based decentralised microgrid solutions, the new energy ecosystem of the nation must be enabled to accept decentralised solutions. Countries need to seize the opportunity to incorporate emerging technologies in the new electrical energy infrastructure to be able to exploit these technologies as they mature, on a case-by-case basis, based on locally available energy sources. The seizure of this opportunity ensures the techno-commercial feasibility as well as reduction of electrical energy costs to supply affordable energy to rural communities and underprivileged people for the overall socio-economic growth. Energy security may be enhanced through the diversification of energy sources and the increase in renewable electricity production and energy efficiency.

Factor 5: Promoting energy security, knowledge, and technology transfer:

Technology transfer is one of the most challenging issues in international collaborations and foreign investments on partnerships for electricity network development and renewable energy electrification. In the context of climate change and de-carbonization concerns emanating from fossil fuels, despite its recognition at international platforms such as the United Nations Framework Convention on Climate Change, G20, etc., there is limited success in the transfer of environmentally sound technologies from advanced nations to developing countries like India. Economic reforms over the next decade promise to transform the way energy is being consumed and supplied. All four major energy-consuming segments—industry, household, transport, and agriculture—will undergo dramatic changes in coming decades. In more advanced economies, technological development involves the generation of new knowledge and applications that can be adopted to carry out productive activities in energy and other sectors. Even developing countries' technological development is strongly influenced by their ability to access, adapt, and disseminate advanced technological knowledge that has been generated outside their shores and occasionally brought in by partners and/or foreign investors. The latter option is applicable more in the case of India in terms of its long-term rural electrification and renewable energy mission.

The second objective requires the researcher to identify a conceptual framework for RE microgrid-based rural electrification, based on the learnings from similar electrification and RE models in several other developed or developing economies such as ROK/South Korea, Laos PDR, Sri Lanka, and the factors identified in Research Objective 1. The conceptual lens derived as an output from Research Objective 2, together with that of the RO1, would evolve the RE microgrid-based rural electrification framework in terms of the grounded theory methodology. The framework method has been found to be the most suitable for developing a conceptual framework. This method is most commonly used for the thematic analysis of semi-structured interview transcripts, where data is compared and contrasted by themes across many cases and each perspective is situated in terms of their contexts by keeping the connection with other aspects of each individual's account. The framework method sits within a broad family of analysis methods that are often termed thematic analysis, textual analysis, or qualitative content analysis. These approaches identify the commonalities and differences in qualitative data prior to focusing on the relationships between different parts of the data; they, therefore, seek to draw descriptive and/or explanatory conclusions that are clustered around themes. In the 1980s, Jane Ritchie and Liz Spencer developed the framework method from the Qualitative Research Unit at the National Centre for Social Research in the United Kingdom for being used in largescale policy research. The defining feature of this method is the matrix output—rows (cases), columns (codes), and 'cells' of summarized data—which provides a structure into which the researcher can systematically reduce the data for the purpose of analysing it by case and by code. A 'case' is an individual interviewee in most cases, but this can be adapted to other units of analysis such as predefined groups or organizations. While in-depth analyses of key themes can take place across the whole dataset, each research participant's views are connected to other aspects of their account within the matrix and therefore the context each individual's view is not lost. It is important to comparing and contrasting data to perform qualitative analysis; the ability to compare data without any complication across cases as well as within individual cases is built into the structure and process of the framework method. When using the framework method that, it is important to note that unlike quantitative research, where data collection and data analysis happen to be strictly sequential and mutually exclusive research process stages, qualitative analysis has a greater or lesser extent depending on the project and the ongoing interplay between data collection, analysis, and theory development. For instance, any new ideas or insights from participants may suggest potentially generative lines of enquiry or there could close analysis revealing subtle inconsistencies in an account that requires further exploration. The researcher collects the qualitative data and analyses it by one of the qualitative data analysis methods. Qualitative data contains in-depth descriptions of circumstances, people, interactions, observed behaviour, events, attitudes, thoughts and beliefs, and direct quotes from people who have experienced or have been experiencing the phenomenon (Patton, 2002). The data may also include excerpts or passages in personal or organizational documents like correspondence, records/diaries, and case histories. Qualitative data is usually documented in text form (i.e., interview transcriptions or organizational documents). However, it may also include non-textual data like tables, pictures, audio, and video recordings (Patton, 2002; Strauss & Corbin, 1998).

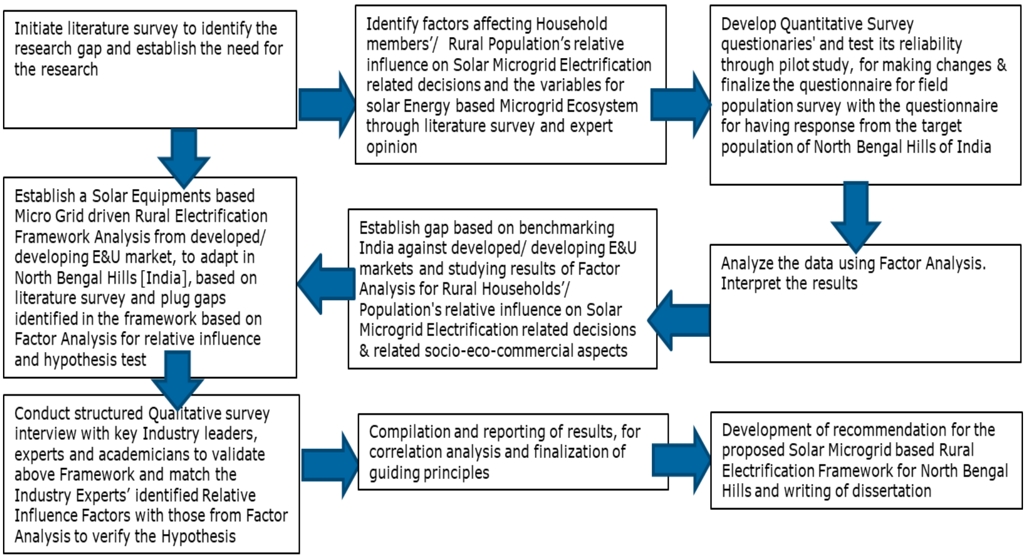


Figure 4.13: Revised research design flow overview

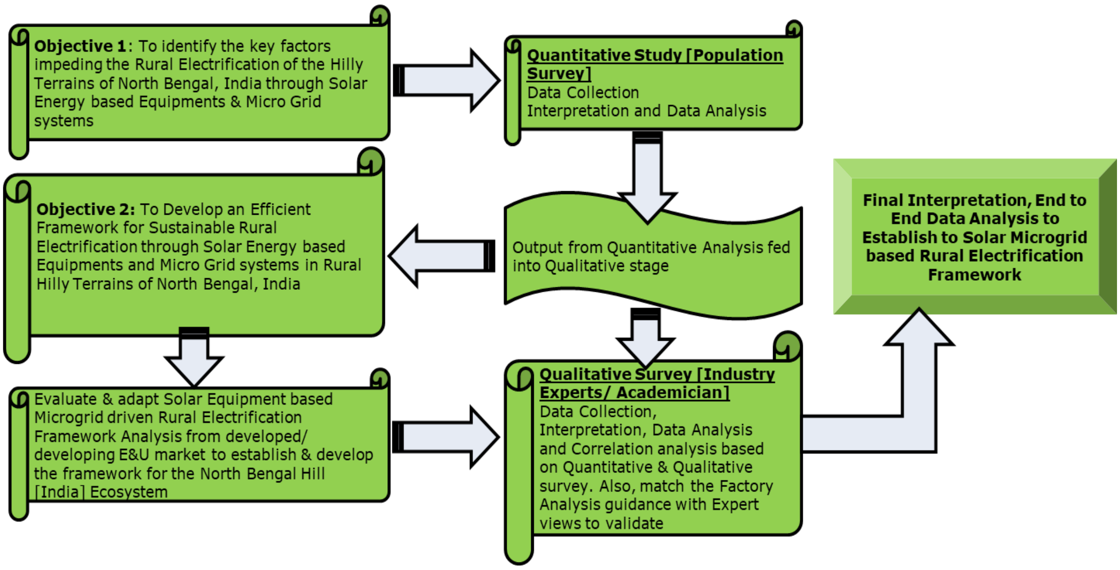


Figure 4.14: Integrated research flow for quantitative & qualitative study

Below are the four major types of research questions suitable for framework analysis:

Table 4.8: Overview of different types of research questions for framework analysis

Category	Objective	Sample Questions
Contextual	Identifying the form and nature of what exists	• What is the nature of people's experiences? • What needs the population of the sample have? • What elements operate within a system?
Diagnostic	Examining the reasons for, or cause of what exists	• What factors underlie particular attitudes or perceptions? • Why are decisions or actions taken, or not taken? • Why do particular needs arise? • Why are services or programs and not been used?
Evaluative	Appraising the effectiveness of what exists	• How are objectives achieved? • What affects the successful delivery of program • How do experiences affect subsequent behaviors • What barriers exist to systems operating?
Strategic	Identifying new theories, policies, plans or actions	• What types of services are required to meet needs • What actions needed to make services more effective? • How can systems be improved? • What strategies are required to overcome the problems?

Framework Analysis Steps Overview:

Framework analysis is flexible during the analysis—it allows the user to either collect all the data and then analyse it or perform the data analysis during the process of collection. The gathered data is sifted, charted, and sorted in the analysis stage in keeping with key issues and themes. This involves a five-step process (Ritchie, & Spencer, 1994):

1. Familiarization
2. Identification of a thematic framework
3. Indexing
4. Charting
5. Mapping and Interpretation

Familiarization is the process during which the researcher becomes familiarized with the collected data transcripts. In this process, the researcher gets an overview of the collected data. In other words, the researcher becomes absorbed in the data by reading the transcripts, listening to audiotapes, or studying the field. The illustration below depicts the five-step process of framework analysis:

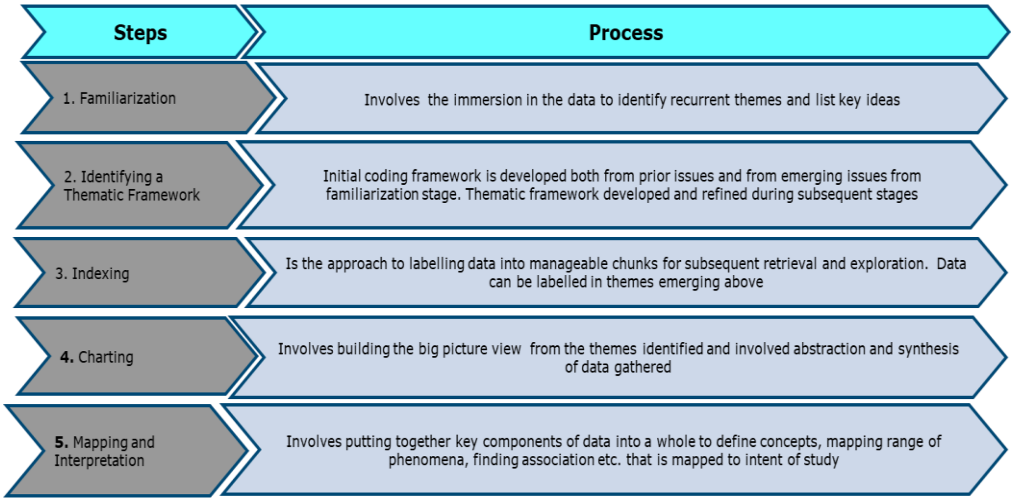


Figure 4.15: Overview of framework analysis concept map

Identifying a thematic framework: The recognition of emerging themes or issues in the dataset by the researcher takes place. The notes taken during the familiarization stage are used in this regard. The key issues, concepts, and themes expressed by the participants now form the platform for a thematic framework that can be used for filtering and classifying the data (Ritchie & Spencer, 1994). The researcher may have a set of a priori issues, but it is important to keep an open mind. Ritchie and Spencer (1994) stress that the thematic framework is only tentative and there are further chances of refining it at subsequent stages of analysis. Indexing refers to the identification of portions or sections of the data that correspond to a particular theme. This process is applied to all the gathered textual data. For the sake of convenience, Ritchie and Spencer (1994) recommend the use of a numerical system for indexing references and its annotation in the margin beside the text. Specific data indexed in the previous stage is now arranged in the charts of the themes. Such data is raised from its original textual context and put in charts comprising headings and subheadings drawn during the thematic framework, or from a priori research inquiries, or in a way that is believed to be the best way to report the research. Mapping and interpretation involve the analysis of the key characteristics that have been mentioned in the charts. This analysis should provide a schematic diagram of the event/phenomenon and accordingly guide the researcher in interpreting the dataset. At this point, the researcher becomes aware the qualitative analysis objectives that are ‘defining concepts, mapping range and nature of phenomena, creating typologies, finding associations, providing explanations, and developing strategies' (Ritchie, & Spencer, 1994). For the researcher, the question of identifying a conceptual framework for RE microgrid-based rural electrification fits with both contextual and strategic categories as we are interested in finding out the form and nature where such conceptual framework exists and help evolve new theories. The researchers following qualitative techniques are divided on whether it would be helpful to use special software for their analysis or any generic software (MS word, Excel spreadsheets).

While deciding on the above, we kept the following in perspective. 1. The Complexity of the data being handled 2. The aim of the research 3. The depth of the analysis required 4. The work justifying the cost of any specialized software 5. The expertise of the researcher in the field being researched 6. The preference of the researcher 7. The value added by using such software (Phelps, Fisher, & Ellis, 2007). Since the number of studies on the RE microgrid-based rural electrification framework happens to be limited, the researcher has gone ahead with the manual method as using any specialized software would not have provided any additional benefit or perspective. The stepwise process description and methodology output of the framework analysis is indicated in the table below:

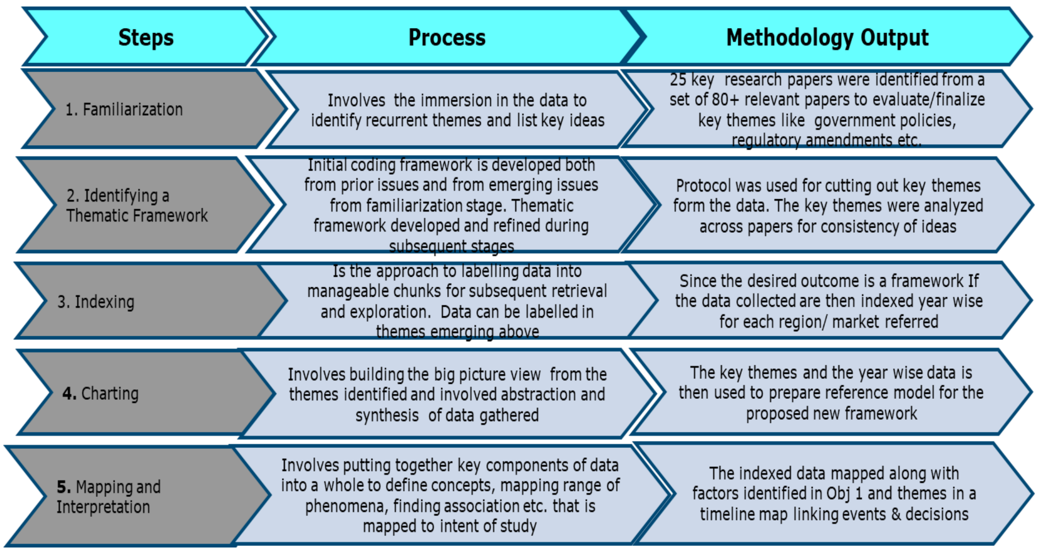


Figure 4.16: Illustration of framework analysis process steps for qualitative analysis

In order to study the evolution of rural electrification, renewable energy adaption, and the microgrid framework model in developing/developed economies [e.g., Laos PDR, South Korea/ ROK] for energy security, using themes and indexing, charts for each country have been drawn:

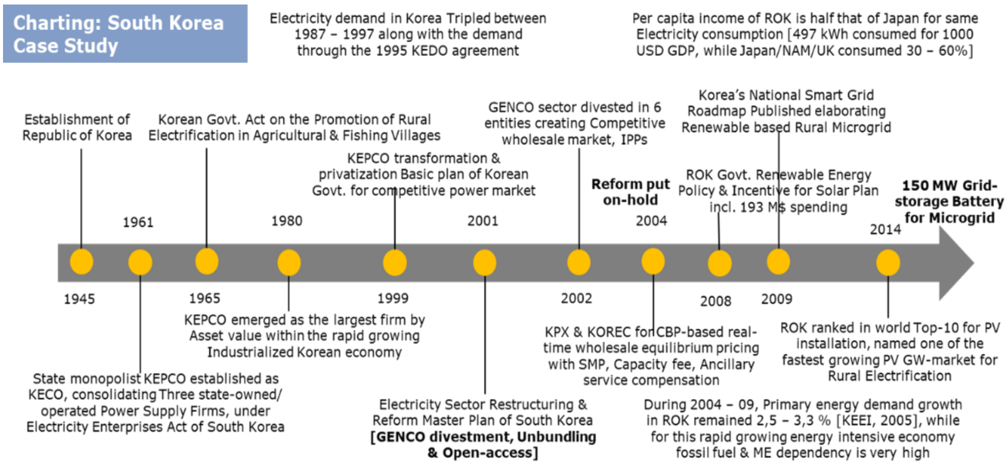


Figure 4.17: ROK/ South Korea Electrification Framework case study

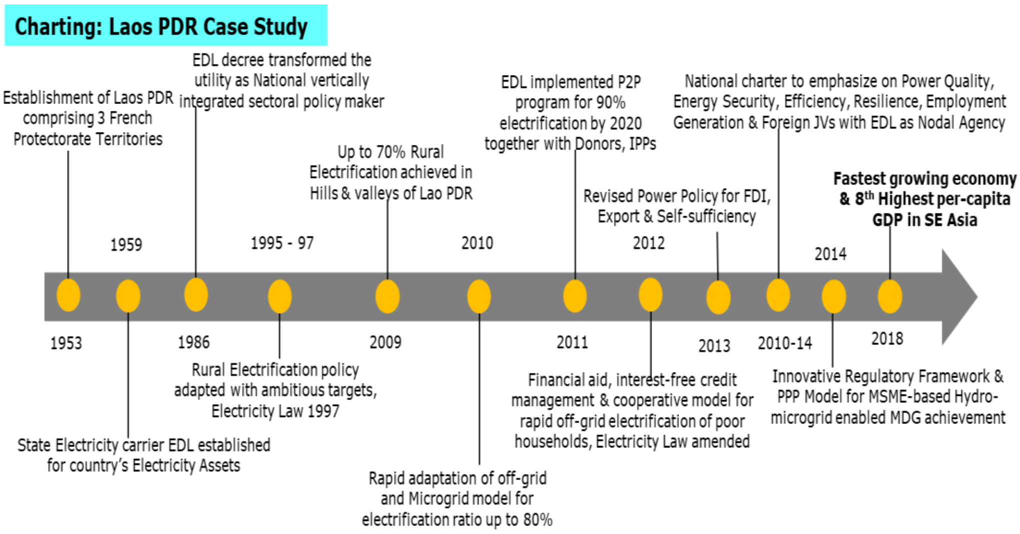


Figure 4.18: Laos PDR Electrification Framework case study

4.10 VALIDITY AND RELIABILITY

The concept of validity and reliability is broader as the present study involves both qualitative and quantitative data. The term 'reliability' in this research is termed to stabilize the study findings, whereas validity is termed to determine the trustworthiness of such findings. In this study, the internal consistency method is used to validate the reliability of the instrument. Below are the key steps to validate the research instruments involved in the study of the research objectives:

- Clear identification of the object of measurement. Concepts like ‘sustainable’ or ‘rural electrification’ are operationalized in concrete terms.
- Defining the relevant elements of these objects to determine the ‘sustainability of rural electrification through microgrid framework’ and reviewing the literature; consulting the stakeholders; and gathering the preliminary qualitative data through focus groups, interviews, or surveys.
- Developing measures (e.g., survey questions) for each of these elements along with a limited number of closed-ended questions to formulate the effective questionnaire.
- Reviewing and pilot testing the survey. Depending on available budget and time, we need to talk through the survey questions with all potential respondents, key stakeholders, and colleagues to review the questions (by completing the survey and taking feedback on the content) for necessary updates in order to ensure the possibly enhanced results over a Likert scale-based analysis.
- Data validation, currency, consistency, correctness etc., out of the seven data quality dimensions, are to be verified and reported as well.

Every research ought to include a thorough description of the population of interest, an explanation of the process that has been used to select and gather data on study subjects, definitions of key variables and concepts, descriptive statistics for main variables, and a description of the analytic techniques. Research quality and validity should be addressed for the users of the research so that they could be comfortable with the outputs. A valid study provides the answers to research questions in a scientifically rigorous manner. There are three areas where a study’s validity could be threatened: Internal, external, and construct validity.

Internal validity shows whether a research study's outcomes could be attributed to independent variables or experimental manipulations, and not to some other factor or set of factors. To find out if a research study has internal validity, it should be checked whether the changes in the outcome are attributable to alternative explanations not explored in the study.

External validity means the extent to which a study's results can be generalized to other settings (ecological validity), other people (population validity), and over time (historical validity). To check if a study has external validity, it is important to find out whether the findings apply to individuals whose place and circumstances are different from those of the study participants. For example, a research study shows that a new curriculum has improved the reading comprehension of third-grade children in Iowa. A research consumer would need to know whether this new curriculum may be effective with third graders in New York or with children in other elementary grades. Those studies are more likely to have external validity which randomly select participants from the most diverse and representative populations and are conducted in natural settings.

Construct validity is the degree to which a variable, test, questionnaire, or instrument measures the theoretical concept that the researcher expects to measure. To check if a study has construct validity, it should be inquired whether the study has adequately measured its key concepts. For example, a study on reading comprehension should present convincing evidence that reading tests measure reading comprehension. Studies are more likely to have construct validity if they use measures that have been independently validated in prior studies.

Corbin and Strauss stress that validity and reliability are terms used more for qualitative inferences. These are not very important when carrying out qualitative research (Corbin & Strauss, 2008, p.301)

Silverman (2005) has suggested many strategies to help increase the validity of research findings. These include the constant comparison method where the data collected is tested in next interviews and the data is treated comprehensively and tabulated. The grounded theory method uses constant comparison to validate the research.

However, Charmaz (2006) offers a list of criteria for evaluating the constructionist grounded theory. Corbin and Strauss find these criteria to be the best and covering all the aspects required for qualitative research (Corbin, & Strauss, 2008).

The four criteria which we will use to test the quality and validity of this research are:

1. Credibility
2. Originality
3. Resonance
4. Usefulness

Credibility:

It is important to check how credible the research is so that it can be referred to with confidence. According to Charmaz, the following points need to be addressed to test the credibility:

1) The gathered data and analysis should be linked logically
2) The data collected should be sufficient to back the results
3) The categories should be based on the large size and array of empirical observations

This research used the mixed method to deduce the result. The use of the mixed method has helped to triangulate the data. Moreover, the grounded theory method used for qualitative analysis uses the constant comparison method that lends credence to the validity of the results. This research has also used all types of data collection methods such as:

1) Primary sources like questionnaire surveys
2) Secondary sources like the key literature on the subject
3) Interviews of key energy utility professionals

All these have provided adequate empirical evidence to support this research. Also, the data is comprehensive and very detailed, which required a few years to collect.

Originality of Research:

The main points to consider for testing whether the research has got originality are:

1) The categories generated by the research should be fresh
2) The categories generated should offer some new insights
3) The output of the research should have social, practical, and theoretical significance
4) The grounded theory method should have helped to refine current ideas, provided challenge to existing concepts, and developed new ideas, practices, or concepts.

The research offers a new insight by providing a framework for distributed RE microgrid-based rural electrification which did not exist earlier. There were many fresh categories which were added to the conceptual lens and a few categories got modified. The grounded theory, therefore, has helped to challenge and extend/refine the current understanding. India, as discussed earlier, is a country of 1.3 billion people who need uninterrupted energy at affordable prices for the purpose of energy security. Development of the framework for distributed RE microgrid-based rural electrification in the Indian scenario will help achieve this objective by adding substantially to other forms of energy sourcing, energy efficiency, and energy conservation.

Resonance:

The key issues to be tested for resonance, according to Charmaz, are:

1) When the people who have been interviewed understand what has been asked and why grounded theory resonate with their circumstances
2) The categories which are built as per the research process should demonstrate completeness.

The framework was created using the grounded theory. The constant comparison method in grounded theory helps to validate the emerging categories. The last two expert interviews in the field validated the previous interviews/categories and did not signal any new category. The fullness of the study is portrayed by the experts' interviews.

Usefulness:

The main areas addressed demonstrate the usefulness of the research as per Charmaz:

1) The output and analysis offer ideas and solution which are useful for everyday work
2) The research work should contribute to existing knowledge and help to make the world a better place to live.
3) The research work and output should help stimulate further research in important areas.

The developed framework can potentially be used by the government, policymakers, regulators, industry experts, and consultants to help develop a mechanism for developing a strong RE microgrid-based rural electrification model for long-term sustainable and reliable electricity supply for rural communities at affordable prices. In addition, this research throws an open window for multiple research types in each category of the areas highlighted in the framework, since the objective was to create a framework and not to go into details of each and every element of the framework. Each element, being a complex issue in itself, can be picked up by future researchers. Hence, it can be stated with confidence that this research meets the criteria of credibility, originality, resonance, and usefulness. Therefore, the research can be termed as potentially as valid and of high quality.

4.11 ETHICAL CONSIDERATION

The author of this research study obtained ethical approval before starting the research. An informed consent, including details of the study and the possible implications of participation, was provided to all the respondents before they participated in the research. This study did not demand any personal information from the participants and also ensured voluntary participation. Moreover, the study participants were not forced to answer the questions which they do not want to. This study does not reveal the identity of the participants in the data collection, data analysis, and in the results of the study, thereby ensuring the anonymity and confidentiality of the participants. The present chapter provides a detailed view of the framework adopted for the study as well as the type of methodology adopted for the present study. In this chapter, a detailed view of the mixed methodology, its significance in case of the present study, and its general features and background are presented in a precise manner. Furthermore, the research design, philosophical paradigm, approach, and conventions tailed in this study were also discussed elaborately. The next chapter uses the proposed data presentation and theoretical methods in order to investigate quantitative and qualitative data based on the methodological recommendations that have been detailed in this chapter.

CHAPTER- 5

QUANTITATIVE DATA ANALYSIS & OBSERVATIONS

This chapter presents the statistical findings for the data collected from the respondents. In the chapter, the researcher provides the results of the quantitative data. The data was first put into an excel file and transferred into the SPSS 20.0 version. Thus, the present study results were analysed using the SPSS software. The sample size taken for the study is n=337. Percentage analysis was performed to find out the demographical information of respondents. Descriptive statistics were used to summarize the data. All the variables were expressed as the mean ± standard deviation (mean ± SD). The independent samples t-test compares two groups on the mean value of a continuous normally distributed variable.

Demographic Information

Table 5.1: Frequency of gender of the respondents

	Frequency (n)	Percentage (%)
Male	193	57.3
Female	144	42.7
Total	**337**	**100.0**

Table 5.1 depicts the gender of the respondents. It shows that 57.3% of the respondents were male and 42.7% of the respondents were female.

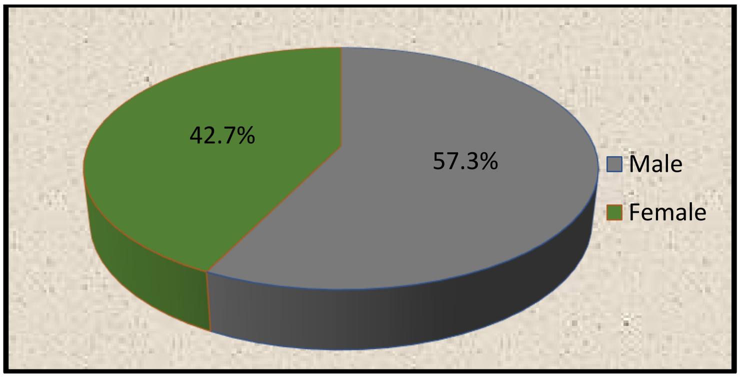


Figure 5.1: Percentage of gender of the respondents

Table 5.2: Frequency of age of the respondents

	Frequency (n)	Percentage (%)
18–30 years	48	14.2
30–40 years	143	42.4
40–50 years	111	32.9
50–60 years	30	8.9
>60 years	5	1.5
Total	**337**	**100.0**

Table 5.2 depicts the age of the respondents. It was found that 42.4% of the respondents are aged 30–40 years, followed by 32.9% of the respondents aged 40–50 years, 14.2% of the respondents aged 18–30 years, and 8.9% respondents aged between 50 and 60 years.

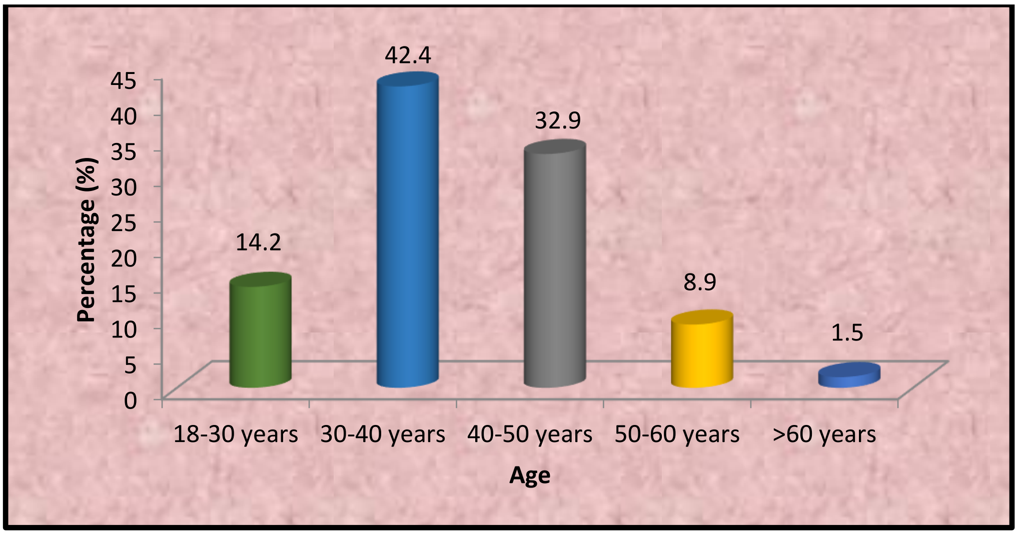


Figure 5.2: Percentage of age of the respondents

Table 5.3: Frequency of people who live in your household

	Frequency (n)	Percentage (%)
< 3 P	18	5.3
3–5 P	218	64.7
5–8 P	92	27.3
> 8 P	3	0.9
Not Known	6	1.8
Total	**337**	**100.0**

Table 5.3 reveals the people who live in your household. Among the respondents, 64.7% stated that 3–5 people live in the household, while 27.3% of the respondents stated that 5–8 people live in the household. Moreover, 5.3% of the respondents stated that < 3 people live in their households. As much as 0.9% of the respondents stated that >8 people live in their households.

Table 5.4: Frequency of people aged under 5 years who live in the household

	Frequency (n)	**Percentage (%)**
< 1 P	110	32.6
1 - 3 P	219	65.0
> 5 P	4	1.2
Not Known	4	1.2
Total	**337**	**100.0**

Table 5.4 reveals that people aged under 5 years live in the household. The majority (65%) of the respondents stated that 1–3 people aged under 5 years live in their households. This is followed by 32.6% of the respondents who stated that <1 people aged under 5 years live in their households. As much as 1.2% of the respondents stated that >5 people aged under 5 years live in their households.

Table 5.5: Frequency of rooms in the house

	Frequency (n)	**Percentage (%)**
< 2 R	164	48.7
2 - 4 R	149	44.2
4 - 6 R	16	4.7
Not Known	8	2.4
Total	**337**	**100.0**

Table 5.5 reveals the frequency of rooms that respondents have in the household. It was found that the majority (48.7%) of the respondents have less than 2 rooms, while 44.2% of the respondents have 2–4 rooms and 4.7% have 4–6 rooms.

Chi-square test

Table 5.6: Association between people who live in households and people aged under 5 years who live in households

People living in the household (Including you)	How many people aged under 5 years live in your household?				Total	p value
	<1 P	1 - 3 P	> 5 P	Not Known		
< 3 P	12 (10.9)	3 (1.4)	1 (25.0)	2 (50.0)	**18 (5.3)**	**0.000****
3–5 P	51 (46.4)	166 (75.8)	1 (25.0)	0 (0.0)	**218 (64.7)**	
5–8 P	44 (40.0)	48 (21.9)	0 (0.0)	0 (0.0)	**92 (27.3)**	
> 8 P	0 (0.0)	1 (0.5)	1 (25.0)	1 (25.0)	**3 (0.9)**	
Not known	3 (2.7)	1 (0.5)	1 (25.0)	1 (25.0)	**6 (1.8)**	
Total	**110 (100.0)**	**219 (100.0)**	**4 (100.0)**	**4 (100.0)**	**337 g(100.0)**	

Chi-square:135.754, **p<0.01

Table 5.6 reveals the association between people living in households and people aged under 5 years who live in households by using the chi-square test. It is observed that 64.7% of the respondents stated that 3–5 people live in their households. Furthermore, 75.8% of the respondents stated that 3–5 people lived in their households and 1–3 people aged under 5 years live in the households. From the chi-square value (135.754) and p value (p=0.000<0.01), it is evident that there is an association between people who live in households and people aged under 5 years who live in the household**.**

Socio-economic aspects of the target geography [Hilly terrain areas of North Bengal, India]

Table 5.7: Frequency of service providers in locality

	Frequency (n)	Percentage (%)
SEB/State utility	193	57.3
Group supply/Co-operative	129	38.3
Panchayat/Municipality	2	0.6
Not known	13	3.9
Total	**337**	**100.0**

Table 5.7 depicts the service provider in locality. It was found that 57.3% of the respondents stated the SEB/state utility as their service provider,

while 38.3% of the respondents stated group supply/co-operative and 0.6% of the respondents stated panchayat/municipality as their service providers.

Table 5.8: Frequency of source of community funding

	Frequency (n)	Percentage (%)
Panchayat	198	58.8
Co-operative	102	30.3
Govt. body	23	6.8
Others	14	4.2
Total	**337**	**100.0**

Table 5.8 depicts the source of community funding. It was found that 58.8% of the respondents stated panchayat as the source of community funding, while 30.3% of the respondents stated co-operatives for that purpose. As much as 6.8% of the respondents stated government bodies as the source of community funding.

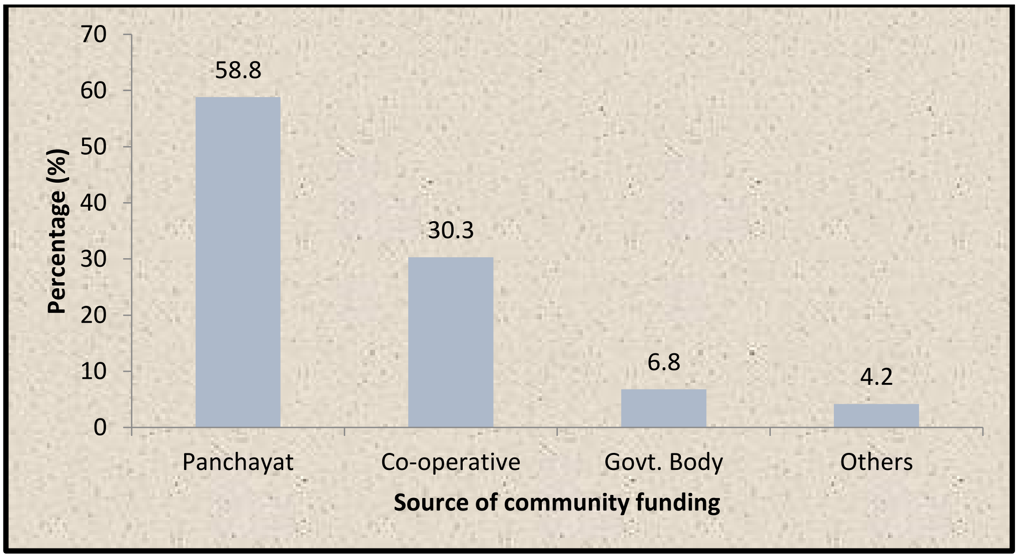


Figure 5.3: Percentage of source of community funding

Table 5.9: Frequency of micro-finance institutions (MFIs) in locality

	Frequency (n)	Percentage (%)
Yes	201	59.6
No	46	13.6
Not known	90	26.7
Total	**337**	**100.0**

Table 5.9 depicts the micro-finance institutions (MFIs) present in the locality. As much as 59.6% of the respondents stated that they have MFIs in

their localities, while 13.6% of the respondents stated that they do not have MFIs in their localities.

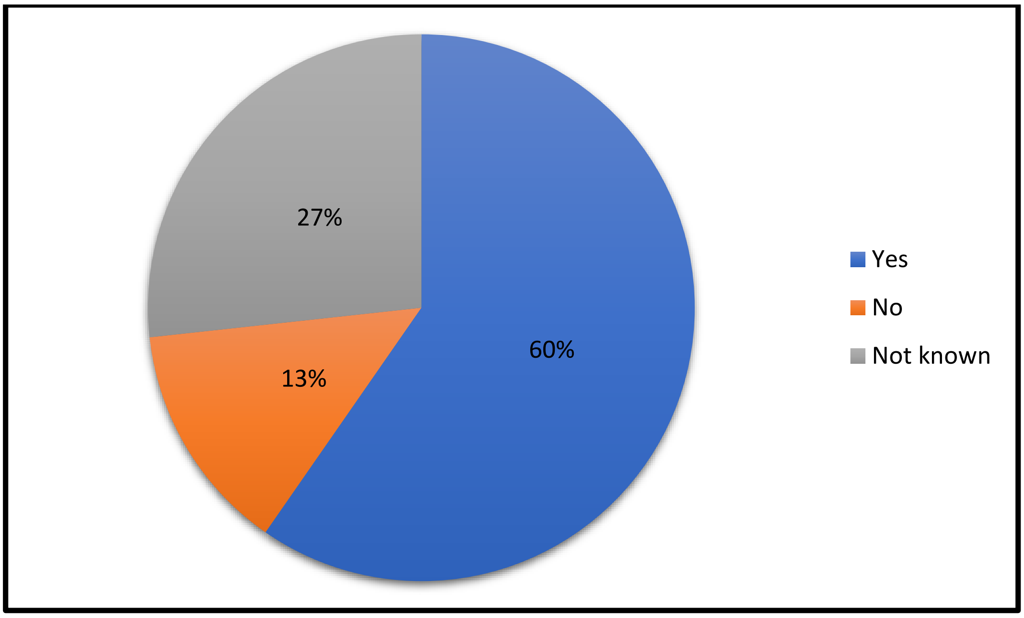


Figure 5.4: Percentage of micro-finance institutions (MFIs) in locality

Table 5.10: Frequency of family income/month (Rs)

	Frequency (n)	**Percentage (%)**
<2500	93	27.6
2500–5000	56	16.6
5000–10000	41	12.2
10000–20000	84	24.9
> 20000	59	17.5
Not Known	4	1.2
Total	**337**	**100.0**

Table 5.10 reveals the frequency of family income/month (Rs). Among the respondents, 27.6% of the respondents' family income is less than INR 2500, while 24.9% of the respondents' family income is INR 10000–20000, 17.5% of the respondents' family income is >INR 20000, and 16.6% of the respondent's family income is INR 2500–5000.

Table 5.11: Frequency of having the membership of any co-operative/society/credit financial institution

	Frequency (n)	Percentage (%)
Yes	171	50.7
No	166	49.3
Total	**337**	**100.0**

Table 5.11 reveals the respondents' membership of any co-operative/society/credit financial institution. Most of the respondents (50.7%) stated that they are members of a co-operative/ society/ credit financial institution, while 49.3% of the respondents stated that they do not have any such membership.

Table 5.12: Frequency of major source(s) of income for family

	Frequency (n)	Percentage (%)
Farming	4	1.2
Service	58	17.2
Teaching	40	11.9
Cattles	18	5.3
Business	21	6.2
Self-employed	5	1.5
Wage labourer	94	27.9
Multiple	97	28.8
Total	**337**	**100.0**

Table 5.12 reveals the frequency of major source(s) of income for the families of the respondents. Among the respondents, 28.8% stated multiple sources. Moreover, 27.9% of the respondents are stated to earn from being wage labourers, while 17.2% of the respondents earn from services. The income of 11.9% of the respondents comes from teaching, while 6.2% of the respondents earn from their businesses and 5.3% of the respondents earn from their cattle.

Chi-square test

Table 5.13: Association between family income/month and micro-finance institutions (MFIs) in locality

Family income	Micro-finance institutions (MFIs) in the respondents' locality			Total	p value
	Yes	**No**	**Not known**		
<2500	6 (3.0)	3 (6.5)	84 (93.3)	93 (27.6)	**0.000****
2500–5000	51 (25.4)	2 (4.3)	3 (3.3)	56 (16.6)	
5000–10000	40 (19.9)	1 (2.2)	0 (0.0)	41 (12.2)	
10000–20000	43 (21.4)	40 (87.0)	1 (1.1)	84 (24.9)	
> 20000	59 (29.4)	0 (0.0)	0 (0.0)	59 (17.5)	
Not known	2 (1.0)	0 (0.0)	2 (2.)	4 (1.2)	
	201 (100.0)	46 (100.0)	90 (100.0)	337 (100.0)	

Chi-square: 373.894, *p<0.01

Table 5.13 reveals the association between family income/month and MFIs present in the locality by using the chi-square test. It is observed that the majority (27.6%) of the respondents' family income is >INR 2500. Moreover, 25.4% of the respondents' family income is INR 2500–5000 and MFIs are present in their localities. From the chi-square value (373.894) and p value (p=0.000<0.01), it is evident that there is an association between family income/month and MFIs in the locality.

Table 5.14: Association between the description of home-based business and having any home-based business

Description of home-based business	Having any home-based business		Total	p value
	Yes	No		
Food/Grocery	38 (24.7)	0 (0.0)	**38 (11.3)**	**0.000****
Trade/Sales	13 (8.4)	0 (0.0)	**13 (3.9)**	
Agriculture products	12 (7.8)	0 (0.0)	**12 (3.6)**	
Other retailer	27 (17.5)	0 (0.0)	**27 (8.0)**	
Finance	51 (33.1)	0 (0.0)	**51 (15.1)**	
Others	13 (8.4)	0 (0.0)	**13 (3.9)**	
Not applicable	0 (0.0)	183 (100.0)	**183 (54.3)**	
Total	**154 (100.0)**	**183 (100.0)**	**337 (100.0)**	

Chi-Square:337.000, **p<0.01

Table 5.14 reveals the association between descriptions of home-based businesses and having any home-based business by using the chi-Square test. It is observed that 15.1% of the respondents stated finance as the home-based business. Furthermore, 33.1% of the respondents stated finance to be their home-based business. From the chi-square value (337.000) and p value (p=0.000<0.01), it is evident that there is an association between descriptions of home-based businesses and having a home-based business.

Table 5.15: Association between current or savings account at a bank/ non-banking financial institution and why not bank/ NBFC A/c or MFI membership

Do you have a current or savings account at a bank/ non-banking financial institution?	Why not bank/NBFC A/c or MFI membership					Total
	There are none nearby	Do not qualify as individual/ family	Documentation issues	Others	Not applicable	
Yes	0 (0.0)	0 (0.0)	94 (93.1)	0 (0.0)	229 (100.0)	**323 (95.8)**
No	2 (100.0)	2 (100.0)	7 (6.9)	3 (100.0)	0 (0.0)	**14 (4.2)**
Total	**2 (100.0)**	**2 (100.0)**	**101 (100.0)**	**3 (100.0)**	**229 (100.0)**	**337 (100.0)**

Chi-square:173.381, p=0.000

Table 5.15 reveals the association between 'current and savings account at a bank/ non-banking financial institution' and 'why not bank/ NBFC A/c or MFI membership' by using the chi-Square test. It is observed that 95.8% of the respondents have current or savings accounts at a bank/ non-banking financial institution. Moreover, 93.1% of the respondents have current or savings accounts at a bank/ non-banking financial institution and mentioned documentation issues. From the chi-square value (173.381) and p value (p=0.000<0.01), it is evident that there is an association between 'current and savings account at a bank/non-banking financial institution' and 'why not bank/ NBFC A/c or MFI membership'.

Table 5.16: Association between family income/month and education

Income	What is the highest level of education of the head of your family/ household?						Total
	No formal education	Primary school completed	Secondary school completed	Higher education completed	University completed	Postgraduate	
<2500	9 (56.2)	83 (94.3)	1 (4.0)	0 (0.0)	0 (0.0)	0 (0.0)	**93 (27.6)**
2500–5000	3 (18.8)	3 (3.4)	23 (92.0)	27 (31.0)	0 (0.0)	0 (0.0)	**56 (16.6)**
5000–10000	1 (6.2)	1 (1.1)	0 (0.0)	39	0 (0.0)	0 (0.0)	**41 (12.2)**
10000–20000	0 (0.0)	0 (0.0)	1 (4.0)	21 (24.1)	22 (40.0)	40 (60.6)	**84 (24.9)**
> 20000	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	33 (60.0)	26 (39.4)	**59 (17.5)**
Not Known	3 (18.8)	1 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	**4 (1.2)**
Total	**16 (100.0)**	**88 (100.0)**	**25 (100.0)**	**87 (100.0)**	**55 (100.0)**	**66 (100.0)**	**337 (100.0)**

Chi-square:664.241, p=0.000

Table 5.16 reveals the association between family income/month and education with the help of the chi-square test. It is observed that 27.6% of the respondents' income happens to be less than INR 2500. Further, 94.3% of the respondents have finished primary school education and are earning less than INR 2500 per month. From the chi-square value (664.241) and p value (p=0.000<0.01), it is evident that there is an association between family income/month and education**.**

Table 5.17: Association between sources of community funding and micro-finance institutions (MFIs) present in locality

Source of community funding	Are micro-finance Institutions (MFIs) present in locality			Total	p value
	Yes	No	Not known		
Panchayat	113 (56.2)	3 (6.5)	82 (91.1)	**198 (58.8)**	**0.000****
Co-operative	58 (28.9)	41 (9.1)	3 (3.3)	**102 (30.3)**	
Govt. body	19 (9.5)	1 (2.2)	3 (3.3)	**23 (6.8)**	
Others	11 (5.5)	1 (2.2)	2 (2.2)	**14 (4.2)**	
Total	**201 (100.0)**	**46 (100.0)**	**90 (100.0)**	**337 (100.0)**	

Chi-square:119.164, **p<0.01

Table 5.17 displays the association between sources of community funding and MFIs present in the locality by using the chi-square test. It is observed that the majority (58.8%) of the respondents stated panchayat to be their source of community funding. Moreover, 56.7% stated panchayat as their source of community funding and have MFIs present in their localities. From the chi-square value (119.164) and p value (p=0.000<0.01), it is evident that there is an association between sources of community funding and MFIs present in the locality.

Table 5.18: Association between the membership of any co-operative/society/credit financial institution and current or savings account at a bank/non-banking financial institution

Current or savings account at a bank/ non-banking financial institution	Membership of any co-operative/ society/ credit financial institution		Total	p value
	Yes	No		
Yes	171 (100.0)	152 (91.6)	**323 (95.8)**	**0.000****
No	0 (0.0)	14 (8.4)	**14 (4.2)**	
Total	**171 (100.0)**	**166 (100.0)**	**337 (100.0)**	

Chi-square:15.047, **p<0.01

Table 5.18 reveals the association between the membership of any co-operative/society/ and credit financial institution and current or savings accounts at a bank/non-banking financial institution by using the chi-square test. It is observed that 95.8% of the respondents have current or savings accounts at a bank/non-banking financial institution. Further, 100% of the respondents have current or savings accounts at a bank/ non-banking financial institution and also have the membership of any co-operative/society/credit financial institution. From the chi-square value (15.047) and p value (p=0.000<0.01), it is evident that there is an association between membership of any co-operative/society/credit financial institution and current or savings accounts at a bank/non-banking financial institution**.** Techno-commercial feasibility of the proposed solar power-based microgrid.

Table 5.19: Frequency of electrical connection at home

	Frequency (n)	Percentage (%)
Yes	306	90.8
No	31	9.2
Total	**337**	**100.0**

Table 5.19 depicts the frequency of respondents having an electrical connection at home. It was found that 90.8% of the respondents have electricity at home, while 9.2% respondents do not enjoy any electrical connection.

Table 5.20: Percentage of different electricity price slabs used by the different consumers for electrical connection at home

	Frequency (n)	Percentage (%)
2–5 INR	149	44.2
5–7 INR	62	18.4
> 7 INR	5	1.5
Not known	121	35.9
Total	**337**	**100.0**

Table 5.20 depicts the price of electricity paid per unit/ kWh. As much as 44.2% of the respondents have paid INR 2–5 for electricity, while 18.4% of the respondents have paid INR 5–7 for electricity. Moreover, 1.5% of the respondents have paid >INR 7 for electricity.

Table 5.21: Perception percentage about available alternative energy sources in the target geography

	Frequency (n)	Percentage (%)
Sunlight	180	53.4
Wind	77	22.8
Biogas	5	1.5
Waterfalls	75	22.3
Total	**337**	**100.0**

Table 5.21 reveals the frequency of alternative energy sources that are amply available in the locality. It was found that 53.4% of the respondents stated sunlight as their alternative energy source. Moreover, 22.8% of the respondents

stated wind and 22.3% of the respondents stated waterfalls, respectively, as their alternative energy sources.

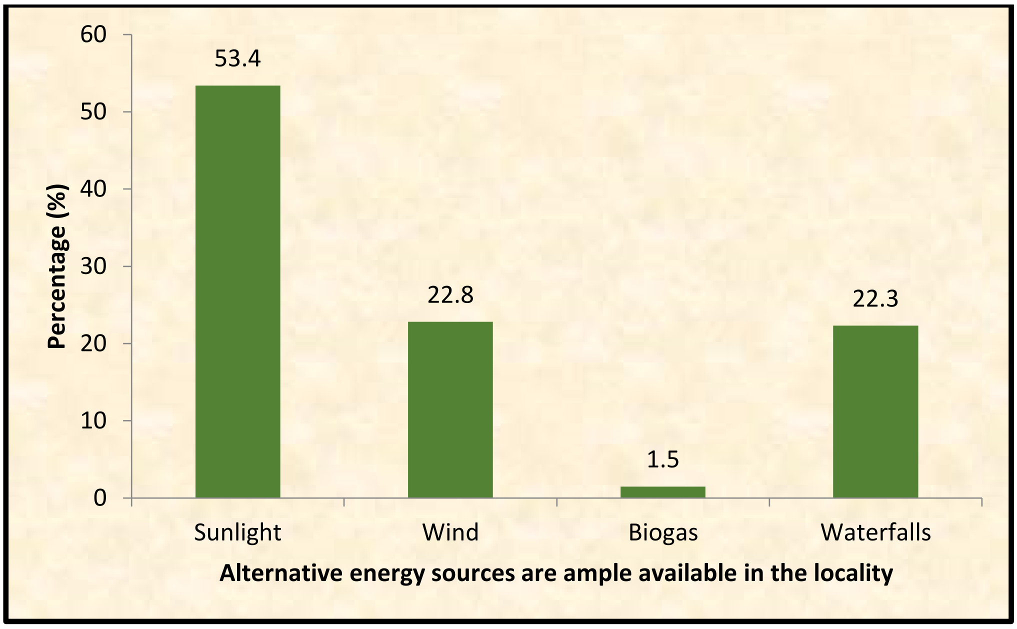


Figure 5.5: Percentage of alternative energy sources is amply available in locality

Table 5.22: Frequency of interest in non-conventional energy for electricity at the respondents' home

	Frequency (n)	Percentage (%)
Yes	312	92.6
No	14	4.2
Not known	11	3.3
Total	**337**	**100.0**

Table 5.22 depicts the interest in non-conventional energy for electricity in the respondents' home. As much as 92.6% of the respondents stated that they are interested in non-conventional energy for electricity at home, while 4.2% of the respondents stated that they are not interested in non-conventional energy for electricity at home.

Table 5.23: Frequency of major driving factor in non-conventional energy-based Electricity

	Frequency (n)	Percentage (%)
Additional income	8	2.4
New business opportunity	4	1.2
Free electricity	175	51.9
Govt. subsidy	67	19.9
Reliable electricity supply	50	14.8
Environmental reasons	33	9.8
Total	**337**	**100.0**

Table 5.23 reveals the frequency of a major driving factor in non-conventional energy-based electricity. Among the respondents, 51.9% pointed out free electricity as the major factor, while 19.9% considered govt. subsidy as the major factor. In addition, 14.8% of the respondents termed reliable electricity supply, 9.8% stated environmental reasons, and 2.4% stated additional income, respectively, as major factors for non-conventional energy-based electricity.

Table 5.24: Frequency of maximum willingness to invest/spend in first year (Rs)

	Frequency (n)	Percentage (%)
<1000	70	20.8
1000–5000	59	17.5
5000–12000	6	1.8
Not willing to pay	202	59.9
Total	**337**	**100.0**

Table 5.24 reveals the frequency of maximum willingness to invest/spend in first year (Rs). As much as 59.9% of the respondents stated that they were not willing to pay, while 20.8% stated that they are willing to pay <INR 1000. Moreover, 17.5% of the respondents stated that they are willing to pay INR 1000–5000. Furthermore, 1.8% of the respondents stated that they are willing to pay INR 5000–12000.

Chi-square test

Table 5.25: Association between electrical connection at home and electric network/ grid power line in locality

Electrical connection at home	Electric network/ grid power line in locality		Total	p value
	Yes	No		
Yes	306 (93.9)	0 (0.0)	**306 (90.8)**	**0.000****
No	20 (6.1)	11 (100.0)	**31 (9.2)**	
Total	**326 (100.0)**	**11 (100.0)**	**337 (100.0)**	

Chi-square:112.244, **p<0.01

Table 5.25 reveals the association between electrical connection at home and an electric network/grid power line in the locality by using the chi-square test. It is observed that the majority (90.8%) of the respondents have electrical connection at home. Further, 93.9% of the respondents have electrical connection at home and also have an electric network/grid power line in their localities. From the chi-square value (112.244) and p value (p=0.000<0.01), it is evident that there is an association between electrical connection at home and an electric network/grid power line in the locality.

Table 5.26: Association between interest in non-conventional energy for home electricity and major driving factor in non-conventional energy-based electricity

Major driving factor in non-conventional energy-based electricity	Interested in non-conventional energy for home electricity				
	Yes	No	Not known	Total	p value
Additional income	8 (100.0)	0 (0.0)	0 (0.0)	**8 (100.0)**	**0.000****
New business opportunity	2 (50.0)	1 (25.0)	1 (25.0)	**4 (100.0)**	
Free electricity	162 (92.6)	4 (2.3)	9 (5.1)	**175 (100.0)**	
Govt. subsidy	57 (85.1)	9 (13.4)	1 (1.5)	**67 (100.0)**	
Reliable electricity supply	50 (100.0)	0 (0.0)	0 (0.0)	**50 (100.0)**	
Environmental reasons	33 (100.0)	0 (0.0)	0 (0.0)	**33 (100.0)**	
Total	**312 (92.6)**	**14 (4.2)**	**11 (3.3)**	**337 (100.0)**	

Chi-Square:36.349, **p<0.01

Table 5.26 reveals the association between interest in non-conventional energy for home electricity and a major driving factor in non-conventional energy-based electricity by using the chi-square test. It is observed 92.6% of the respondents are interested in non-conventional energy for home electricity. Furthermore, 92.6% of the respondents stated that they have been interested in non-conventional energy for home electricity and also stated that free electricity is the major driving factor in non-conventional energy-based electricity. From the chi-square value (36.349) and p value (p=0.000<0.01), it is evident that there is an association between interest in non-conventional energy for home electricity and a major driving factor in non-conventional energy-based electricity.

Table 5.27: Association between electrical connection at home and distance to the electricity supply office

Electrical connection at home	**Distance to the electricity supply office**				**Total**	**p value**
	<0.5 km	**0.5 to 2 km**	**2 to 5 km**	**>5 km**		
Yes	156 (97.5)	102 (85.0)	48 (87.3)	0 (0.0)	**306 (90.8)**	**0.000****
No	4 (2.5)	18 (15.0)	7 (12.5)	2 (100.0)	**31 (9.2)**	
Total	**160 (100.0)**	**120 (100.0)**	**55 (100.0)**	**2 (100.0)**	**337 (100.0)**	

Chi-Square:33.993, **p<0.01

Table 5.27 reveals the association between electrical connection at home and distance to the electricity supply office by using the chi-square test. It is observed 90.8% of the respondents have electrical connection at home. Further, 97.5% of the respondents have electrical connection at home and also stated that their houses are at a distance of <0.5km from the electricity supply office. From the chi-square value (33.993) and p value (p=0.000<0.01), it is evident that there is an association between electrical connection at home and distance to the electricity supply office.

Table 5.28: Association between electrical connection at home and price of electricity paid per unit/kWh

Electrical connection at home	Price of electricity paid per unit/kWh				Total	p value
	2-5 INR	**5-7 INR**	**> INR**	**Not known**		
Yes	149 (100.0)	62 (100.0)	5 (100.0)	90 (74.4)	**306 (90.8)**	**0.000****
No	0 (0.0)	0 (0.0)	0 (0.0)	31 (25.6)	**31 (9.2)**	
Total	**149 (100.0)**	**62 (100.0)**	**5 (100.0)**	**121 (100.0)**	**337 (100.0)**	

Chi-square:60.945, **p<0.01

Table 5.28 reveals the association between electrical connection at home and the price of electricity paid per unit/kWh by using the chi-square test. It is observed that 90.8% of the respondents have electrical connection at home. Furthermore, 100% of the respondents have electrical connection at home and also stated that they have paid 2–5 INR for electricity per unit/kWh. From the chi-square value (60.945) and p value (p=0.000<0.01), it is evident that there is an association between electrical connection at home and the price of electricity paid per unit/kWh.

Prosumer behaviour

Table 5.29: Frequency of access to affordable electricity

	Frequency (n)	**Percentage (%)**
Completely agree	153	45.4
Partially agree	47	13.9
Somewhat agree	76	22.6
Partially disagree	30	8.9
Completely disagree	31	9.2
Total	**337**	**100.0**

Table 5.29 reveals the access to affordable electricity. It was found that 45.4% of the respondents completely agree with this notion, while 22.6% of the respondents somewhat agreed, 13.9% partially agree, 9.2% completely disagree, and 8.9% partially disagree.

Table 5.30: Frequency of willingness to pay some addl. amount for reliable electricity supply at home

	Frequency (n)	Percentage (%)
Partially agree	308	91.4
Somewhat agree	11	3.3
Partially disagree	8	2.4
Completely disagree	10	3.0
Total	**337**	**100.0**

Table 5.30 reveals the willing to pay some addl. amount for reliable electricity supply at home. It was found that 91.4% of the respondents partially agree with this. However, 3.3% of the respondents somewhat agree with this notion, 3% re completely agree, and 2.4% partially disagree.

Table 5.31: Frequency of maximum willingness to pay for reliable electric/month

	Frequency (n)	Percentage (%)
50–100	234	69.4
100–150	60	17.8
150–200	19	5.6
200–300	9	2.7
300–500	5	1.5
Not Willing	10	3.0
Total	**337**	**100.0**

Table 5.31 reveals the spending for electricity/month. It was found that 69.4% of the respondents pay INR 50–100, while 17.8% pay INR 100–150 and 5.6% pay INR 150–200. However, 3% of the respondents are not willing to pay anything. As much as 1.7% of the respondents pay INR 300–500.

Table 5.32: Frequency of reasons for not willing to pay for reliable electricity supply

	Frequency (n)	**Percentage (%)**
The electricity tariff is already too high.	189	56.1
I want to see improvement in electricity supply before I can pay more charges.	15	4.5
Government should provide funds for improvement and provide electric for free/at min. cost	75	22.3
I do not trust that the extra money will be used for the intended purpose	13	3.9
There is more pressing use of extra income to my household than reliable electricity supply	45	13.4
Total	**337**	**100.0**

Table 5.32 reveals the reasons for not willing to pay for reliable electricity supply. It was found that 56.1% of the respondents stated: ‘The electricity tariff is already too high’. As much as 22.3% of the respondents stated: ‘Government should provide funds for improvement and provide electric for free/ min. cost’, while 13.4% stated: ‘There is more pressing use of extra income to my household than reliable electricity supply’. As much as 4.5% of the respondents stated: “I want to see improvement in electricity supply before I can pay more charges”. Moreover, 3.9% of the respondents stated: ‘I do not trust the extra money will be used for the intended purpose’.

Chi-square test

Table 5.33: Association between willingness to pay for reliable electric supply/month and willingness to pay some addl. amount

Maximum willingness to pay for reliable electric supply/month	Are you willing to pay some addl. amount for reliable electricity supply at your home?				Total	p value
	Partially agree	Somewhat agree	Partially disagree	Completely disagree		
50–100	223 (72.4)	10 (90.9)	1 (12.5)	0 (0.0)	**234 (69.4)**	**0.000****
100–150	53 (17.2)	0 (0.0)	7 (87.5)	0 (0.0)	**60 (17.8)**	
150–200	18 (5.8)	1 (9.1)	0 (0.0)	0 (0.0)	**19 (5.6)**	
200–300	9 (2.9)	0 (0.0)	0 (0.0)	0 (0.0)	**9 (2.7)**	
300–500	5 (1.6)	0 (0.0)	0 (0.0)	0 (0.0)	**5 (1.5)**	
Not willing	0 (0.0)	0 (0.0)	0 (0.0)	10 (100.0)	**10 (3.0)**	
Total	**308 (100.0)**	**11 (100.0)**	**8 (100.0)**	**10 (100.0)**	337 (100.0)	

Chi-square:89.345, **p<0.01

Table 5.33 reveals the association between the willingness to pay for reliable electric supply/month and the willingness to pay some addl. amount. It is observed that the majority (69.4%) of the respondents were willing to pay INR 50–100 per month for reliable electric supply. Further, 72.4% of the respondents were willing to pay INR 50–100 per month and also partially agreed with the statement concerning the willingness to pay some addl. amount for reliable electricity supply at home. From the chi-square value (89.345) and p value (p=0.000<0.01), it is evident that there is an association between the willingness to pay for reliable electric supply/month and the willingness to pay some addl. amount.

Independent sample t test

Table 5.34: Difference in means of reasons for not willing to pay for reliable electricity supply between genders of the respondents

	Gender	N	Mean	SD	95% Confidence interval for mean		t value	p value
					Lower bound	Lower bound		
Reasons for not willing to pay for reliable electricity supply	Male	193	2.68	1.863	-.180	0.648	1.104	0.271
	Female	144	2.44	1.975	-0.183	0.652		

Table 5.34 depicts the difference in means of reasons for not willing to pay for reliable electricity supply between genders of the respondents. Since the p values for reasons for not willing to pay for reliable electricity supply is greater than 0.05 significant levels, it can be concluded that there is no difference in the reasons for not willing to pay for reliable electricity supply between genders of the respondents.

Table 5.35: Difference in means of access to affordable electricity, willingness to pay some addl. amount for reliable electricity supply at home, and looking for addl./ new sources of income between genders of the respondents.

	Gender	N	Mean	SD	t value	p value	95% confidence interval of the difference	
							Lower	Upper
Looking for addl./ new sources of income	Male	193	1.60	.579	-0.127	0.899	-.137	.121
	Female	144	1.60	.606				
Have access to affordable electricity	Male	193	2.33	1.405	1.703	0.089	-.038	.535
	Female	144	2.08	1.260				
Willingness to pay some additional amount for reliable electricity supply at your home	Male	193	2.16	.586	-0.295	0.768	-.153	.113
	Female	144	2.18	.633				

Table 5.35 depicts the difference in means of access to affordable electricity, the willingness to pay some addl. amount for reliable electricity

supply at home, and looking for addl./new sources of income between genders of the respondents. Since the p values for looking for addl./ new sources of income, having access to affordable electricity, and the willingness to pay some additional amount for 5 at your home are greater than 0.05 significant levels, it can be concluded that there is no difference in means of looking for addl./new sources of income, having access to affordable electricity, and the willingness to pay some additional amount for reliable electricity supply at home between genders of the respondents.

ANOVA (Analysis of Variance)

Table 5.36: Difference in means of reasons for not willing to pay for reliable electricity supply between ages of the respondents.

	18–30 years	**30–40 years**	**40–50 years**	**50–60 years**	**>60 years**
	Mean±SD				
Reasons for not willing to pay for reliable electricity supply	2.50±2.02	2.27±1.81	3.15±1.95	2.13±1.71	2.00±1.41

	N	**95% confidence interval for mean**		**F value**	**p value**
		Lower bound	**Upper bound**		
18–30 years	48	1.91	3.09	4.109	**0.003****
30–40 years	143	1.97	2.57		
40–50 years	111	2.79	3.52		
50–60 years	30	1.49	2.77		
>60 years	5	.24	3.76		
Total	**337**	**2.37**	**2.78**		

**p<0.01

Table 5.36 depicts the difference in means of reasons for not willing to pay for reliable electricity supply between ages of the respondents. Since the p values for reasons for not willing to pay for reliable electricity supply (F=4.109, p<0.01) is less than 0.05 significant levels, it can be concluded that there are differences in means of reasons for not willing to pay for reliable electricity supply between ages of the respondents.

Table 5.37: Difference in means of access to affordable electricity, willingness to pay some addl. amount for reliable electricity supply at home, and looking for addl./ new sources of income between ages of the respondents.

		N	Mean	SD	SE	95% confidence interval for mean	
						Lower bound	Upper bound
Looking for addl./ new sources of income	18–30 years	48	1.75	.758	.109	1.53	1.97
	30–40 years	143	1.65	.596	.050	1.55	1.75
	40–50 years	111	1.50	.502	.048	1.40	1.59
	50–60 years	30	1.50	.509	.093	1.31	1.69
	>60 years	5	1.60	.548	.245	.92	2.28
	Total	337	1.60	.590	.032	1.54	1.66
Having access to affordable electricity	18–30 years	48	2.08	1.269	.183	1.71	2.45
	30–40 years	143	2.07	1.325	.111	1.85	2.29
	40-50 years	111	2.56	1.431	.136	2.29	2.83
	50-60 years	30	2.07	1.143	.209	1.64	2.49
	>60 years	5	1.60	.894	.400	.49	2.71
	Total	337	2.23	1.348	.073	2.08	2.37
Willing to pay some additional amount for reliable electricity supply at your home	18-30 years	48	2.19	.734	.106	1.97	2.40
	30–40 years	143	2.16	.577	.048	2.07	2.26
	40–50 years	111	2.20	.615	.058	2.08	2.31
	50–60 years	30	2.10	.548	.100	1.90	2.30
	>60 years	5	2.00	.000	.000	2.00	2.00
	Total	337	2.17	.606	.033	2.10	2.23

ANOVA						
		Sum of squares	df	Mean square	F	Sig.
Looking for addl./ new sources of income	Between groups	2.955	4	.739	2.152	0.074
	Within groups	113.965	332	.343		
	Total	116.920	336			
Having access to affordable electricity	Between groups	19.457	4	4.864	2.731	**0.029***
	Within groups	591.403	332	1.781		
	Total	610.861	336			
Willingness to pay some additional amount for reliable electricity supply at your home	Between groups	.406	4	.102	2.274	**0.035***
	Within groups	122.953	332	.370		
	Total	123.359	336			

*p<0.05

Tables 5.37 depicts the difference in means of access to affordable electricity, the willingness to pay some addl. amount for reliable electricity supply at home, and looking for addl. /new sources of income between ages of the respondents. The p values for having access to affordable electricity

(F=2.731, p<0.05) and the willingness to pay some additional amount for reliable electricity supply at home (F=2.274, p<0.05) are less than 0.05 significant levels. Hence, it can be concluded that there is difference in means of having access to affordable electricity and the willingness to pay some additional amount for reliable electricity supply at home between ages of the respondents.

Correlation Analysis

The Pearson correlation coefficient measures the strength and direction of any association between two variables. In this case, the two variables must be measured on a continuous (interval) scale (Srmuniv, 2018). The correlation coefficient (r) ranges from -1 to 1. Based on the sign of the correlation coefficient, we may conclude the following (Gogtay & Thatte, 2017):

- When r is –1, we say there is a perfect negative correlation.
- When r is a value between –1 and 0, we say there is a negative correlation
- When r is 0, we say there is no correlation
- When r is a value between 0 and 1, we say there is a positive correlation
- When r is 1, we say there is a perfect positive correlation

Table 5.38: Relationship between prosumer behaviour, socio-economic characteristics, and techno-commercial penetration

	Prosumer behaviour	**Socio-economic characteristics**	**Techno-commercial penetration**
Prosumer behaviour	1		
Socio-economic characteristics	.373**	1	
Techno-commercial penetration	.261**	.571**	1

**p<0.01

Table 5.38 reveals the relationship between prosumer behaviour, socio-economic characteristics, and techno-commercial penetration by using Pearson correlation analysis. From the table above, it is depicted that socio-economic characteristics (r=0.373, p<0.01) and techno-commercial penetration (r=0.261, p<0.01) have a positively significant relationship with prosumer behaviour.

Hence, there is a relationship between prosumer behaviour, socio-economic characteristics, and techno-commercial penetration.

Regression Analysis

Regression is used to find the association between independent and dependent variables. It means that there is a significant impact of independent variables on the dependent ones. In linear regression, we have to use only one independent variable and dependent variable. But in multiple regression, we can use more than one independent variable and one dependent variable. Both types of regression analysis are used to predict the value of a dependent variable based on the value of an independent variable. A dependent (predictand) variable refers to the variable we want to predict, and independent variable refers the variable we are using to predict the value of the dependent variable.

Table 5.39: Association between socio-economic characteristics and prosumer behaviour

	Unstandardized coefficients		**R Square**	**t value**	**p value**
	Beta	**SE**			
(Constant)	3.044	.122	0.349	24.872	0.000
Socio-economic characteristics	.529	.072		7.369	**0.000****

Dependent variable: prosumer behaviour, **p<0.01

Table 5.39 presents the association between socio-economic characteristics and prosumer behaviour using linear regression analysis. Since the p value for socio-economic characteristics (beta=0.529, t=7.369, p=0.001<0.01) is less than 0.05 significant levels, it is depicted that socio-economic characteristics has a positive and significant impact on prosumer behaviour. In addition, 35% of the variation in prosumer behaviour is dependent on socio-economic characteristics (R-square=0.349).

Table 5.40: Association between techno-commercial penetration and prosumer behaviour

	Unstandardized coefficients		**R square**	**t value**	**p value**
	Beta	**SE**			
(Constant)	1.037	0.239	0.169	4.344	0.000
Techno-commercial penetration	0.376	0.076		4.945	**0.000****

Dependent variable: prosumer behaviour, **p<0.01

Table 5.40 presents the association between techno-commercial penetration and prosumer behaviour using linear regression analysis. Since the p value for techno-commercial penetration (beta=0.376, t=4.945, p=0.000<0.01) is less than 0.05 significant levels, it is depicted that techno-commercial penetration has a positive and significant impact on prosumer behaviour. In addition, 17% of the variation in prosumer behaviour is dependent on techno-commercial penetration (R-square=0.169).

The number of factors has been analysed and identified as below:

Table 5.41:

List of Items	Component					Factor Name
	1	2	3	4	5	
To have affordably priced electricity services	.734					Long term stable policy and promoting electricity trading best practices
To assure equitable access to electricity services to all citizens	.793					
To have stable, predictable, and transparent price policy	.790					
To promote trade in electricity & related products and Technologies	.733					
To promote electricity trading within different states of India	.628					
To promote adaptation and investment in latest technologies	.614					
To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation		.560				Concessional Government funding and financial incentives for Rural Electrification & Renewable Energy Microgrids
To have better tools to estimate the demand potential and capacity planning		.530				
To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors		.729				
Concessional State funding & Financial Incentives for Rural Electrification & Renewable Microgrids		.759				
Stable Fiscal Regimes in Governing Contracts		.656				
To maximise exploitation of locally abundant available renewable energy resources for each of the regions			.670			Resource sharing & Shared Services Approach as well as Risk optimization through JV/ PPP Model adaptation
Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players			.737			
Resource Sharing & Shared Services Approach			.710			

Reducing risk through JV/ PPP Model in Rural Electrification project development			.786			
To have a secured and uninterrupted supply of electricity				.580		Decentralization to secure uninterrupted high-quality supply of Electricity for Energy Security
Decentralisation and small-scale Grid-connected/ Off-grid Ecosystems				.589		
Research and Development				.825		
Promoting electricity conservation by people and industry					.556	Promoting energy efficiency, Electricity conservation, knowledge and technology transfer
To encourage low electrical energy intensity					.616	
To achieve Knowledge and Technology Transfer					.897	

The worked-out rotation component matrix is depicted as below:

Table 5.42:

List of Items	Component				
	1	2	3	4	5
To have a secured and uninterrupted supply of Electricity	.364	.375	-.085	.580	-.076
To have affordably priced electricity services	.734	.293	.067	.059	-.084
To assure equitable access to electricity services to all citizens	.793	.202	.106	.068	-.057
To have stable, predictable, and transparent price policy	.790	.095	.011	.165	.103
To promote trade in electricity & related products and technologies	.733	.197	.116	.052	-.006
To promote electricity trading within different states of India	.628	.406	.072	-.041	-.124
To encourage low electrical energy intensity	-.040	.350	.235	-.017	.616
To promote adaptation and investment in latest technologies	.614	.476	.268	-.013	.079
To maximise exploitation of locally abundant available renewable energy resources for each of the regions	.354	.440	.670	.008	.154
To ensure healthy relations between Union Govt. & State Govts. For effective collaboration & Cooperation	.454	.560	.420	-.047	-.121
Promoting electricity conservation by people and industry	-.005	.489	.451	.071	.556
To have better tools to estimate the demand potential and capacity planning	.448	.530	.380	-.008	-.085
To provide financial incentives for investment in Rural Electrification & Renewable Energy Microgrids by Utilities/ Investors	.320	.729	.198	.019	.044
Maximise strategic tie-up between State Utilities & IPPs/ FIIs/Pvt. Sector Players	.324	.158	.737	.000	-.073
Reducing risk through JV/ PPP Model in Rural Electrification project development	.297	-.003	.786	.025	-.019
Concessional State funding & Financial Incentives for Rural Electrification & Renewable Microgrids	.069	.759	-.075	.025	.116
Stable Fiscal Regimes in Governing Contracts	.656	-.053	-.273	-.428	.344
To achieve Knowledge and Technology Transfer	-.100	.054	.026	.028	.897
Resource Sharing & Shared Services Approach	.142	.034	.710	.004	-.012
Decentralisation and small-scale Grid-connected/ Off-grid Ecosystems	.054	.048	.466	.589	.303
Research and Development	.104	-.108	-.092	.825	-.006

Please find herewith the five factors determined through the factor analysis process for deriving the conceptual lens for the proposed research work:

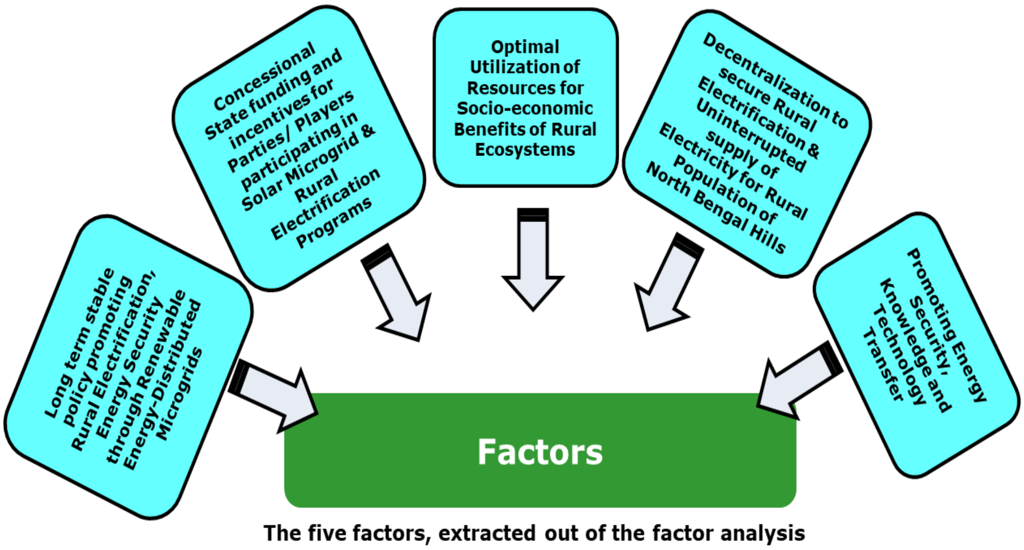
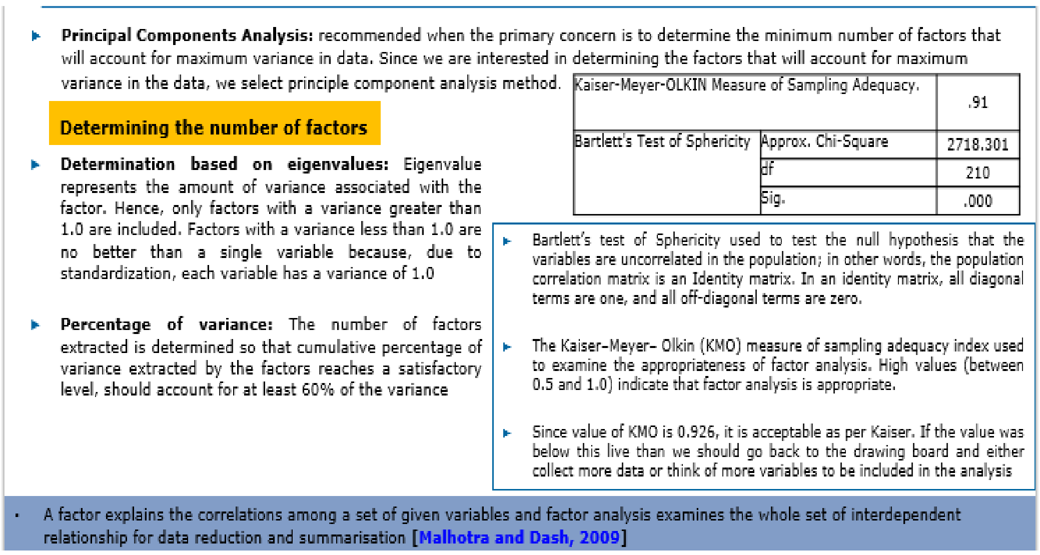


Figure 5.6 Five factors extracted through determination of Factor Analysis process to derive the conceptual lens of the research work

The diagram below depicts the methodology adapted for factor analysis:



- **Principal Components Analysis:** recommended when the primary concern is to determine the minimum number of factors that will account for maximum variance in data. Since we are interested in determining the factors that will account for maximum variance in the data, we select principle component analysis method.

Kaiser-Meyer-OLKIN Measure of Sampling Adequacy.		.91
Bartlett's Test of Sphericity	Approx. Chi-Square	2718.301
	df	210
	Sig.	.000

Determining the number of factors

- **Determination based on eigenvalues:** Eigenvalue represents the amount of variance associated with the factor. Hence, only factors with a variance greater than 1.0 are included. Factors with a variance less than 1.0 are no better than a single variable because, due to standardization, each variable has a variance of 1.0
- **Percentage of variance:** The number of factors extracted is determined so that cumulative percentage of variance extracted by the factors reaches a satisfactory level, should account for at least 60% of the variance

- Bartlett's test of Sphericity used to test the null hypothesis that the variables are uncorrelated in the population; in other words, the population correlation matrix is an Identity matrix. In an identity matrix, all diagonal terms are one, and all off-diagonal terms are zero.
- The Kaiser-Meyer- Olkin (KMO) measure of sampling adequacy index used to examine the appropriateness of factor analysis. High values (between 0.5 and 1.0) indicate that factor analysis is appropriate.
- Since value of KMO is 0.926, it is acceptable as per Kaiser. If the value was below this live than we should go back to the drawing board and either collect more data or think of more variables to be included in the analysis

- A factor explains the correlations among a set of given variables and factor analysis examines the whole set of interdependent relationship for data reduction and summarisation [Malhotra and Dash, 2009]

Figure 5.7 Factor Analysis method summary

- Bartlett's test of Sphericity used to test the null hypothesis that the variables are uncorrelated in the population; in other words, the population correlation matrix is an Identity matrix. In an identity matrix, all diagonal terms are one, and all off-diagonal terms are zero
- The Kaiser-Meyer- Olkin (KMO) measure of sampling adequacy index used to examine the appropriateness of factor analysis. High values (between 0.5 and 1.0) indicate that factor analysis is appropriate. Values below 0.5 imply that factor analysis may not be appropriate on the collected sample
- Since the value of KMO is 0.91, it is acceptable as per Kaiser. If the value is below this range, then we should go back to the drawing board and either collect more data or think of more variables to be included in the analysis

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.91
Bartlett's Test of Sphericity	Approx. Chi-Square	2718.301
	df	210
	Sig.	.000

KMO and Bartlett's Test output

KMO Score	Interpretation
0.9+	Perfect
0.8 - 0.89	Great
0.7 - 0.79	Good
0.5 - 0.69	Mediocre
<0.5	Unacceptable

KMO Table

Figure 5.8 KMO and Bartlett's test results finding summary

Data Analysis - Mapping and Interpretation – Conceptual Framework

The developed concepts, themes, and charts are linked in order to create a conceptual lens. It links various themes depending upon its occurrence in developed markets:

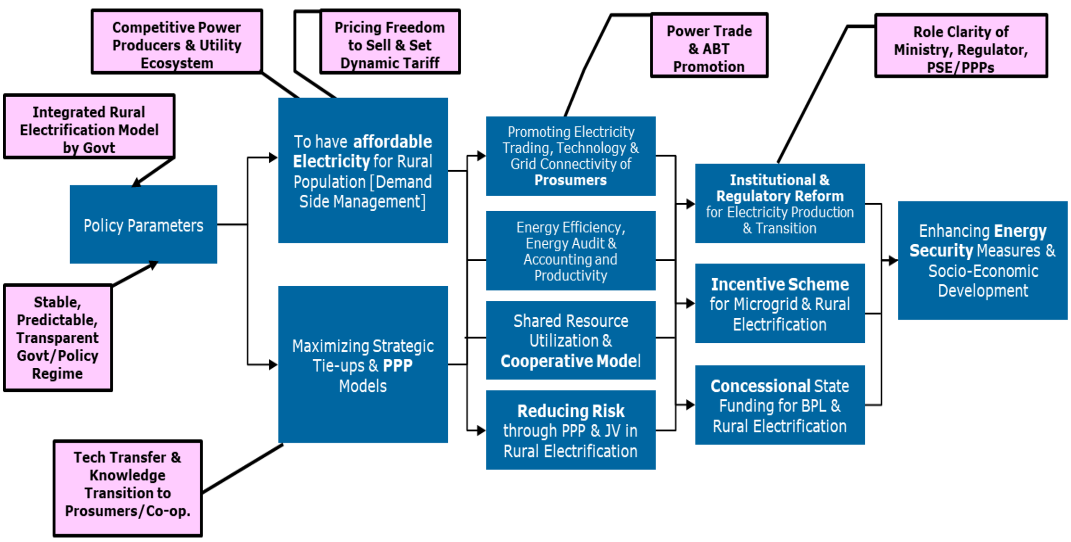


Figure 5.9 Conceptual lens of the research work derived through Quantitative Analysis and related study

CHAPTER- 6

QUALITATIVE DATA ANALYSIS & OBSERVATIONS

This chapter presents the statistical findings pertaining to the data collected from the respondents of the research study. In this chapter, the researcher provides the results of the qualitative data. The data was first put into an excel file and transferred into the SPSS 20.0 version. The study results were analysed using the SPSS software. The sample size taken for the study is n=21. Percentage analysis was carried out to find out the demographical information of the respondents. Descriptive statistics are used to summarize the data. Variables are expressed as the mean ± standard deviation (mean ± SD). Regression analysis is used to find the association between independent and dependent variables. Correlation analysis is used to find the relationship between independent and dependent variables. The independent samples t-test compares two groups on the basis of the mean value of a continuous normally distributed variable.

Table 6.1: Respondents' profession

	Frequency (n)	Percentage (%)
Industry expert	6	28.6
Policymaker	4	19.0
Academician	3	14.3
Entrepreneur	4	19.0
Govt. official	1	4.8
Service sector SME	3	14.3
Total	**21**	**100.0**

Table 6.1 depicts the professional of the respondents. Among the respondents, majority 28.6% of the respondents were industry expert followed by, each 19% of the respondents were police makers and entrepreneur, each

14.3% of the respondents were academician and service Sector SME and 4.8% of the respondent were Govt. Officials.

Table 6.2: Frequency of best choice for rural electrification in NB Hills

	Frequency (n)	Percentage (%)
SEB/State Utility	2	9.5
Group Supply/Co-operative	5	23.8
Private Sector	3	14.3
Panchayat/ Municipality	3	14.3
Multi-provider	8	38.1
Total	**21**	**100.0**

Table 6.2 depicts the frequency of the best choice for rural electrification in North Bengal hilly regions for the respondents. It was found that 38.1% of the respondents opted for Multi-providers, while 23.8% were in favour of 'Group supply/Co-operative'. As much as 14.3% of the respondents stated the private sector and panchayat/municipality to be the best choice. Moreover, 9.5% of the respondent were in favour of SEB/state utility in this regard.

Table 6.3: Rank investing agencies for community funding

Rank investing agencies for community funding	Rank1	Rank2	Rank3	Rank4	Rank5
	n (%)				
Panchayat/Municipality	6 (28.6)	4 (19.0)	6 (28.6)	2 (9.5)	3 (14.3)
Co-operative/Self-help group	-	9 (42.9)	7 (33.3)	2 (9.5)	3 (14.3)
Govt./REC/SEB	3 (14.3)	5 (23.8)	6 (28.6)	2 (9.5)	5 (23.8)
MFIs	-	2 (9.5)	-	13(61.9)	5 (23.8)
Private operators	12(57.1)	-	2 (9.5)	2 (9.5)	5 (23.8)

Table 6.3 reveals the frequency of rank investing agencies for community funding. It was found that 28.6% of the respondents kept Rank1 and Rank3 for the statement 'Panchayat/Municipality'. However, 42.9% of the respondents kept Rank2 for the statement 'Co-operative/Self-help group', while 28.6% kept Rank3 for the statement 'Govt./REC/SEB', 61.5% kept Rank4 for

the statement 'MFIs', and 57.1% kept Rank1 for the statement "Private operators".

Table 6.4: Rank electric supply agencies for rural electrification in North Bengal hills

	Rank1	Rank2	Rank3	Rank4	Rank5	Rank 6
	n(%)					
Self-help group	6 (28.6)	3 (14.3)	1 (4.8)	10 (47.6)	1 (4.8)	-
Individual entrepreneurs	5 (23.8)	7 (33.3)	1 (4.8)	2 (9.5)	4 (19.0)	2 (9.5)
Co-operatives	1 (4.8)	5 (23.8)	4 (19.0)	2 (9.5)	4 (19.0)	5 (23.8)
Panchayats/ Municipalities	3 (14.3)	2 (9.5)	4 (19.0)	3 (14.3)	7 (33.3)	2 (9.5)
Group supply units	4 (19.0)	2 (9.5)	4 (19.0)	1 (4.8)	2 (9.5)	8 (38.1)
Private sector commercial firms (Utilities)	2 (9.5)	2 (9.5)	7 (33.3)	3 (14.3)	3 (14.3)	4 (19.0)

Table 6.4 reveals the frequency of rank electric supply agencies for rural electrification in North Bengal Hills. Among the respondents, 28.6% kept Rank1 for the statement 'Self-help group', while 33.3% kept Rank2 for the statement 'Co-operatives', 33.3% kept Rank5 for the statement 'Panchayats/ Municipalities', 38.1% kept Rank6 for the statement 'Group supply units, and 33.3% kept Rank3 for the statement 'Private sector commercial firms (Utilities)'.

Table 6.5: Intensive electrification possible through electricity sector reform

	Frequency (n)	Percentage (%)
Completely agree	9	42.9
Partially agree	5	23.8
Somewhat agree	3	14.3
Partially disagree	3	14.3
Completely disagree	1	4.8
Total	**21**	**100.0**

Table 6.5 depicts the frequency of intensive electrification possible through electricity sector reform. It was found that 42.9% of the respondents completely agreed with the statement 'Intensive electrification possible through electricity sector reform**'.** As much as 23.8% of the respondents partially agreed, 14.3% somewhat agreed and partially disagreed, and 4.8% completely disagreed with the same statement.

Table 6.6: Rank electric supply agencies for rural electrification in North Bengal hills

	Rank1	**Rank2**	**Rank3**	**Rank4**	**Rank5**
	n(%)				
Limiting cross-subsidy scheme, gradually transforming towards the DBT model	3 (14.3)	10 (47.6)	3 (14.3)	3 (14.3)	2 (9.5)
Multiple licences for electricity supply in same region, while wheeling remains with DISCOMS	6 (28.6)	3 (14.3)	3 (14.3)	6 (28.6)	3 (14.3)
Right to open access (Demand>1 MW) for the consumers and the rightful bidding mechanism	6 (28.6)	1 (4.8)	8 (38.1)	2 (9.5)	4 (19.0)
Renewable purchase obligations	4 (19.0)	2 (9.5)	6 (28.6)	5 (23.8)	4 (19.0)
Enrichment of major developmental schemes like UDAY and SAUBHAGYA	2 (9.5)	4 (19.0)	2 (9.5)	5 (23.8)	8 (38.1)

Table 6.6 reveals the frequency of rank electric supply agencies for rural electrification in North Bengal Hills. It was found that 47.6% of the respondents kept Rank2 for the statement 'Limiting cross-subsidy scheme, gradually transforming towards DBT model'. However, 28.6% of the respondents kept Rank4 for the statement 'Multiple licences for electricity supply in same region, while wheeling remains with DISCOMS, while 38.1% kept Rank3 for the statement 'Right to open access (Demand>1 MW) for the consumers and the rightful bidding mechanism'. As much as 28.6% of the respondents kept Rank3 for the statement 'Renewable purchase obligations' and 38.1% kept Rank5 for the statement 'Enrichment of major developmental schemes like UDAY and SAUBHAGYA'.

Table 6.7: Privatization of Discoms and state distribution utilities can play a major role in rapid rural electrification

	Frequency (n)	Percentage (%)
Completely agree	1	4.8
Partially agree	12	57.1
Somewhat agree	1	4.8
Partially disagree	5	23.8
Completely disagree	2	9.5
Total	**21**	**100.0**

Table 6.7 reveals that 57.1% of the respondents partially agreed that 'privatization of Discoms and state distribution utilities can play a major role in rapid rural electrification'. However, 23.8% of the respondents partially disagreed with the statement and 9.5% of the respondents disagreed completely.

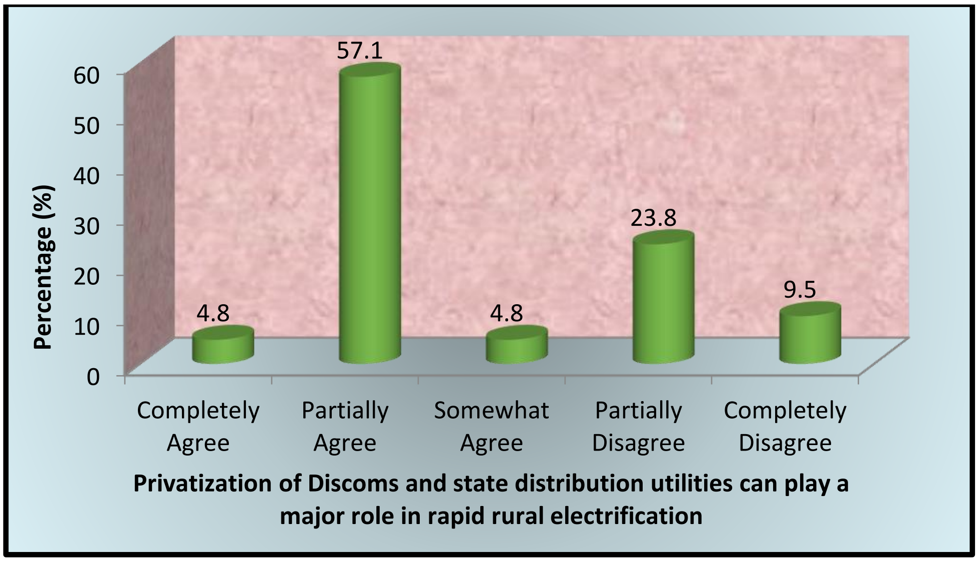


Figure 6.1: Percentage of privatization of Discoms and state distribution utilities can play a major role in rapid rural electrification

Table 6.8: Commercialization of rural electrification can play a significant role in the development of rural India

	Frequency (n)	Percentage (%)
Completely agree	6	28.6
Partially agree	7	33.3
Somewhat agree	5	23.8
Partially disagree	3	14.3
Total	**21**	**100.0**

Table 6.8 reveals that 33.3% of the respondents partially agreed that the 'commercialization of rural electrification can play a significant role in the development of rural India'. Some 28.6% of the respondents completely agreed with the statement, 23.8% somewhat agreed, and 14.3% partially disagreed.

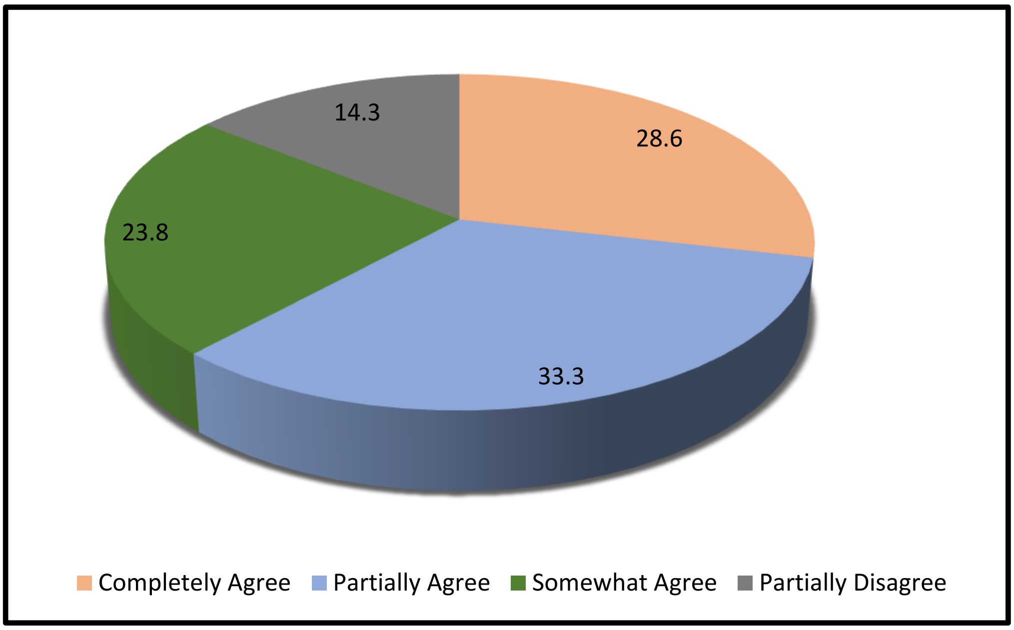


Figure 6.2: Percentage of commercialization of rural electrification can play a significant role in the development of rural India

Table 6.9: Implementation of a multi-modal utility through microgrids can be a commercially viable and feasible model for rural electrification in India

	Frequency (n)	Percentage (%)
Completely agree	7	33.3
Partially agree	4	19.0
Somewhat agree	3	14.3
Partially disagree	5	23.8
Completely disagree	2	9.5
Total	**21**	**100.0**

Table 6.9 reveals that 33.3% of the respondents completely agreed that 'implementation of a multi-modal utility through microgrids can be a commercially viable and feasible model for rural electrification in India'. Some

23.8% of the respondents partially disagreed with the statement, 19% partially agreed, and 14.3% somewhat agreed.

Table 6.10: Rural BPL people (50 %+) in the hilly terrains of North Bengal have affordable electricity

	Frequency (n)	Percentage (%)
Completely agree	3	14.3
Partially agree	9	42.9
Somewhat agree	1	4.8
Partially disagree	6	28.6
Completely disagree	2	9.5
Total	**21**	**100.0**

Table 6.10 reveals that 42.9% of the respondents partially agreed that 'rural BPL people (50 %+) in the hilly terrains of North Bengal have affordable electricity'. Around 28.6% of the respondents partially disagreed with the statement, 14.3% agreed completely, and 9.5% disagreed completely.

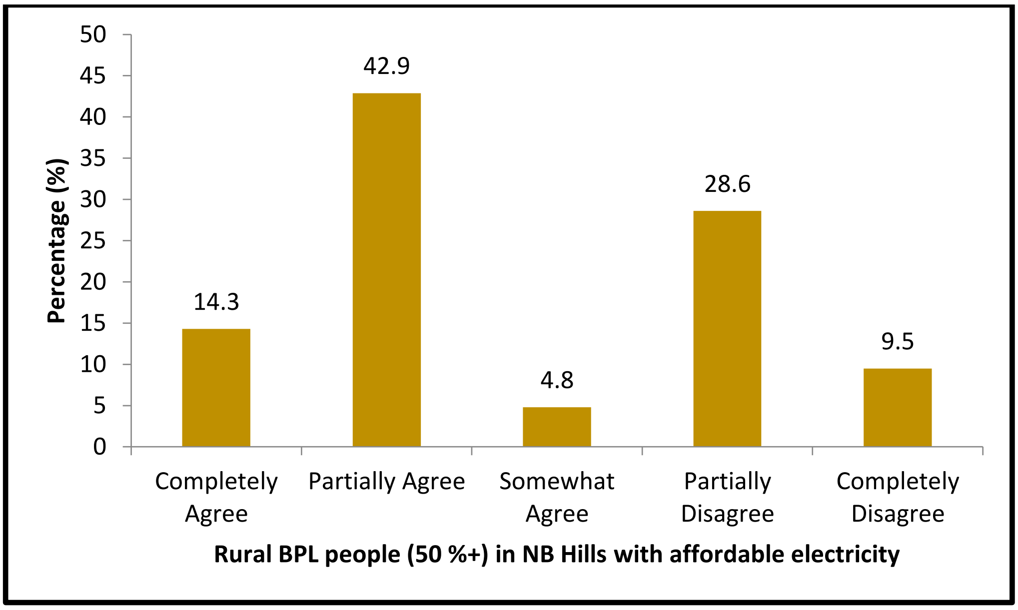


Figure 6.3: Percentage of rural BPL people (50 %+) in the hilly terrains of North Bengal with affordable electricity

Table 6.11: Rural BPL people (50 %+) in the hilly terrains of North Bengal get an electricity subsidy or government benefits

	Frequency (n)	Percentage (%)
Completely agree	5	23.8
Partially agree	8	38.1
Somewhat agree	5	23.8
Partially disagree	3	14.3
Total	**21**	**100.0**

Table 6.11 illustrates that around 23.8% of the respondents agreed completely that "rural BPL people (50 %+) in the hilly terrains of North Bengal get an electricity subsidy or government benefits". Another 23.8% somewhat agreed with the statement, 38.1% agreed partially, and 14.3% disagreed partially.

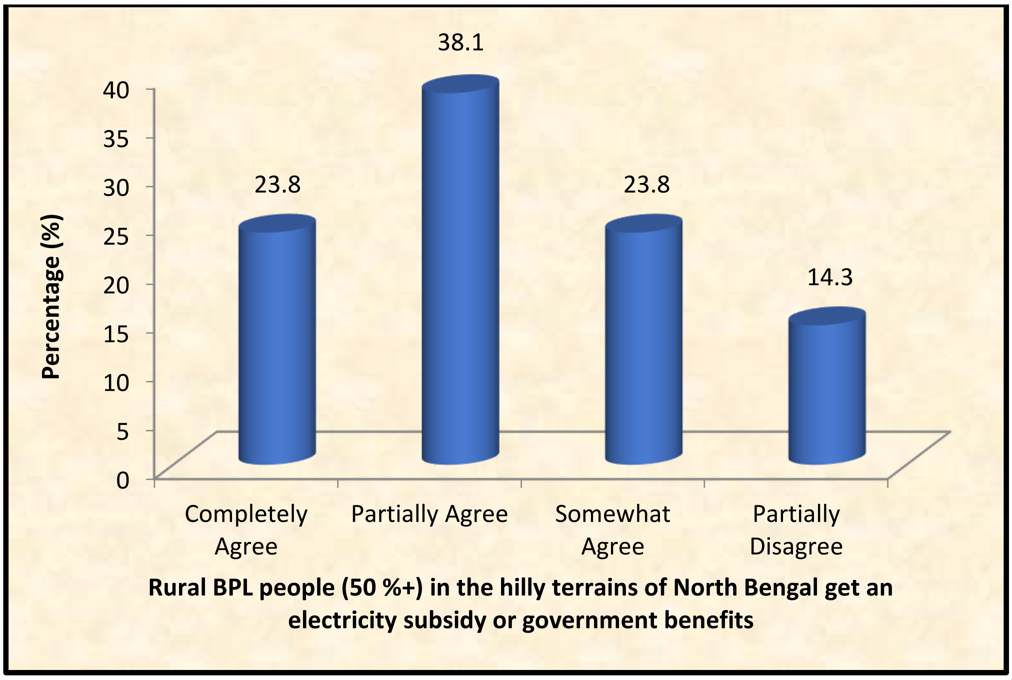


Figure 6.4: Percentage of rural BPL people (50 %+) in the hilly terrains of North Bengal with an electricity subsidy or government benefits

Table 6.12: Rural BPL people (50 %+) in the hilly terrains of North Bengal are willing to pay an additional amount for reliable electricity

	Frequency (n)	Percentage (%)
Completely agree	6	28.6
Partially agree	4	19.0
Somewhat agree	3	14.3
Partially disagree	5	23.8
Completely disagree	3	14.3
Total	**21**	**100.0**

Table 6.12 reveals that 28.6% of the respondents agreed completely that 'rural BPL people (50 %+) in the hilly terrains of North Bengal are willing to pay an additional amount for reliable electricity'. Some 23.8% of the respondents partially disagreed with the statement, 19% partially agreed, 14.3% somewhat agreed, and another 14.3% disagreed completely.

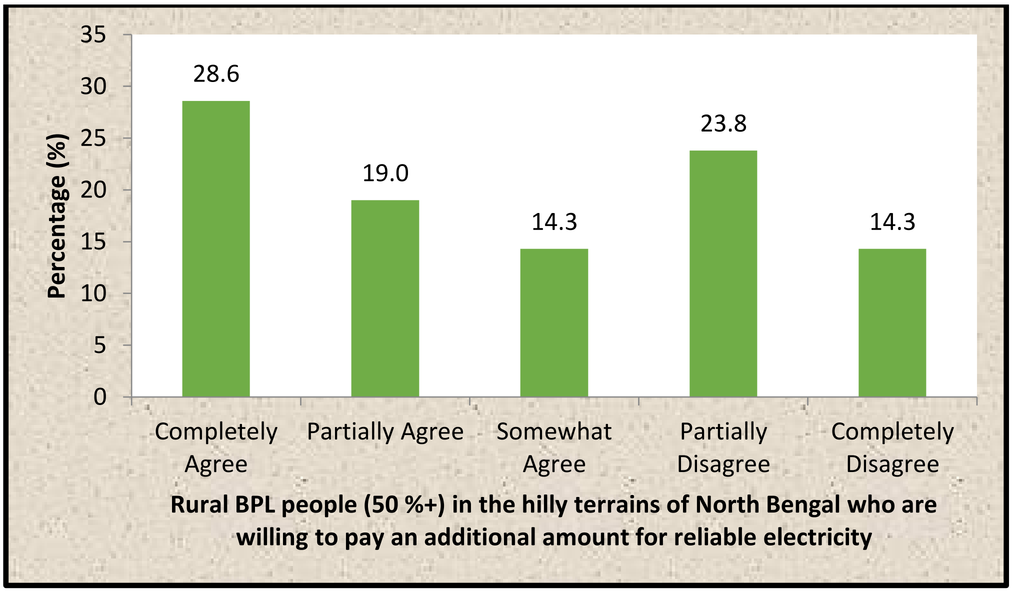


Figure 6.5: Percentage of rural BPL people (50 %+) in the hilly terrains of North Bengal who are willing to pay an additional amount for reliable electricity

ANOVA (Analysis of Variance)

Table 6.13: Difference in means of focus areas and amendments in new draft electricity bill with respect to intensive electrification through electricity sector reform groups

		N	Mean	SD	95% confidence interval for mean		F value	p value
					Lower bound	Upper bound		
Limiting cross-subsidy scheme, gradually moving towards DBT model	Completely agree	9	2.67	1.118	1.81	3.53	4.407	**0.014***
	Partially agree	5	1.60	.548	.92	2.28		
	Somewhat agree	3	4.33	1.155	1.46	7.20		
	Partially disagree	3	2.00	.000	2.00	2.00		
	Completely disagree	1	3.00	.	.	.		
Multiple licenses for electricity supply in same region, while wheeling remains with Discoms	Completely agree	9	2.78	1.563	1.58	3.98	4.816	**0.034***
	Partially agree	5	3.20	1.643	1.16	5.24		
	Somewhat agree	3	2.00	1.000	-.48	4.48		
	Partially disagree	3	2.67	1.528	-1.13	6.46		
	Completely disagree	1	5.00	.	.	.		
Right to open access (demand>1 MW) for consumers and rightful bidding mechanism	Completely agree	9	2.67	1.414	1.58	3.75	0.644	0.639
	Partially agree	5	3.00	1.414	1.24	4.76		
	Somewhat agree	3	3.67	1.528	-.13	7.46		
	Partially disagree	3	3.00	2.000	-1.97	7.97		
	Completely disagree	1	1.00	.	.	.		
Renewable purchase obligations	Completely agree	9	3.44	1.424	2.35	4.54	0.808	0.538
	Partially agree	5	3.40	1.140	1.98	4.82		
	Somewhat agree	3	2.00	1.732	-2.30	6.30		
	Partially disagree	3	2.67	1.528	-1.13	6.46		
	Completely disagree	1	4.00	.	.	.		
Enrichment of major developmental schemes like UDAY and SAUBHAGYA	Completely agree	9	3.56	1.590	2.33	4.78	4.862	**0.007****
	Partially agree	5	3.80	1.643	1.76	5.84		
	Somewhat agree	3	3.00	1.000	.52	5.48		
	Partially disagree	3	4.67	.577	3.23	6.10		
	Completely disagree	1	2.00	.	.	.		

**p<0.01, *p<0.05

Table 6.13 depicts the difference in means of the focus areas and amendments in the new draft electricity bill with respect to intensive electrification through electricity sector reform groups by using analysis of variance. The p values for three key outcomes are less than the 0.05 significance levels: limiting the cross-subsidy scheme and gradually moving towards the DBT model (F=4.407, p=0.014<0.05), multiple licenses for electricity supply in same region while wheeling remains with Discoms (F=4.816, p=0.034<0.05), and enrichment of major developmental schemes like UDAY and SAUBHAGYA (F=4.862, p=0.007<0.01). Thus, there is evidently a difference in the means of the three outcomes with respect to intensive electrification through electricity sector reform groups.

Table 6.14: Difference in means of rank rural development schemes to be leveraged for electrification work with respect to intensive electrification through electricity sector reform groups

<table>
<tr><th colspan="2" rowspan="2"></th><th rowspan="2">N</th><th rowspan="2">Mean</th><th rowspan="2">SD</th><th colspan="2">95% confidence interval for mean</th><th rowspan="2">F value</th><th rowspan="2">p value</th></tr>
<tr><th>Lower bound</th><th>Upper bound</th></tr>
<tr><td rowspan="5">Deen Dayal Upadhyaya Grameen Kaushalya Yojana</td><td>Completely agree</td><td>9</td><td>2.11</td><td>1.054</td><td>1.30</td><td>2.92</td><td rowspan="5">4.170</td><td rowspan="5">0.050*</td></tr>
<tr><td>Partially agree</td><td>5</td><td>2.40</td><td>1.342</td><td>.73</td><td>4.07</td></tr>
<tr><td>Somewhat agree</td><td>3</td><td>2.00</td><td>1.732</td><td>-2.30</td><td>6.30</td></tr>
<tr><td>Partially disagree</td><td>3</td><td>2.33</td><td>1.155</td><td>-.54</td><td>5.20</td></tr>
<tr><td>Completely disagree</td><td>1</td><td>3.00</td><td>.</td><td>.</td><td>.</td></tr>
<tr><td rowspan="5">Deen Dayal Upadhyaya Antyodaya Yojana/ Swarnajayanti Gram Swarozgar Yojana</td><td>Completely agree</td><td>9</td><td>1.67</td><td>.707</td><td>1.12</td><td>2.21</td><td rowspan="5">0.990</td><td rowspan="5">0.441</td></tr>
<tr><td>Partially agree</td><td>5</td><td>2.20</td><td>.837</td><td>1.16</td><td>3.24</td></tr>
<tr><td>Somewhat agree</td><td>3</td><td>2.00</td><td>1.000</td><td>-.48</td><td>4.48</td></tr>
<tr><td>Partially disagree</td><td>3</td><td>1.33</td><td>.577</td><td>-.10</td><td>2.77</td></tr>
<tr><td>Completely disagree</td><td>1</td><td>1.00</td><td>.</td><td>.</td><td>.</td></tr>
<tr><td rowspan="5">Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA)</td><td>Completely agree</td><td>9</td><td>2.44</td><td>.882</td><td>1.77</td><td>3.12</td><td rowspan="5">4.461</td><td rowspan="5">0.040*</td></tr>
<tr><td>Partially agree</td><td>5</td><td>2.00</td><td>1.225</td><td>.48</td><td>3.52</td></tr>
<tr><td>Somewhat agree</td><td>3</td><td>3.33</td><td>1.155</td><td>.46</td><td>6.20</td></tr>
<tr><td>Partially disagree</td><td>3</td><td>2.33</td><td>.577</td><td>.90</td><td>3.77</td></tr>
<tr><td>Completely disagree</td><td>1</td><td>4.00</td><td>.</td><td>.</td><td>.</td></tr>
<tr><td rowspan="5">Sampoorna Grameen Rozgar Yojana</td><td>Completely agree</td><td>9</td><td>3.78</td><td>.667</td><td>3.27</td><td>4.29</td><td rowspan="5">3.134</td><td rowspan="5">0.044*</td></tr>
<tr><td>Partially agree</td><td>5</td><td>3.40</td><td>.894</td><td>2.29</td><td>4.51</td></tr>
<tr><td>Somewhat agree</td><td>3</td><td>2.67</td><td>.577</td><td>1.23</td><td>4.10</td></tr>
<tr><td>Partially disagree</td><td>3</td><td>4.00</td><td>.000</td><td>4.00</td><td>4.00</td></tr>
<tr><td>Completely disagree</td><td>1</td><td>2.00</td><td>.</td><td>.</td><td>.</td></tr>
</table>

**p<0.01, *p<0.05

Table 6.14 depicts the difference in means of rank rural development schemes to be leveraged for electrification work with respect to intensive electrification through electricity sector reform groups by using analysis of variance. The p values for Deen Dayal Upadhyaya Grameen Kaushalya Yojana (F=4.170, p=0.050<0.05), Mahatma Gandhi National Rural Employment

Guarantee Act (MNREGA) (F=4.461, p=0.040<0.05), and Sampoorna Grameen Rozgar Yojana (F=3.134, p=0.044<0.05) are less than the 0.05 significance levels. Thus, there is a difference in means among these schemes with respect to intensive electrification through electricity sector reform groups.

Table 6.15: Difference in means of government priorities for rural electrification with respect to intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes

		N	Mean	SD	95% confidence interval for mean		F value	p value
					Lower bound	Upper bound		
Agricultural sector, irrigation	Completely agree	1	4.00	.	.	.	0.312	0.866
	Partially agree	6	3.00	.894	2.06	3.94		
	Somewhat agree	2	3.00	1.414	-9.71	15.71		
	Partially disagree	6	2.50	1.225	1.21	3.79		
	Completely disagree	6	2.67	1.862	.71	4.62		
Rural and semi-urban households	Completely agree	1	1.00	.	.	.	0.671	0.621
	Partially agree	6	2.83	2.041	.69	4.98		
	Somewhat agree	2	3.00	2.828	-22.41	28.41		
	Partially disagree	6	2.17	1.941	.13	4.20		
	Completely disagree	6	3.67	1.633	1.95	5.38		
Drinking water supply to families	Completely agree	1	2.00	.	.	.	0.663	0.627
	Partially agree	6	3.17	2.229	.83	5.51		
	Somewhat agree	2	4.50	2.121	-14.56	23.56		
	Partially disagree	6	3.33	1.506	1.75	4.91		
	Completely disagree	6	4.33	1.633	2.62	6.05		
Providing benefits of electrification to small traders	Completely agree	1	5.00	.	.	.	0.774	0.558
	Partially agree	6	4.67	1.966	2.60	6.73		
	Somewhat agree	2	3.00	1.414	-9.71	15.71		
	Partially disagree	6	5.33	1.862	3.38	7.29		
	Completely disagree	6	4.00	1.789	2.12	5.88		
Providing benefits of electrification to manufacturers and SMBs	Completely agree	1	6.00	.	.	.	0.875	0.500
	Partially agree	6	4.17	1.835	2.24	6.09		
	Somewhat agree	2	3.00	2.828	-22.41	28.41		
	Partially disagree	6	4.00	1.897	2.01	5.99		
	Completely disagree	6	2.83	1.722	1.03	4.64		
Emphasis on rapid mass industrialization	Completely agree	1	3.00	.	.	.	0.269	0.894
	Partially agree	6	3.50	1.761	1.65	5.35		
	Somewhat agree	2	4.50	2.121	-14.56	23.56		
	Partially disagree	6	4.00	.894	3.06	4.94		
	Completely disagree	6	3.50	1.871	1.54	5.46		
Electrification of public bodies and institutes (e.g. panchayats, schools, administrative offices, health centres)	Completely agree	1	7.00	.	.	.	0.857	0.510
	Partially agree	6	6.67	.516	6.12	7.21		
	Somewhat agree	2	7.00	.000	7.00	7.00		
	Partially disagree	6	6.67	.516	6.12	7.21		
	Completely disagree	6	7.00	.000	7.00	7.00		

**p<0.01, *p<0.05

Table 6.15 depicts the difference in means of government priorities for rural electrification with respect to intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes through the use of analysis of variance. In the above outcomes, the p value for government priorities for rural electrification is greater than the 0.05 significance levels. This suggests that there is no difference in the means of government priorities for rural electrification in this respect.

Table 6.16: Difference in means of rank government policies for rural electrification with respect to intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes

		N	Mean	SD	95% confidence interval for mean		F value	p value
					Lower bound	Upper bound		
Free electricity for BPL rural households	Completely agree	1	4.00	.	.	.	0.326	0.827
	Partially agree	6	2.33	1.033	1.25	3.42		
	Somewhat agree	2	3.00	2.828	-22.41	28.41		
	Partially disagree	6	2.50	1.049	1.40	3.60		
	Completely disagree	6	2.67	1.506	1.09	4.25		
Intensive electrification of partially electrified villages	Completely agree	1	1.00	.	.	.	1.281	**0.018***
	Partially agree	6	3.67	1.506	2.09	5.25		
	Somewhat agree	2	2.00	.000	2.00	2.00		
	Partially disagree	6	3.50	1.643	1.78	5.22		
	Completely disagree	6	2.83	1.169	1.61	4.06		
Strengthen only public body units, government entities, and home and defence ministry units (for border terrains)	Completely agree	1	3.00	.	.	.	0.364	0.831
	Partially agree	6	3.00	1.789	1.12	4.88		
	Somewhat agree	2	4.00	.000	4.00	4.00		
	Partially disagree	6	2.50	1.517	.91	4.09		
	Completely disagree	6	3.17	1.602	1.49	4.85		
Only electrification of unelectrified villages and outfits	Completely agree	1	5.00	.	.	.	0.469	0.758
	Partially agree	6	2.83	1.169	1.61	4.06		
	Somewhat agree	2	3.00	2.828	-22.41	28.41		
	Partially disagree	6	3.33	1.633	1.62	5.05		
	Completely disagree	6	2.83	1.602	1.15	4.51		
Focus on reliable power supply to domestic and industrial consumers	Completely agree	1	2.00	.	.	.	0.212	0.928
	Partially agree	6	3.17	1.722	1.36	4.97		
	Somewhat agree	2	3.00	.000	3.00	3.00		
	Partially disagree	6	3.17	1.472	1.62	4.71		
	Completely disagree	6	3.50	1.643	1.78	5.22		

**p<0.01, *p<0.05

Table 6.16 depicts the difference in means of rank government policies for rural electrification with respect to intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes through analysis of variance. In the above outcomes, the p value for intensive electrification of partially electrified villages (F=1.281, p=0.018<0.05) is less than the 0.05 significance levels. Therefore, there is a difference in the means with respect to the intensive electrification of partially electrified villages and intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes.

Table 6.17: Difference in means of government strategies and instruments for accelerating rural electrification with respect to intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes

		N	Mean	SD	95% confidence interval for mean		F value	p value
					Lower bound	Upper bound		
Flexi and easy loan terms for longer period by REC, banks, and financial institutes	Completely agree	1	4.00	.	.	.	0.852	0.513
	Partially agree	6	2.67	1.633	0.95	4.38		
	Somewhat agree	2	3.50	2.121	-15.56	22.56		
	Partially disagree	6	2.67	1.033	1.58	3.75		
	Completely disagree	6	2.00	.894	1.06	2.94		
Increase in grants for participating bodies and utilities	Completely agree	1	2.00	.	.	.	0.186	0.943
	Partially agree	6	3.33	1.506	1.75	4.91		
	Somewhat agree	2	3.50	.707	-2.85	9.85		
	Partially disagree	6	3.33	1.966	1.27	5.40		
	Completely disagree	6	3.33	1.211	2.06	4.60		
Emphasis on incentive model at all levels of employees at electrification agencies and other key stakeholders	Completely agree	1	3.00	.	.	.	0.069	0.990
	Partially agree	6	2.67	1.506	1.09	4.25		
	Somewhat agree	2	2.50	2.121	-16.56	21.56		
	Partially disagree	6	2.33	1.633	0.62	4.05		
	Completely disagree	6	2.33	1.633	0.62	4.05		
Focus on milestone-based grant increase for electrification agencies and utilities	Completely agree	1	5.00	.	.	.	2.078	**0.031***
	Partially agree	6	2.67	1.366	1.23	4.10		
	Somewhat agree	2	2.00	1.414	-10.71	14.71		
	Partially disagree	6	3.83	.983	2.80	4.87		
	Completely disagree	6	3.67	1.033	2.58	4.75		
Promotion of commercial model through PPP, co-operative bodies, private sector participation, FDI etc.	Completely agree	1	1.00	.	.	.	0.872	0.502
	Partially agree	6	3.67	1.366	2.23	5.10		
	Somewhat agree	2	3.50	2.121	-15.56	22.56		
	Partially disagree	6	2.83	1.329	1.44	4.23		
	Completely disagree	6	3.67	1.751	1.83	5.50		

**p<0.01, *p<0.05

Table 6.17 depicts the difference in means of government strategies and instruments for accelerating rural electrification in the hilly terrains of North Bengal by leveraging government schemes through use of the analysis of variance. In the above outcomes, the p value for focus on milestone-based grant increase for electrification agencies and utilities (F=2.078, p=0.031<0.05) is less than the 0.05 significance levels. Thus, there is a difference in the means of focus on milestone-based grant increases for electrification agencies and utilities with respect to intensive rural electrification in the hilly terrains of North Bengal by leveraging government schemes.

Chi-square test

Table 6.18: Association between commercialization of rural electrification playing a significant role in the development of rural India and privatization of Discoms and state distribution utilities playing a major role in rapid rural electrification

Commercialization of rural electrification can play a significant role in the development of rural India	Privatization of Discoms and state distribution utilities can play a major role in rapid rural electrification					Total	p value
	Completely agree	Partially agree	Somewhat agree	Partially disagree	Completely disagree		
	n(%)						
Completely agree	0 (0.0)	5 (41.7)	1 (100.0)	0 (0.0)	0 (0.0)	**6 (28.6)**	**0.011***
Partially agree	1 (100.0)	3 (25.0)	0 (0.0)	2 (40.0)	1 (50.0)	**7 (33.3)**	
Somewhat agree	0 (0.0)	3 (25.0)	0 (0.0)	1 (20.0)	1 (50.0)	**5 (23.8)**	
Partially disagree	0 (0.0)	1 (8.3)	0 (0.0)	2 (40.0)	0 (0.0)	**3 (14.3)**	
Total	**1 (100.0)**	**12 (100.0)**	**1 (100.0)**	**5 (100.0)**	**2 (100.0)**	**21 (100.0)**	

*Chi-square: 11.215, *p<0.05*

Table 6.18 depicts the association between the commercialization of rural electrification playing a significant role in the development of rural India and the privatization of Discoms and state distribution utilities playing a major role in rapid rural electrification by using the chi-square test. Some 33.3% of the respondents partially agreed that the commercialization of rural electrification can play a significant role in the development of rural India. Further, 41.7% of the respondents partially agreed that the privatization of

Discoms and state distribution utilities can play a major role in rapid rural electrification; they also completely agreed that the commercialization of rural electrification can play a significant role in the development of rural India. The chi-square value (11.215) and the p value (p=0.011<0.05) suggest an association between the commercialization of rural electrification playing a significant role in the development of rural India and the privatization of Discoms and state distribution utilities playing a major role in rapid rural electrification.

Table 6.19: Association between commercialization of rural electrification playing a significant role in the development of rural India and the implementation of a multi-modal utility through microgrids being a commercially viable and feasible model for rural electrification in India

Commercialization of rural electrification can play a significant role in the development of rural India	Implementation of a multi-modal utility through microgrids can be a commercially viable and feasible model for rural electrification in India					Total	p value
	Completely agree	Partially agree	Somewhat agree	Partially disagree	Completely disagree		
	n(%)						
Completely agree	5 (71.4)	1 (25.0)	0 (0.0)	0 (0.0)	0 (0.0)	**6 (28.6)**	**0.050***
Partially agree	1 (14.3)	2 (50.0)	2 (66.7)	2 (40.0)	0 (0.0)	**7 (33.3)**	
Somewhat agree	1 (14.3)	1 (25.0)	0 (0.0)	1 (20.0)	2 (100.0)	**5 (23.8)**	
Partially disagree	0 (0.0)	0 (0.0)	1 (33.3)	2 (40.0)	0 (0.0)	**3 (14.3)**	
Total	**7 (100.0)**	**4 (100.0)**	**3 (100.0)**	**5 (100.0)**	**2 (100.0)**	**21 (100.0)**	

*Chi-square: 21.027, *p<0.05*

Table 6.19 uses the chi-square test to depict the association between commercialization of rural electrification playing a significant role in the development of rural India and implementation of a multi-modal utility through microgrids being a commercially viable and feasible model for rural electrification in India. About 33.3% of the respondents partially agreed that the commercialization of rural electrification can play a significant role in the development of rural India. Further, 71.4% of the respondents agreed completely that implementation of a multi-modal utility through microgrids can be a commercially viable and feasible model for India’s rural electrification; they also completely agreed that the commercialization of rural electrification can play a significant role in the development of rural India. The chi-square value (21.027) and the p value (p=0.050<0.05) suggest an association between the commercialization of rural electrification playing a significant role in the development of rural India and the implementation of a multi-modal utility through microgrids being a commercially viable and feasible model for rural electrification in India.

Correlation Analysis

The strength and direction of the association between two variables is measured by using the Pearson correlation coefficient. The two variables must be measured on a continuous (interval) scale (Srmuniv, 2018). The correlation coefficient (r) ranges from –1 to 1. Based on the sign of the correlation coefficient, we may conclude the following (Gogtay & Thatte, 2017):

- When r is –1, we say there is a perfect negative correlation.
- When r is a value between –1 and 0, we say there is a negative correlation.
- When r is 0, we say there is no correlation.
- When r is a value between 0 and 1, we say there is a positive correlation.
- When r is 1, we say there is a perfect positive correlation.

Table 6.20: Relationship of socio-economic behaviour with government policy and legal provisions

	Socio economic behaviour	**Government policy and legal provision**
Socio economic behaviour	1	
Government policy and legal provisions	.669**	1

**p<0.01

Table 6.20 reveals the relationship of socio-economic behaviour with government policy and legal provisions by using the Pearson correlation analysis. The above table illustrates that socio-economic behaviour (r=0.669, p<0.01) has a positively significant relationship with government policy and legal provisions.

Regression Analysis

Regression is used to find an association between independent and dependent variables. This means determining if there is a significant impact of the independent variable on the dependent variable. In a linear regression, we can use only one independent variable and a dependent variable. But in multiple regressions, we can use more than one independent variable and one dependent variable. Both types of regression analysis are used to predict the value of a dependent variable based on the value of an independent variable. The dependent (predictand) variable is the variable we want to predict, whereas the independent variable is the variable we are using to predict the value of the dependent variable.

Table 6.21: Association of socio-economic behaviour with government policy and legal provisions

	Unstandardized coefficients		R square	t value	p value
	Beta	SE			
(Constant)	-.024	.690	0.448	-0.034	0.973
Government policy and legal provisions	.996	.254		3.923	**0.001****

Dependent variable: socio-economic behaviour, **p<0.01

Table 6.21 presents the association of socio-economic behaviour with government policy and legal provisions using linear regression analysis. Since the p value for government policy and legal provisions (beta=0.996, t=3.923, p=0.001<0.01) is less than the 0.05 significance levels, it is depicted that government policy and legal provisions has a positive significant impact on socio-economic behaviour. In addition, 45% of the variation in socio-economic behaviour is dependent on government policy and legal provisions (R square=0.448).

CHAPTER- 7
DISCUSSION AND CONCLUSION

The present section offers an overview of the entire research study and details the conclusions drawn from the previous chapter. The business problem in this study is that the lack of adequate cost-effective and high-quality electricity supply through the national grid system affects the economic and social growth of the hilly rural terrains of North Bengal. This warrants local solutions in the form of renewable energy-based equipment as part of the microgrid solutions for rural electrification. Thus, the present research aims to address the following objectives:

- To identify the key enablers and related variables or factors for the electrification of the rural hilly terrains of North Bengal, India, through solar energy-based equipment as part of microgrid systems
- To develop an efficient framework for sustainable rural electrification through solar energy-based equipment as part of the microgrid systems in the rural hilly terrains of North Bengal, India

7.1 SUMMARY OF FINDINGS

Quantitative and Qualitative Data Analysis Summary

The hilly terrains of North Bengal—especially the new Kalimpong district (the erstwhile Kalimpong sub-division of Darjeeling district) and the nearby localities of the Darjeeling district which are adjacent to the Jalpaiguri district—have been identified as not adequately developed economically. They have a per capita GDP of approximately USD 1,100–1,200 (2017 census), which is less than the per capita GDP of the state of West Bengal which is around USD 1,500 (2017; approximately USD 1,700–1,800 in 2018–19). The slow economic growth of the region dates back to the 1960s, when trading through the Jelep La Pass (part of the erstwhile Silk Route via Tibet) was permanently closed as a result of the Chinese annexation of Tibet in 1959 and the subsequent Sino–Indian war (1962).

The district town of Kalimpong, along with the adjacent geographies, has a recorded population of 49,403 (circa 10,000 families, Census 2011) with a population density of 40.70 per sq. km. The overall district, which is covered mostly by the Sino-Himalayan Subtropical and Temperate Forests, has a recorded population of approximately 1.32 lakh (Census 2011). The major occupations of the people here are in cultivation and tourism services. About 90% of the farmlands in the districts are good for cultivation. Moreover, the aggregate tea production of the district represents approximately 4% of the overall tea production in the region. It is believed that the lack of energy security and the unavailability of adequate and uninterrupted quality electricity supply to most of the households and consumers of the geography is one of the major factors that has slowed down the socio-economic growth of the overall region.

We had targeted a smaller and economically under-developed region spanning an approximately 58.8-km-long and 43.2-km-wide geography, covering the Sukna forest through Rohini estate, Jorebunglow up to the Kaffir, Nimbong, and Mongpong region on the eastern part of the river Teesta, including an extended part of Kalimpong town, which covers a population of circa 9,800 people (Census 2011)—approximately 2,500 families in the region. Considering the population size in the target geography, we had aimed to draw a minimum sample size of 500 people, each representing a family, with a 95% level of confidence, for the proposed quantitative sample survey-based data analysis. However, due to several socio-economic and administrative challenges as well as climate issues and other operational challenges (like cost, timeline etc.), we were able to collect only 439 samples as interviews leveraging the local support and administrative patronages. Moreover, approximately 23% of the collected sample data could not be used due to ambiguity and erroneous trends in the response data, hostility of the interviewed persons, as well as data quality and consistency issues. The remaining (n1=337) samples with good-quality consistent data were leveraged for tabulation and further tool-based data analysis and deduction of inference-related activities.

The initial questionnaire for this sample survey was created based on discussions and mutual agreement with the research supervisors and several industry experts. This was fine-tuned and revised based on the initial sample survey results with 20–25 interviews in order to arrive at the final questionnaire with mostly close-ended questions, multiple response-options, and Likert scale-measuring options. Another qualitative survey questionnaire comprising both close- and open-ended questions was created through multiple iterations with several subject matter experts, industry specialists, and research supervisors. This was run through 20–25 relevant stakeholders and specialists (actual sample n2 = 21), which comprised policy makers, academicians, industry leaders, and SMEs etc., in order to pursue the qualitative data analysis for the proposed microgrid framework for the target geography of the hilly rural terrains of North Bengal.

This chapter presents the statistical findings based on data collected from the respondents of the research study. In this chapter, the researcher provides the results of the quantitative data. The good-quality consistent response data was first tabulated into an Excel file and transferred into SPSS 20.0 version. Thus, using SPSS software, the present study results were analysed. The final good-quality and consistent data-driven sample size that has been taken for the study was n1=337.

A percentage analysis was carried out to ascertain the demographic information of the respondents. Descriptive statistics are used to summarize the data. Variables are expressed as the mean ± standard deviation (mean ± SD). The independent samples t-test compares two groups using the mean value of a continuous and normally distributed variable. The association and correlation between multiple attributes and variables are evaluated using the chi-square test and ANOVA. In addition, regression analysis was used to identify the link between the independent and dependent variables, whereas correlation analysis was used to assess the association between the independent and dependent variables.

Observations from the Quantitative Data Analysis

Of the respondents, 57.3% were male and 42.7% were female. Moreover, 42.4% of the respondents were between 30 and 40 years of age and 32.9% were between 40 and 50 years. About 64.7% of the respondents belonged to family households of three to five members. Also, 48.7% of the respondents had less than two rooms at home, while 44.2% of the respondents had two to four rooms.

Approximately 57.3% of the respondents stated that the SEB or state utility was the sole provider of electricity in their localities. Around 58.8% mentioned that the gram panchayat was the only source of community funding in their area.

Around 27.6% of the respondents reported a monthly family income of less than INR 2,500. Furthermore, 26.1% of the respondents had completed only primary school while 25.8% had completed their higher secondary education.

The data revealed that 95.8% of the respondents hold a current or savings account at a bank or a non-banking financial institution. Approximately 27.9% of the respondents are wage labourers. About 45% of the respondents have home-based businesses. Of these, 15.1% are financial services and 11.3% are food or grocery businesses. The association between monthly family income and education was evaluated through a chi-square test. It was observed that 27.6% of the respondents earn less than INR 2,500. Notably, some 94.3% of the respondents had completed only their primary schooling and were earning less than INR 2,500 per month. The chi-square value (664.241) and p value ($p=0.000<0.01$) thus reveal an association between monthly family income and education. The study also evaluated the link between sources of community funding and the availability of micro-finance institutions (MFIs) in the respondents' localities by using the chi-square test. In this regard, 58.8% of the respondents stated that the major source of community funding was the panchayat; further, 56.7% were aware of there being MFIs in their locality. Thus, the chi-square value (119.164) and p value ($p=0.000<0.01$) suggest an association between sources of community funding and the presence of MFIs in the area.

During the sample survey data analysis, it was noted that approximately 9.2% respondents still do not have electricity supply at home. Meanwhile, 44.2% of the respondents claimed to pay INR 2–5 per unit of electricity consumption. Also, 46.3% of the respondents stated that power cuts, blackouts, and outages occur daily for four to six hours, 45.4% said that power cuts, blackouts, and outages occur at least eight to 12 days per month, and 38% said that they occur four to eight days per month. As per the respondents, alternative energy sources are amply available in the locality. Some 53.4% of the respondents stated that sunlight is the prime source of alternative energy in the region.

Finally, 92.6% of the respondents evinced interest in using non-conventional energy for their home electricity. However, 51.9% stated that free electricity is the major factor driving their willingness to adopt non-conventional energy-based electricity. The association between their interest in non-conventional energy sources for home electricity and the major driving factor in non-conventional energy-based electricity was evaluated by using the chi-square test. The chi-square value (36.349) and p value ($p=0.000<0.01$) suggest an association between the interest in using non-conventional energy for home electricity and free supply being a major driving factor in non-conventional energy-based electricity adaptation.

Further, 39.5% of the respondents had received no subsidy or government electrification benefits as rural electricity consumers as on the date of the survey. Moreover, 32.6% received no subsidy or government electrification scheme benefit despite being BPL consumers. In fact, 67.4% of the respondents were not even aware of such schemes or whether they were eligible for the benefits. Notably, 56.1% of the respondents said they were unwilling to pay for reliable electricity supply as ‘The electricity tariff is already too high’, whereas 22.3% said that the ‘Government should provide funds for improvement and provide electricity for free or at minimum cost’.

We also studied the means of the reasons for the respondents’ unwillingness to pay for reliable electricity supply based on their gender. The p values of the reasons for this unwillingness are greater than the 0.05 significance levels. Hence, one might conclude that there is no difference in the reasons for this unwillingness based on the respondents' gender. Further, we evaluated the difference in means of access to affordable electricity, willingness to pay an additional amount for reliable electricity supply at home, and eagerness for additional or new sources of income as per the genders of the respondents. The p values for each of these factors were greater than the 0.05 significance levels. Hence, we can conclude that there is no difference in the means based on the genders of the respondents.

Finally, the strength and the direction of the association between two variables were measured by using the Pearson correlation coefficient. Here, the two variables must be measured on a continuous (interval) scale (Srmuniv, 2018). The correlation coefficient (r) ranges from –1 to 1. Based on the sign of the correlation coefficient, we may conclude the following (Gogtay & Thatte, 2017):

When r is –1, we say there is a perfect negative correlation.

When r is a value between –1 and 0, we say there is a negative correlation.

When r is 0, we say there is no correlation.

When r is a value between 0 and 1, we say there is a positive correlation.

When r is 1, we say there is a perfect positive correlation.

Table 7.1: Relationships among prosumer behaviour, socio-economic characteristics, and techno-commercial penetration

	Prosumer behaviour	Socio-economic characteristics	Techno-commercial penetration
Prosumer behaviour	1		
Socio-economic characteristics	.373**	1	
Techno-commercial penetration	.261**	.571**	1

**p<0.01

The above table reveals the relationship between prosumer behaviour, socio-economic characteristics, and techno-commercial penetration by using Pearson correlation analysis. The table depicts that socio-economic characteristics (r=0.373, p<0.01) and techno-commercial penetration (r=0.261, p<0.01) have a positively significant relationship with prosumer behaviour. Hence, there is a relationship between prosumer behaviour, socio-economic characteristics, and techno-commercial penetration.

Here are the observations that we gathered from our qualitative data analysis of the interviews with industry experts and academicians:

The subject matter specialists—the majority of whom are industry experts (28.6%), entrepreneurs (19%), policy makers (19%), and academicians (14.3%)—confirmed their willingness to adapt a multi-provider license-based grid-connected ecosystem (38.1%) for rural electrification and socio-economic development in the hilly terrains of North Bengal.

We also noted that the specialists preferred to adapt the self-help group (28.6%) and group supply-driven (19%) co-operative model so as to speed up the rural electrification process.

Gram panchayats and municipalities have been identified as the preferred investing agency (28.5%) for community funding to ensure the desired rural electrification and growth model at present. In the near future, however, private operators (57.1%) are the top choice for such an rural electrification mission, along with a self-help group to run it.

A majority of the specialist respondents (23.8%) also believe that the rural BPL populations should get the necessary government subsidies from the union government.

The specialists identified reliable electricity supply-based energy security, 100% electrification for rural India (42.7%), and provisioning for an additional source of income for the rural population through a solar power microgrid as the top priorities for the government.

Based on the ranking by the majority of specialist respondents, the top measures that need to be adapted for the sustainable techno-commercial model are: maximizing energy metering for all levels of consumers and ensuring revenue assurance as well as theft protection (42.6%); adaptation of the best benefits of ICT systems (28.6%); focusing on solar energy (28.6% kept rank1 and rank2 for solar power) for the microgrid economy; and AT&C loss reduction achieving energy efficiency (42.9%) for the target distribution zone.

The specialists noted the following as being the key drivers for the rural population adapting to a solar power-based microgrid:

Environmental factor together with reliable green energy (38.1%)

Availability of necessary provider and resources for affordable energy (28.5%)

Provision for government financial aid as rural electrification subsidy (23.8%)

The specialist respondents indicated that licensing to multiple providers in the same electricity distribution zone with provision for wheeling through the common state electricity distribution utility infrastructure (28.6%), right to open access (>1 Mw consumers, 28.2%), involvement of private players in the distribution operation focusing on Agricultural and SME consumers (23.8% and 18.9% respectively), as well as home electrification (38.1%) and emphasis on renewable energy purchase obligation (19%) for all the participating utilities in the region would be the key success factors for the proposed solar power microgrid model.

The specialist respondents added that the national capacity-building schemes and the National Rural Livelihood Mission (NRLM; 42.9%), as well as national rural employment and self-employment schemes (14.3%) are the main social inclusion levers that could be leveraged to set up the proposed solar power microgrid model effectively, alongside a rural electrification objective-linked incentive model (38%) for the utility workforce and flexible easy financing and convertible loan provisions (23.6%) for the participating utilities.

7.2 DEMOGRAPHIC INFORMATION

In this study, the results of the descriptive statistics reveal that the majority of the respondents in the study were male (42.4%) and most were aged between 30 and 40 years. Around 64.7% of the respondents had three to five people in their household. Further, around 65% of the respondents had one to three individuals in their household who were under five years of age, and most of the respondents had less than two rooms. The chi-square value suggests an association between the number of people in a household and the number of people in the household who are under five years of age.

7.2.1 SOCIO-ECONOMIC ASPECTS OF THE TARGET GEOGRAPHY

Rural electrification with microgrid electricity systems offers rural communities increased income-generation opportunities, improved community income, improved social networks, and better community health, all of which facilitates the socio-economic development of the rural community (Jha et al., 2016). The percentage analysis conducted for the present study reveals that most of the respondents stated that the SEB and state utilities provide the electricity service to them as well as that panchayats are the main source of community funding. Many respondents also stated that they have MFIs in their locality.

However, it was also noted that their family income is less than INR 2,500. This suggests that the region has very low socio-economic development. Moreover, most of the respondents have completed only their primary schooling, which indicates the low education level of the region. Furthermore, most of the respondents stated that their drinking water is supplied by the government pipeline. A majority of the respondents said they had toilets or bathrooms inside their house with electricity and a drainage facility. It was also found that 51.6% of the respondents cook with gas.

The data collected for the study revealed that 95.8% of the respondents have a current or savings account at a bank or non-banking financial institution. A majority of the respondents (50.7%) stated that they held membership of a co-operative society or credit financial institution. Many of the respondents said that documentation issues are the leading reason for their not having a bank account, an NBFC account, or an MFI membership. Most of the respondents get their household income from multiple sources and most of them have home-based businesses. Many respondents said that their home-based business was related to finance. Majority 69.1% of the respondents were ranking 8 for Radio as the rank of appliances or things at their home.

The results of the present study reveal an association between monthly household income and education level. The lower income and education levels of the respondents surveyed in North Bengal's Kalimpong district can be related to the inadequate access to electricity in that region, as around 60% of the population reported in the survey that electricity access is exclusively provided by the SEB or state utility. The study findings also imply an association between family income per month and MFIs. As many respondents have a very low family income, most of them did not know about MFIs as reported in the analysis. The study findings make it clear that almost 90% of the respondents have a savings or current account in a bank or non-banking financial institution. All of this indicates that the prospects of electrifying the region through microgrid energy technologies are high, and this could help to improve the education and income levels in the Kalimpong district of North Bengal.

7.2.2 TECHNO-COMMERCIAL FEASIBILITY OF THE PROPOSED SOLAR POWER-BASED MICROGRID

The percentage analysis reveals that 90.8% of the respondents have electricity at home and have an electric network or grid power line in their locality. A majority of the respondents (47.5%) have an electric supply office within 0.5 km from their home. Further, it was found that 44.2% of the respondents paid INR 2–5 for electricity. However, a majority of the respondents said that power cuts, blackouts, and outages occur for four to six hours per day, for eight to 12 days per month in the summer and for 30 minutes to two hours per day, and for four to eight days per month in the winter.

Some 53.4% of the respondents stated that sunlight is the alternative energy source available in their locality. The survey thus revealed that a majority of the respondents were interested in non-conventional energy for their home. Moreover, free electricity was found to be the main reason for their willingness to adopt electricity supply based on non-conventional energy sources. Some 59.9% of the respondents said they were unwilling to pay, invest, or spend in the first year. Most of them claimed to have people or providers that supplied equipment such as rooftop solar panels and they had a repair service facility or organization in their locality for such equipment. The chi-square test revealed an association between the respondents' interest in using non-conventional energy sources for home electrification and the driving factors that lead them to agree to using technology-based non-conventional energy. Thus, it appears that most of the respondents are willing to use non-conventional sources to electrify their home.

This signifies that the prospects for electrifying the region through the deployment of microgrid energy technologies are high. However, one must address challenges like power quality, reliability, variable energy generation, and bi-directional power flow while setting up the solution for rural electrification (Gambino et al., 2019). There are technical challenges to microgrid implementation that focus on microgrid system-based operation control in the electrical region. These are centralized controls for the optimization of microgrid operations, and they can be highlighted via numerous strategies based on power grid and microgrid interconnection (Plutshack, 2020).

7.2.3 PROSUMER BEHAVIOUR

The percentage analysis of the present study reveals that most of the respondents completely agreed that they have affordable electricity. Thus, there is an association between having an electrical connection at home and having an electrical network or grid power line in the locality surveyed. However, most of the respondents did not get any subsidy or government benefit as rural electricity consumers. Many added that they were not receiving any subsidy or government electrification scheme benefit despite being BPL consumers. It was also found that most of the respondents spent INR 50–100 every month on electricity. The survey revealed that most of the respondents partially agreed to pay an additional amount for a reliable electricity supply at home and most of them were willing to pay INR 50–100 per month for reliable electricity at their home.

Earlier studies have reported that the microgrids play a major part in the consumer’s readiness to pay for electricity and rural electrification in rural India, and that this has a direct impact on the price and reliability of the electricity supply provided by the energy systems (Graber et al., 2018). In line with this, given the findings of the present study, it was observed that they feel the electricity tariff is already too high and hence they are unwilling to pay for reliable electricity at their home. Thus, the government should provide funds for improvement and provide electricity for free or at minimum cost. From the chi-square value (89.345) and p value ($p=0.000<0.01$) it becomes evident that there is an association between the willingness to pay for reliable electricity every month and the willingness to pay an additional amount.

The survey revealed no differences between male and female respondents in terms of their willingness to pay for an electricity supply that is reliable and their seeking additional or new sources of income. The findings also indicate no difference in the reasons for the reluctance to pay for reliable electricity supply among the respondents across various age groups. If the non-conventional energy sources for home electric supply bring them considerable benefits such as affordability and opportunities for earning additional income, then they have no objection to paying for electricity. Also, respondents across the age groups consider electricity to be one of the most important parameters for the socio-economic development of the region.

However, the findings reveal a significant difference among the respondents across the various age groups in terms of enjoying access to affordable electricity and being willing to pay an additional amount to ensure reliable access to electricity at home. Here it should be specified that the households which earn relatively higher incomes are willing to pay an additional amount to access reliable electricity supply at home whereas families with lower income levels are not willing to pay extra to access reliable electricity supply. Hence, the difference in earnings highlights the ability of consumers and their willingness to access reliable electricity supply at home. The quantitative results of the present study thus reveal a positive relationship between prosumer behaviour, socio-economic characteristics, and techno-commercial penetration.

7.3 DISCUSSION ON FINDINGS

In the qualitative analysis of the present study, insights from industry experts, policy makers, entrepreneurs, academicians, service-sector SMEs, and government officials have helped the researcher to enhance their understanding of the current electrification arrangement in the target geography of the hilly rural terrains of North Bengal. The literature review revealed that in recent years, various advancements in the energy-generating technologies—such as by Akinyele and Rayadu (2016), and Eswar (2015)—have focused on developing environmentally friendly energy generation and distribution systems which significantly diminish the use of fossil fuel, which is the major factor for climate change across the globe (Martinez & Rivier, 2016). In this connection, renewable energy-based electrification systems are given a major preference with respect to energy access in rural regions across the world.

The review of literature on smart grid technology reveals that these applications bring in energy efficiency and climate change mitigation through the integration of different renewable energy resources with the existing power infrastructure (Wazeer, 2018; Maheswari & Ramkumar, 2017). Previous studies indicate that advanced microgrid technology brings a synergy between energy generators and consumers, wherein the users of energy become aware of their energy consumption pattern and optimize their usage according to the energy availability (Nigam et al., 2019; Eswar, 2015). In line with the results of previous research, the present study has revealed that the implementation of a multi-modal utility through microgrids can be a commercially viable and feasible model for rural electrification in India. Such studies also provide insights on the measures that need to be adopted to employ non-conventional energy-based energy technologies in the study region. Some studies have reported that the potential problems of grid integration are generally encountered while using smart grid technology that harnesses renewable energy sources, such as solar and wind energy, and that these problems can be avoided by utilizing other renewable energy sources such as biomass and hydrothermal sources (Harrison & Adams, 2017). However, the present study examined the specific challenges in the electrification of hilly terrains such as location constraints, difficulty of access, and establishment of reliable and cost-effective electrification systems in the hilly terrains of the region.

The literature review highlights that various factors have considerable influence on familial behavioural patterns in utilizing solar energy-based equipment and microgrids for electrification purposes (Quak, 2018). Past research studies indicate that these critical factors act as either catalysts or deterrents in their decision to install alternative sources of electrifying the household and the surrounding neighbourhood. These earlier researches have indicated that solar-based equipment like solar PV technologies have a significant and positive influence on the quality of life of both individual rural households and entire communities (Opiyo, 2016). However, various studies reported that the initial cost of investment involved in solar energy-based equipment and microgrids is a major factor that commonly discourages rural households from accessing them (Grimm et al., 2016). Some of the other important factors that have been widely mentioned in these past researches include the cost of investment, affordability (Harrison & Adams, 2017), the availability of financial schemes and subsidies, and the promotional strategies of marketing companies. In the present study, industry experts have suggested employing rural electrification in the study region with the help of a community funding exercise. They also suggested using municipalities as investing agencies and said that intensive electrification is possible through electric sector reform.

The literature review summarizes the evolution of rural electrification by reviewing the approaches that are followed in various countries through the deployment of solar-based energy and microgrid systems (Harrison et al., 2017). Past studies in this context highlighted cost reduction as a major benefit of using photovoltaic microgrids rather than extending the national grid for rural electrification (Grimm et al., 2016). Besides, earlier research has also emphasized that solar power-based energy technologies provide a significant improvement in electrification services while also mitigating the environmental pollution that results from using fossil fuel to meet the energy needs of rural communities across the globe. Some studies also recommend the importance of private sector participation and the deployment of environmentally friendly energy-generation technologies using renewable sources that are available in the region.

Despite ambitious plans for achieving rural electrification by extending the central grids, implementing such plans and achieving the desired electrification in the rural regions has remained a challenge due to the financial constraints of electricity distributors in the public sector. Past research on the rural electrification of India using renewable energy resources has critically examined the feasibility of energy-generation technologies such as home energy systems, microgrids, off-grid distribution applications, and distributed generation technologies for the electrification of the rural regions of India. The present study reveals that developing a framework for sustainable rural electrification in the hilly terrains of North Bengal with solar equipment as part of microgrid solutions is the appropriate way of electrifying the hilly regions of North Bengal. Also, the interviewed industry experts and policy makers have said that implementing microgrid energy systems which use solar power could generate new business opportunities, additional income, free electricity, and government subsidies for rural communities in the hilly terrains of North Bengal. Thus, the above benefits are the key driving factors that demand the use of microgrid systems powered by solar energy to provide electricity to the rural hilly terrains of North Bengal. The experts have also identified the key drivers for adaptation of the solar power-based microgrid in the rural region as environmental factors, together with reliable green energy, the availability of necessary providers and resources for the affordable energy, and the provision for government financial aid as rural electrification subsidies. The experts have also pointed to the rural development schemes that could be leveraged for electrification work, such as the NRLM, national capacity-building schemes, self-employment schemes, and national rural employment, in order to attain the most benefits from the projected energy systems for rural electrification that run on solar power. Also, the provision of flexible financing, easy convertible loans, and utility workforce incentives will motivate active contribution and engagement among the stakeholders who are linked to the goal of achieving rural electrification by using energy systems that are powered by solar energy.

On completion of the grounded theory methodology, a new modified conceptual lens emerged from the outcomes. The categories which emerged were compared using the conceptual lens.

The following model depicts the updated conceptual lens for the research, based on the overall research, data analysis, and literature review:

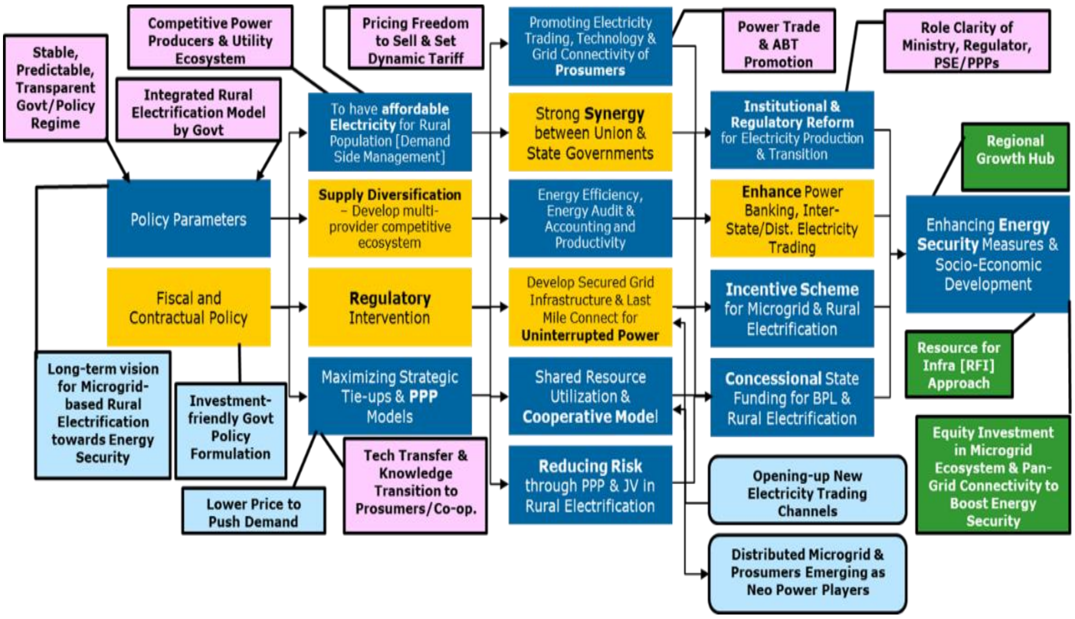


Figure 7.1: Modified conceptual lens derived from quantitative & qualitative analysis

- A new **modified conceptual lens** emerged from the grounded theory outcomes. The categories were compared with the conceptual lens:
- **Supply diversification** with multi-providers
- **Regulatory** intervention for RE promotion
- Strong **synergy between union and state** governments to promote institutional or regulatory reforms and a cooperative prosumer model for microgrid-based rural electrification
- Development of secured grid infrastructure and last-mile network for **uninterrupted power** supply and energy security for rural regions
- New electricity trading channels, incentive scheme, state concession for equity investment, and distributed microgrid-based rural socio-economic **growth model**

Below is a comparison of the categories for the conceptual lens and the final evolved framework related to RE microgrid-based rural electrification in India:

Table 7.2: Comparison of categories for evolution of modified conceptual lens

Matched Categories	New Categories	Modified Categories
1. Policy parameters 2. Affordable pricing for reliable electricity supply 3. Strategic tie-up between state-owned utilities, foreign investors, union and state governments 4. Promoting electricity trading through PPA or energy exchanges 5. Technologies and innovation 6. Energy efficiency and energy productivity 7. Reduce risk through joint venture or PPP model 8. Institutional and regulatory reforms 9. Fiscal and tax incentives 10. Concessional state funding and incentive schemes	1. Fiscal and contractual policy 2. Supply diversification 3. Regulatory intervention 4. Healthy union and state government relations 5. Developing secured grid infrastructure and last-mile connection for uninterrupted supply 6. Regional growth hubs 7. Energy conservation and efficiency 8. Encourage electricity trading and availability-based tariffing along with pricing freedom 9. R&D, technology, and innovation of operating model	1. Distributed microgrid and shared resource or shared service approach for prosumers to emerge as new power players 2. Decentralization approach and opening up new electricity trading channels 3. Equity investment in RE microgrid ecosystem and pan-grid connectivity to boost energy security 4. Resource for infrastructure approach

Evolution of framework for solar microgrid-based rural electrification leveraging modified conceptual lens:

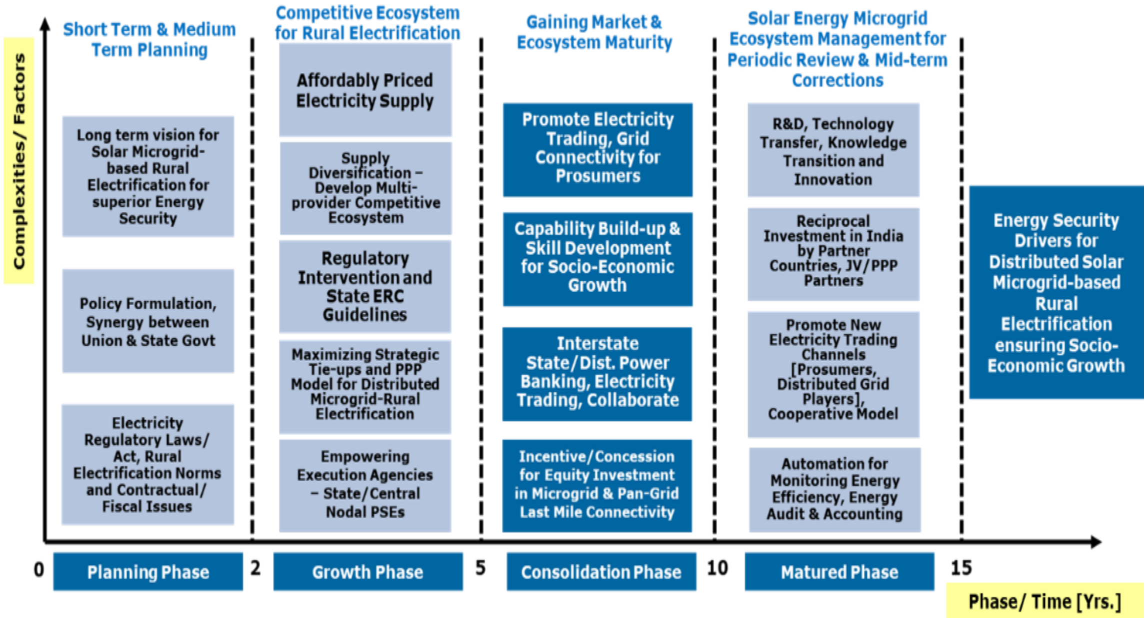


Figure 7.2: Solar microgrid-based rural electrification framework derived on the basis of the modified conceptual lens

- Based on the modified conceptual lens and taking into considerations the new categories brought forward by qualitative analysis using grounded theory, the **framework for solar energy microgrid**-based rural electrification in India has been established.
- The initial construct of the proposed solar microgrid-based **rural electrification** framework has been proposed based on the empirical studies done using population data and reference data from the **hilly terrains of North Bengal**.
- The solar energy **distributed microgrid**-based rural electrification framework would enable a **self-sustainable cooperative model** for the prosumers, thus ensuring socio-economic growth through **energy security**.

7.4 CONTRIBUTIONS TO LITERATURE, PRACTICE, AND BUSINESS

Contribution to Literature

- A step by Step framework for Solar Energy Microgrid-based Rural Electrification in Indian scenario. Previous researches have not provided a comprehensive step by step framework for addressing the issues for development of Renewable Energy Microgrid-based Rural Electrification for North Bengal Hills. This research attempts to fill this gap.
- The framework provides two outcomes: One) it provides the **factors to be addressed** for Solar Energy Microgrid-based Rural Electrification in Hilly terrains of North Bengal and Two) the **timelines and sequence** in which the complete framework has to be made. This is a major addition to literature in this sector.
- This research will enrich the understanding on **Solar Energy Microgrid-based Rural Electrification ecosystem** in the developing and emerging economies, bringing in specially the context of Indian Hilly terrains.
- Each country is unique, and India is no exception, hence the international best practices cannot be applied to India as it exists. There must be unique features to the Indian environment, which this research has attempted to address, especially for the **North Bengal Hills and North-Eastern Terrains** of the nation

Contribution to Practice and Business

- Government, Regulators and Business entities can use this framework getting additional insights to develop **Solar Energy Distributed Microgrid-based Rural Electrification** Framework & Socio-economic models for the concern ecosystem
- The Step by Step Framework would guide decision makers to approach Renewable Energy Distributed Microgrid-based **Rural Electrification scheme in a phased manner**, keeping in mind the elements illustrated in the framework in a phase has been put in place, before going to the next phase
- Increasing the Energy Supply provisions & related Socio-economic Growth through Solar Energy Microgrid-based Rural Electrification, would help India to meet its **Energy Security** needs, keeping in view its fast-growing electrical energy demands on account of economic growth and lifestyle improvement, especially in the **Rural India and Remote Geographies of the North-Eastern provinces**.

Figure 7.3: Summary of contribution of the research work to literature, practice & business

Contribution to Literature:

This research provides a framework for RE microgrid-based rural electrification in the Indian scenario, especially for the remote hilly terrains of the country. Previous research studies have not provided a comprehensive step-by-step framework for addressing the issues related to distributed RE microgrid-based rural electrification. The aim of the present research is to fill this gap. The framework offers two outcomes: First, it provides the factors to be addressed for distributed RE microgrid-based rural electrification. Second, it mentions the timelines and the sequence in which the complete framework has to be made. This is a major addition to literature in this sector. This research will enrich the overall understanding and best practice knowledge for distributed RE microgrid-based rural electrification in longer-term rural or remote community electricity supply by developing and emerging economies, bringing in the special Indian context, especially the hilly terrains of India, including factors like:

1. Utility alliances and foreign as well as private-sector and PPP investments in the sector

2. Capacity-building aspects
3. Regulatory compliance perspectives
4. Promoting a federated energy ecosystem within the union and state governments along with FIIs and FDIs as well as private or cross-sector players
5. Tax and fiscal incentives
6. Transnational electrification collaboration, especially with the neighbouring countries of India, like Bangladesh, Nepal, Bhutan, Sri Lanka, Myanmar etc.
7. Reciprocal investments by joint venture partners, private players, and FIIs in PPP models, opening up new geographical sectors for Indian enterprises including in the Middle East, in Africa, and in other developing or developed nations
8. Constitutional or government body-driven rural or social co-operative model for community development with a prosumer approach to ensure inclusive socio-economic growth
9. R&D, technology transfer, and innovation

Each country is unique, and India is no exception. Hence, the international best practices cannot be applied to India in their current form. There are unique features to the Indian terrains and markets, which this research is attempting to address. Sustainable demand means demand at a price point which Indian rural/semi-urban consumers can afford and use in the longer run. Similarly, tax incentives and other financial incentives play a significant role in the Indian scenario, since India lacks private sector, FII, and FDI investments in the energy utility sector. Tax and fiscal incentives help develop sustainable markets. Moreover, the ease of doing business is unique to the Indian market, given the current policies of the Government of India, especially the Ministry of Power (MOP).

Further, this empirical research has attempted to examine the underpinning theories that were considered for the evolution of this framework, including key theories like Rogers' diffusion of innovation theory (2003), theory of adoption, perceived attributes theory, and consumer socialization theory in light of the rural community cooperative-driven distributed RE microgrid-based rural electrification model for the remote hilly terrains of India.

Five key attributes of innovation—relative advantage, compatibility, complexity, trialability, and observability—were extensively covered through this research study to evolve with the proposed framework model. Adoption theory examines the individual and the choices an individual makes to accept or reject a particular innovation. In this research to develop a distributed RE microgrid-based rural electrification framework model, we observed that the choice of the rural population to adopt the RE microgrid-based ecosystem not only depends on socio-economic growth through a rural co-operative model that brings affordable and reliable electrical energy but also the evolution of new sources of income through selling excess power to the national grid, as a prosumer model, has played a major role from the perspectives of adoption theory and consumer socialization behaviour.

Contribution to Practice and Business:

The theoretical building blocks for distributed RE microgrid-based rural electrification are drawn from a wide range of thematic areas like rural electrification, industrial economics, socio-economic aspects of Indian under-privileged communities, rural economics, international business, renewable energy ecosystem, finance, geopolitical theories, and strategic considerations within jurisdictions. The eclectic framework and OLI (ownership, location, internalization) model postulates the occurrence of cross-border electrification-related investments and acquisitions, the transfer of ownership of assets, globalization benefits in remote electrification, and the dynamic relation between structural changes in the Indian utility sector and the rural economic development of the nation. According to industrial economics, a commercial enterprise strives for growth and expansion in two ways: The first is to enhance core competencies like developing new technologies, skill development, increasing managerial efficiency, creating joint ventures and PPP models, and global brand value creation. The other is to acquire or merge with another pre-existing company or firm in the target rural or semi-urban geographies in order to achieve lead market position by taking over an existing lease or license or by acquiring the franchisee, and to use the resources and expertise of the combined entity. The literature review underlines that the Indian distributed RE microgrid-based rural electrification approach possessed three major objectives: access to extensive untapped markets both within the Indian sub-continent and in future leveraging the same experience to access the overseas markets in similar economies or geographies, specific assets created by a larger and stronger state-owned company, and supporting governmental objectives of augmenting energy security through strategic tie-ups and PPP models for rapid expansion of the rural electrification programme with the untapped potential of renewable green energy sources. The literature review also highlights that the Indian energy utility segment lacks adequate funding in comparison to the huge requirements for rural electrification and the renewable energy augmentation mission. The union and state governments, state-owned utilities, government bodies, enterprises and companies, and private-sector business houses can use this framework to gain additional insights into the rapid development of a distributed RE microgrid-based rural electrification network that augments the energy security of India. Initially the government needs to play an important role so as to provide a basis on which government-controlled companies can build a structure which is sustainable and workable for Indian conditions, such as in the remote hilly terrains of the country. Since the framework provides guidance on a step-by-step approach along with the indicative timelines, the framework would guide decision makers to approach the phase-wise development of distributed RE microgrid-based rural electrification under Indian conditions.

7.5 CONCLUSION

The theoretical premise focuses on the standard mode of electricity supply which involves extension of the central grid. However, such an extension is not always feasible. It might not match the electricity demand of the rural households located in the study region, as electrifying the remote hilly terrains of North Bengal poses many challenges. The results of the study indicate that the rural inhabitants are willing to pay extra money to access affordable, reliable, and quality electricity supply. They favour the adoption of non-conventional energy source-based electrification systems as well. The main conclusion of this research work is that the rural populations in the study region are interested to adopt RE or solar power-based energy systems. However, they do expect suitable incentives that would motivate them to take this step to meet their energy needs.

Regardless of the actions taken by the Indian government to provide electricity to the rural communities through grid extensions and off-grid rural electrification schemes implemented at the level of state governments, remote locations—especially the hilly areas—and their electrification remains a major challenge for India. The microgrid energy technologies, including renewable sources of energy, may be recognized as a sound solution for the provisioning of sustainable and reliable sources of electricity to the rural parts of India (Bhushan & Kumarankandath, 2016; Banerjee et al., 2014). This further indicates that there is a need for the government to make provisions for the appropriate incentives to motivate each of the stakeholders in such an RE microgrid-based rural electrification ecosystem, including investors, electricity workers, government-affiliated bodies that might manage the programme, enterprises and private players that might be interested to engage through a joint venture or PPP model, and the families or consumers to encourage the adoption of RE-based energy systems for rural electrification and, in turn, comprehensive and inclusive socio-economic development. However, the survey findings reveal that the benefit of government subsidies does not reach almost 40% of the respondents. This indicates that the level of awareness among the BPL population regarding the benefit schemes is quite low. Accordingly, government interventions through wide-ranging campaigns and financial inclusion through the involvement of local government bodies (e.g., gram panchayats) to set-up rural community co-operatives are critical for comprehensive expansion of this RE microgrid-based rural electrification framework model.

Most critically, with the adoption of the distributed (grid-connected as well as off-grid islanded, as and when required) RE microgrid-based rural electrification framework model and adoption of the solar PV-based electricity ecosystem, the rural co-operatives and their respective member populations can pump out their excess power generation to the connected national grid for further electricity trading, resulting in the potential for significant additional revenue for them through this new channel, leading to the industrialized term, the 'prosumer' model, as part of this proposed rural electrification framework. This would not only ensure a self-sufficient approach for the rural cooperative communities but also boost the comprehensive socio-economic development of the rural population through income and employment generation. Thus, within the theoretical premises of alternative energy sources and the abundant RE-based islanded distributed power supply ecosystem for rural community development, a successful, self-sufficient, and self-contained rural electrification framework model is evident for the remote rural terrains of India.

However, the results of the study suggest that the government must initiate communication and financial measures in order to spread awareness and interest among the population regarding the financial benefits, schemes, and incentives that are available to rural households that adopt non-conventional or RE energy sources. This would encourage the rural population to move away from traditional fuels and towards solar-based systems for their day-to-day energy needs. Eventually, this would result in comprehensive socio-economic growth of the rural communities. The surveyed stakeholders have recommended that the government should prioritize a few areas to ensure successful rural electrification. These include achieving energy security based on affordable and reliable electricity supply, as well as planning for comprehensive electrification of rural India. The subject experts also recommended deploying a government body-led (e.g. gram panchayat) and group supply-driven rural cooperative model, while also drawing active engagement from self-help groups to generate significant employment in the electricity distribution or retail segment as well as to ensure quality electricity supply in the remote hilly regions of North Bengal by leveraging this distributed RE microgrid-based rural electrification framework model.

7.6 IMPLICATIONS

The study also indicates the potency of implications in the Indian subtext, particularly for policymakers when evaluating policies for rural electrification. There are challenges that persist beyond the policymaking scope. Therefore, mindfulness that a market is made up of individuals can alter the thought process beyond the analysis. Though the alteration in the landscapes with regard to give the changes in support, can sometimes be predicted. This helps improve policy-level engagement via enterprise-level thinking, which may further help in the improvement of efficiency for these programmes. By 2030, it is expected that huge strides would have been taken in the electrification of the country, but that largely depends on the government over the span of time to keep up such environment of support for the country and its people. The participation of the states is another necessary element in this regard. Programmes and policies remaining constant, the engagement of private participation, social organization, and non-government organizations with regard to the manufacture, sale, and distribution of the technology needs to be encouraged. Access to customers, provision systems, and keeping up their educational and functional uses at the end-user platform could be achieved better with the help of such enterprises.

7.7 QUALITY OF RESEARCH AND VALIDITY

Charmaz's (2008) four criteria of evaluation:

Table 7.3: Charmaz's (2008) four criteria research quality & validity evaluation, with which this research work has been aligned

SL No	Criteria	Indicators	Assessment
1	Credibility	• Are there strong logical links between the gathered data and analysis • Do the categories cover a wide range of empirical observations • Are the data sufficient to merit your claim	• The researcher has used multiple modes of data collection e.g. literature, industry reports and experts. Also experts interviewed were from varied institutions to provide a holistic views. Constants comparison method also lends credibility through validity of data at each stage. • Mixed method has helped to triangulation of key data
2	Originality	• Are your categories fresh. Do they offer new insights • What is the social and theoretical significance of the work • How does the grounded theory challenge, extend, or refine current ideas, concepts and practices	• Research has offered new integrated conceptual Framework for Solar Energy Microgrid-based Rural Electrification in Indian Hilly scenario. Also new categories were added like Co-operative model for Electric supply, Technology, Infrastructure, Prosumer Model, and Cross-revenue channel provisioning.
3	Resonance	• Do categories portray fullness of studied experience • Does your grounded theory make sense to your participants or people who share their circumstances	• Constant comparison method in grounded theory helps in validating emerging categories. Also, framework evaluation & comparison for adapting in the context of Rural Hilly Terrains of North Bengal helps in establishing new Rural Electrification model construct
4	Usefulness	• Does your analysis offer interpretations that people can use in their everyday worlds. • How does your work contribute to knowledge? How does it contribute to make world better. • Can the analysis spark further research in other substantive areas?	• The framework provided by the research would be useful for the government and decision makers to help establishing distributed Solar Microgrid-based Rural Electrification, which in turn would help in Energy Security, fostering country's Rural economy. • The data, information gathered and analysis on the vital topic would certainly spark further research in the area.

7.8 LIMITATIONS OF THE STUDY

This study is limited to the rural hilly terrains of North Bengal in India. The study aims to develop a framework for successful rural electrification through solar energy-based equipment as part of microgrid systems in the rural hilly terrains of North Bengal, India (based on learnings from developed countries). Hence, the developed framework is limited only for successful rural electrification through the solar energy-based microgrid, while the following observations are to be noted regarding the limitations:

- ► Each research has its own limitations and we have no exceptions.
- ► Interview transcripts were prepared. A few interviews were not recorded but the researcher has used the following techniques to ensure data is captured correctly and completely:
  - Paraphrasing
  - Questioning
  - Checking
  - Working on data immediately post interview
- ► The output being a substantive conceptual framework for the rural electrification of India, it cannot be generalized for other sub-sectors.
- ► The research does not claim that this is the only possible way to develop a solar microgrid-based rural electrification framework for energy security. There could be other theoretical matrices that meet the same objective.
- ► Any research project like the present one takes a few years to complete. Hence, there can be a bias with respect to the respondents, based on the year they responded or were interviewed.

7.9 RECOMMENDATIONS FOR FUTURE RESEARCH

The study findings can help understand the key requirements of people living in rural areas, especially in hilly regions, with regard to the adoption of clean energy-based technologies that may help the government to plan suitable policies and further incentivize the active engagement in planning by the rural community. The government would need to undertake initiatives with regard to the willingness of the consumer regarding the pay and the electricity tariff, which may vary across regions. However, it may be concluded through the findings that the criteria of wilful payment may not completely represent all the rural considerations, as they would be limited to the sample of the study. It can also pave ground for future research that examines the challenges and opportunities associated with integrating the microgrid and central grid systems.

This would help ensure a reliable and affordable supply of electricity for the rural regions of the nation. In case of future work, the following points are recommended and these are categorized based on the expected outcomes:

- Microgrid developers may be involved in the implementation of community microgrids. This requires an examination of consumer behaviour after the installation of the grid. Such a study may help to develop the appropriate roles within the microgrid after the arrival of this system. The community in this case may assess all these roles and thereby choose any one among them.
- The utility of this system needs to be determined for the operation and management of the distribution system network which refers to more economical and that may pay the microgrid system to control the back-up. It would help to measure the exit or the utilization of several distributed generators that are required for the implementation.
- The proper remuneration can be considered to increase the costing tool which may be useful for establishing the microgrid system. It is recommended that the remuneration minimizes the burden of expenditure for the customers of electricity.

CHAPTER- 8

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
ARR	Aggregate Revenue Requirement
AT&C	Aggregate Technical & Commercial
BPL	Below Poverty Line
CAGR	Compound Annual Growth Rate
CKM	Circuit Kilometers
CoD	Commercial Operation Date
DDG	Decentralized Distributed Generation
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana
DPR	Detailed Project Report
DSM	Demand Side Management
DT/ DTR	Distribution Transformer
EBIDTA	Earnings Before Interest Depreciation Taxes and Amortization
ECBC	Energy Conservation Building Code
EE	Energy Efficiency
EPC	Engineering, Procurement and Construction
EPS	Electric Power Survey
ER	Eastern Region
FY	Financial Year
GoI	Government of India
GSS	Grid Substation
GWp	Giga Watt Peak
HH	Household
IPDS	Integrated Power Development Scheme
IPP	Independent Power Producer
ISTS	Inter State Transmission System
LED	Light-emitting Diode
LILO	Loop In Loop Out
LT	Low Tension
MNRE	Ministry of New and Renewable Energy
MoC	Ministry of Coal
MoEF	Ministry of Environment & Forests, Government of India
MoP	Ministry of Power, Government of India
MU	Million Unit of Electricity (in kWh)
MVA	Mega Volt Ampere
MW	Mega Watt
NAD	Need Assessment Document
NESCL	NTPC Electric Supply Company Limited
NHPC	National Hydroelectric Power Corporation

NTPC	National Thermal Power Corporation
O&M	Operation & Maintenance
PAT	Profit After Taxes
PBT	Profit Before Taxes
PFA	Power For All
PFC	Power Finance Corporation
PGCIL	Power Grid Corporation Of India Limited
PLF	Plant Load Factor
PMA	Project Monitoring Agency
PPA	Power Purchase Agreement
PPP	Public–private Partnership
PSS	Power Sub-station
R&M	Renovation & Modernization
RE	Renewable Energy
REC	Rural Electrification Corporation
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
ROW	Right of Way
RPO	Renewable Energy Purchase Obligation
SCADA	Supervisory Control and Data Acquisition
SHR	Station Heat Rate
SLDC	State Load Dispatch Center
T&D	Transmission & Distribution
TBCB	Tariff Based Competitive Bidding
ToR	Terms of Reference
TPS	Thermal Power Station
UMPP	Ultra-Mega Power Project
WBERC	West Bengal Electricity Regulatory Commission
WBSEDCL	West Bengal State Electricity Distribution Company Limited
WBPDCL	West Bengal Power Development Corporation Limited
WBREDA	West Bengal renewable Energy Development Agency

APPENDICES

Appendix – I: Quantitative Survey Questionnaire

DEVELOPING A FRAMEWORK FOR RURAL ELECTRIFICATION IN HILLY TERRAINS OF NORTH BENGAL- ANALYSIS OF THE PROSPECTS OF MICRO-GRID SOLUTIONS

Date**:** ________________

Section I: General Information

1. Name of the respondent (Optional): ……………………………………………

2. Sex ❑ Male ❑ Female 2A. Location:

3. Age ……………………. (Years) 3A. Occupation:

4. Do you have Electrical connection at home? ❑ Yes ❑ No

4 A. Does Electric network/ grid power line exist in your locality? ❑ Yes ❑ No

5. What is the distance to the Electric supply office: ………km ………. time on foot/by car

6. Price of electricity paid per unit/ kWh

Residential Area: ……………………. Commercial area: ....

7A. Power cut/ Blackouts/ Outage (Summer): …Mins/ day: ……Days/ week: ……Days/ month

7B. Power cut/ Blackouts/ Outage (Winter): …Mins/ day: ……Days/ week: ……Days/ month

8. Provider in Locality: ❑ SEB ❑ Group Supply ❑ Private ❑ Multiple ❑ Municipality

9. Source of Community Funding: ❑ Panchayat ❑ Co-operative ❑ Govt. Body ❑ Others

10. Are Micro-finance Institutions (MFIs) present in your locality? ❑ Yes ❑ No

Section II: Techno-commercial Penetration

11. Which of the following alternative energy sources are ample available in the locality?

❑ Sunlight ❑ Wind ❑ Biogas ❑ Waterfalls ❑ Large Waterbodies ❑ Others, please specify:

12. Are you interested in non-conventional energy for your Home electricity? ❑ Yes ❑ No

13. What will be the major driving factor for you in non-conventional energy-based electricity?

❑ Additional Income ❑ New Business Opportunity ❑ Free Electricity ❑ Govt. Subsidy ❑ Reliable Electricity Supply ❑ Environmental Reasons ❑ Others, please specify:

14. Max. willingness to invest/ spend in first year (Rs)? ❑ <1000 ❑ 1000-5000 ❑ 5000-12000 ❑ >12000 ❑ No Pay

15. Are there people/ provider available for such equipments (e.g. Roof Top Solar Panel)? ❑ Yes ❑ No

16. Are there repair service facility/ organization in locality for such equipments? ❑ Yes ❑ No

Section III: Socio-Economic Characteristics

17. How many people live in your household? (Including you) ……………….

17A. How many people under 5 years live in your household? …………………

17B. How many rooms does your house have? ……………………………….

18. Family income/Month (Rs): ❑ <2500 ❑ 2500-5000 ❑ 5000-10000 ❑ 10000-20000 ❑ >20000

19. What is the highest level of education of the head of your family/ household?

❑ No formal education ❑ Primary school completed ❑ Secondary school completed ❑ Higher education completed ❑ University completed ❑ Postgraduate ❑ Other

20. Where does your drinking water come from?

❑ Govt. Pipeline supply ❑ Surface ❑ Boring Well ❑ Local Waterbodies/Falls ❑ Other

20A. Bathroom/Toilet: ❑ Inside ❑ Outside ❑ With Electricity ❑ With Drainage

21. Which of the following appliances or things do you have at Home?

SL NO	Appliances	Tick (✓)
1.	Radio	❑
2.	TV	❑
3.	Refrigerator	❑
4.	Sewing Machine	❑
5.	Internet Device	❑
6.	Music System	❑
7.	Hot Water Supply Geyser	❑
8.	Electric Fan & Light	❑
9.	Generator/ Inverter	❑

21A. How are you cooking?

❑ With electricity ❑ With gas ❑ With wood ❑ Others If other specify ………

22. Do you have a current or savings account at a Bank/ Non-banking financial institution?

❑ Yes ❑ No ❑ Don't know

22A. Do you have membership of any co-operative/ society/ credit financial institution?

❑ Yes ❑ No ❑ Don't know

22B. If no in Q 22 – 22A, then why not?

❑ There are none nearby ❑ Do not qualify ❑ others

If other specify ……

23. What is/are the major source(s) of income for your family?

Occupation	Farming	Service	Teaching	Cattles	Business	Self-Employed	Other
Amount (Rs)							

23A. Do you have any home-based business? ❑ Yes ❑ No

23B. What is the best description of your home-based business?

❑ Food/Grocery ❑ Trade/Sales ❑ Agriculture ❑ Other Retailer ❑ Small Manufacturer ❑ Service/Repair ❑ Finance

23C. If your home-based business in Agro-sector, do you have farmland for irrigation? ❑ Yes ❑ No

23D. If yes, how much …………………….hectares.

24. Are you looking for addl./ new source of income (e.g. non-conventional electricity)?

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

Section IV: Prosumer Behaviour (Willingness to Pay and Adapt)

25. Do you have access to affordable electricity?
    ❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree
26. Do you get subsidy/Govt. electrification benefit as rural electricity consumer ❑ Yes ❑ No
27. Do you receive subsidy or Govt. electrification scheme benefit as BPL consumer ❑ Yes ❑ No

28. What is your spending for electricity/month(Rs)? ❑ <50 ❑ 50-100 ❑ 100-150 ❑ 150-200 ❑ >200
29. Are you willing to pay some addl. amount for reliable electricity supply at your home?
❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree
30. Max. willingness to pay for reliable electric/month(Rs)? ❑ Not Willing ❑ <50 ❑ 50-100 ❑ 100-200 ❑ >200

SL NO	Reasons for not willing to pay for reliable electricity supply	Tick (✓)
1.	The electricity tariff is already too high.	❑
2.	I do not have enough income to pay for reliable electricity services.	❑
3.	I want to see improvement in electricity supply before I can pay more charges.	❑
4.	Government should provide funds for improvement and provide electric for free/ min. cost	❑
5.	I do not trust the extra money will be used for the intended purpose	❑
6.	There is more pressing use of extra income to my household than reliable electricity supply	❑
7.	The electricity companies should bear the extra cost	❑

Appendix – II: Qualitative Survey Questionnaire

DEVELOPING A FRAMEWORK FOR RURAL ELECTRIFICATION IN HILLY TERRAINS OF NORTH BENGAL - ANALYSIS OF THE PROSPECTS OF MICRO-GRID SOLUTIONS

Date: ______________

Section I: General Information & Investment Opinion

1. Name of the respondent (Optional): ………………………………………

2. Sex ❑ Male ❑ Female 2A. Location:

3. Age ……………………. (Years) 3A. Occupation/ Role as Expert:

4. Which of the following best describes you as professional?

❑ Industry Expert ❑ Policy Maker ❑ Academician ❑ Entrepreneur ❑ Govt. Official ❑ Service Sector SME

5. In your opinion which Provider/ institutional instrument should be the best choice to deliver Rural electrification and micro-grid supply facilities in the Localities of Hilly terrains of North Bengal? Kindly explain Why ……….....

❑ SEB/State Utility ❑ Group Supply/Co-operative ❑ Private Sector ❑ Panchayat/ Municipality ❑ Multi-provider

6. Kindly rank preferred investing agency of Community Funding for Rural electrification in North Bengal hills? Why.

❑ Panchayat/Municipality ❑ Co-operative/Self-Help Group ❑ Govt./REC/SEB ❑ MFIs ❑ Private Operators

6A. Rank from below list the potentially preferred electrification and electricity supply partnering agency for Rural hilly terrains of North Bengal:

(a) Self-Help Group
(b) Individual Entrepreneurs
(c) Co-operatives
(d) Panchayats/ Municipalities
(e) Group Supply Units
(f) Private Sector Commercial Firms (Utilities)

Section II: Government Policy and Legal Provisions

7. Can unbundling of state utilities, Higher FDI limit towards Open Economy and de-regulation of electricity market in India, ensure/ achieve 100% intensive electrification in the Rural hilly terrains of North Bengal by March 2021?

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

7A. Could you Pl rank the following potential key amendments/ focus areas of interest in the context of upcoming draft of the new/ amended Electricity Act and new Tariff Policy, which could be the key differentiators in remote Rural electrification within India (e.g. intensive electrification of hilly rural terrains of North Bengal)?

(a) Limiting Cross-subsidy scheme, gradually transforming towards DBT model
(b) Multiple licenses for Electricity supply in same region, while wheeling remains with Discoms
(c) Right for Open Access (Demand>1 MW) for the consumers and rightful bidding mechanism
(d) Renewable Purchase Obligations
(e) Enrichment of the major developmental schemes like UDAY and SAUBHAGYA

8. Kindly rank which of the following rural development and employment schemes could be best utilized/ leveraged to engage the local/ rural youth in capacity building for electrical grid expansion/ electrification work in the rural hilly terrains of North Bengal:

❑ Deen Dayal Upadhyaya Grameen Kaushalya Yojana

❑ Deen Dayal Upadhyaya Antyodaya Yojana/ Swarnajayanti Gram Swarozgar Yojana

❑ Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA)

❑ Sampoorna Grameen Rozgar Yojana

9. More than 90% villages in the Rural hilly terrains of North Bengal have been intensively electrified leveraging the Govt. schemes like (a) Deen Dayal Upadhyaya Gram Jyoti Yojana and (b) SAuBHaGYa, Ujala and Uday.

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

10. Kindly Rank in your view, which areas should be the priorities for the Union/ State Govt. for intensive Rural electrification penetration in the hilly terrains of North Bengal:

(a) Agricultural sector/ Irrigation
(b) Rural/ Semi-urban Households
(c) Drinking Water Supply to the Families
(d) Providing benefits of Electrification to the Small Traders
(e) Providing benefits of Electrification Manufacturers/ SMBs
(f) Emphasis on Rapid Mass Industrialization
(g) Electrification of the Public Bodies/ Institutes (e.g. Panchayat, School, Administrative Offices, Health Centres)

11. Rank following Government policies from the electrification perspective of Rural hilly terrains of North Bengal:

(a) Free electricity for BPL Rural Households
(b) Intensive electrification of partially electrified villages
(c) Strengthen only Public Body Units/ Govt Entities/ Home & Defence Ministry units (for border terrains)
(d) Only electrification of unelectrified villages/ outfits
(e) Focus on Reliable Power Supply to the Domestic/ Industrial consumers

12. Rank the following potential Govt. strategy/ instruments for accelerating rural/ semi-urban sector electrification and intensive electrification inclusion work through set-up of microgrid based ecosystem in India:

(a) Flexi/ easy loan terms for longer period by REC/ Banks/ Financial Institutes
(b) Increase Grants for the participating bodies/ utilities
(c) Emphasis on incentive model at all levels of employees of electrification agencies and other key stakeholders
(d) Focus on milestone-based grant increase for the electrification agencies/ utilities
(e) Promote commercial model through PPP/ Co-operative bodies/ Private Sector participation/ FDI etc.

13. Privatization of state distribution utilities and Electricity Discoms can play major role in rapid rural electrification and intensive electrification penetration across the remote rural terrains of India (e.g. hilly terrains of North Bengal).

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

14. Commercialization of Rural Electrification and intensive electrification penetration work through PPP model, Co-operative model through Panchayat/ Self-Help Group/ Municipality or formation of Group Supply units at the block/ sub-division level can play significant role in socio-economic development in rural India (e.g. GDP improvement and per capita electricity consumption improvement in rural hilly terrains of North Bengal).

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

15. Implementation of Multi-modal utility model for the rural/ semi-urban India can play major role in Rural electrification & non-conventional energy based microgrid set-up objective, from the feasibility and commercial viability improvement perspective (e.g. for the hilly terrains of North Bengal, the integrated multimodal utility model covering electricity, gas, water, heating, waste management work, can bring in GDP growth, microgrid based energy security and per capita income enhancement through a commercially viable & economically sustainable approach).

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

16. Rank from the following list the Top priorities for Govt. from the microgrid based rural electrification perspective:

(a) Achieve Higher Energy efficiency for the Consumers/ Electricity network
(b) Achieve 100% Electricity Grid Connection even for the remote Rural/ Semi-urban Terrains
(c) Digitalization of the Electricity supply operations (commercial and Technical aspects)
(d) Consumer Assistance for Enhancements of people's Experience, uninterrupted Lifestyle and GDP Growth
(e) AT&C Loss Reduction for achieving Energy Security and Cheaper Electricity for the Nation
(f) Discom/State Utility/Electrification Agency enablement for sustainability and commercial viability

Section III: Techno-commercial Perspective

17. Rank the below mentioned key drivers of Rural electrification in the context of North Bengal hilly terrains :

(a) Govt. financial aid
(b) Availability of equipments and providers
(c) Abundance of resources/ energy sources
(d) Govt. policy and Electricity act amendment
(e) Human consciousness for reliable power and green energy

18. Rank the following initiatives from the Govt./ industry priorities perspective for enhanced electrification penetration in NB hilly terrains:

(a) Maximize Consumer and Industrial/ Operational Metering
(b) Enhance Connection Rate (new and Reconnection)
(c) Sub-transmission/ distribution Infrastructure Improvement
(d) Theft Protection Measures adaptation
(e) IT Systems (e.g. GARV II App) implementation/ frequent usage
(f) Surveillance of electricity supply systems Locally (e.g. Panchayat level monitoring)
(g) Incentive Scheme for key stakeholders (e.g. utility employees, partners/ suppliers, consumers)

19. Which of these alternative energies to be focused primarily for Rural electrification in NB hilly terrains? Why ...

❑ Sunlight ❑ Wind ❑ Biogas ❑ Waterfalls ❑ Large Waterbodies ❑ Others, please specify:

Section IV: Socio-Economic Behavioural Pattern of the Prosumers

20. What could be the major driving factor for non-conventional energy-based electricity in North Bengal hills?

❑ Additional Income ❑ New Business Opportunity ❑ Free Electricity ❑ Govt. Subsidy ❑ Reliable Electricity Supply ❑ Environmental Reasons ❑ Others, please specify and kindly explain why ....

21. More than 50% of the Rural BPL people in North Bengal hills have access to affordable electricity.

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

22. More than 50% of Rural BPL people in NB hills get electricity subsidy/Govt. electrification scheme benefit.

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

23. More than 50% of Rural BPL people in NB hills are willing to pay addl. amount for reliable electricity at home.

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

24. Possible reason for people in North Bengal hills not willing to pay extra for reliable electricity:

SL NO	Reasons for not willing to pay for reliable electricity supply	Tick (✓)
1.	The electricity tariff is already too high.	❑
2.	They do not have enough income to pay for reliable electricity services.	❑
3.	From experience, they want to see improved supply before paying more charges	❑
4.	Government should provide funds for improvement and provide electric for free/ min. cost	❑
5.	Based on experience, they do not trust that extra money will be used for intended purpose	❑
6.	There is more pressing use of extra income to households than reliable electricity supply	❑
7.	The electricity companies should bear the extra cost for the potential revenue addition	❑

25. Rank following Potential Govt. measures for rural electrification encouragement among the NB Hill consumers:

(a) Pre-paid Metering for Flexi usage and Spot Bill Discount
(b) Direct Bask Transfer (DBT) based subsidy mechanism
(c) Monthly Quota for Free Electricity to Consumers
(d) Introduction of Economic & Energy Efficient Smart devices for Lifestyle enhancements

26. Long-term PPP agreements, Clear provision for settlement & fiscal implications in Energy trading through Electricity Act Amendment & centralized moderation by Govt. are absolutely necessary to protect the interest of the PPP players, FDIs, and Private Players in Renewables & Rural Electrification

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

27. Union Govt. & State Govts to play pivotal roles to ensure Nation-wide capacity building, job-oriented-training for rural youth and setting-up of shared service units for the common support function activities to promote commercial viability, abundant supply of skilled-economic resources for Electrification penetration partners and also for employment boosting across the country as part of the Rural Electrification initiatives through RE-microgrid.

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

28. Distributed RE-Microgrids can ensure adequate supply of Quality Electricity as well as Employment & Source of Addl. Income or new income channels for the Rural population in the Hilly terrains of India

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

29. India should try to have strategic tie-ups with World's best 5 Electrically advanced countries for Rural Electrification, Renewable Energy & Microgrid Technology & skill transfer arrangement within next Three years

❑ Completely Agree ❑ Partially Agree ❑ Somewhat Agree ❑ Partially Disagree ❑ Completely Disagree

Appendix – III: Curriculum Vitae with List of Publications

Archan Bhanja

Professional Synopsis

16+ years of diverse experience in E&U ICT Industry covering Large Turn-key Power System Engineering solutions, Sustainable & Renewable Energy Ecosystem design, and Techno-domain Consulting for Digital Utility Systems including Smart Grid & Distributed Microgrid Integration across geographies like EU, NAM, APAC and IMEA

Work Experience

- **16+ Years** of Hands-on Industry Experience & In-depth E&U Sector Knowledge incl. Decarbonization
- **July'15 - Present** with **Atos Global IT** as Principal Consultant for large E&U engagements worldwide
- **Extensively** worked for **Cognizant** & **TATA** Globally, executing E&U Revenue Assurance & Energy Trading soln.
- **Strategic role** for **SIEMENS** in Generation SCADA, Distribution Management and Remote S/S Automation etc.

Academic Details

- **Master of Business Management** (Marketing | Finance) from University of Calcutta [2 Years' Full Time Course]
- **Bachelor's Degree** in Electrical Engineering from BPUT Rourkella [4 Years' Full Time Course]
- **ITIL** V 3.0 Certified Professional + **PRINCE2 Practitioner** Certified Agile Program Expert

Publication Details

Paper Title	Journal Details	Publication Status
key factors that are influencing the decision of the households for adapting the solar energy based equipment & micro grid systems for rural electrification in the rural hilly terrains of the north bengal	International Journal of Social Science and Economic Research [ISSN: 2455-8834] – UGC Care Volume: 03, Issue: 04 "April 2018"	Published
Solar Equipment Based Micro Grid in Hilly Terrains of Rural India - A Broad Perspective	International Journal of Innovative Technology and Exploring Engineering [ISSN: 2278-3075] – SCOPUS Volume: 10, Issue: 02, December 2020	Published
Developing a Framework for Rural Electrification in India – Analysis of the Prospects of Microgrid Solutions	International Journal of Sustainable Development and Planning [ISSN: 1743-7601] - SCOPUS Final Revised Draft along with Copyright Transfer Agreement submitted in December 2020	Provisionally Accepted – Publishing Expected soon

PLAGIARISM REPORT

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Sources included in the report

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SA	**Review Manuscript.pdf** Document Review Manuscript.pdf (D57967926)	2
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W	URL: https://www.researchgate.net/publication/278412396_Development_of_photovoltaic_pow ... Fetched: 2/10/2020 10:36:20 PM	2
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