Sustainability Study of Village Micro Hydro Power Plants Installed In Mansehera, Khyber Pukhtoonkhawa.

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Dedication

I dedicate this project to Allah Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this work.

This study is also wholeheartedly dedicated to my beloved parents, who have been my source of inspiration and gave me strength when I thought of giving up, who continually provided their moral, spiritual, emotional, and financial support. And who encouraged me all the way and whose encouragement has made sure that I give it all it takes to finish that which I have started.

It is also dedicated to my brother and some of my genuine and constant friends who kept me motivated and believed in me to accomplish this. And lastly, to myself for all my hard work, dedication, and sincerity to achieve my goals and for not giving up despite all the challenges.

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Librarians at Bahria University also deserve special thanks for their assistance in supplying the relevant literatures. My fellow postgraduate students should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members for constant support.

ABSTRACT

Pakistan has been facing a financial crisis in recent times. The energy sector is more affected due to the economic situation. More than 70 million people in Pakistan cannot connect to the national grid due to a lack of investment and infrastructure in rural areas. Therefore rural electrification is a major issue. Many micro hydropower plants (MHPs) are installed for rural electrification in northern areas of Pakistan. The benefits to local communities through these MHPs are immediate and substantial, but their sustainability continues to be a major concern over the long term. Without proper sustainability, projects may run into operational problems. Therefore, the research aims to study the long-term sustainability of two installed MHP projects. The research determined the environmental, social and economic benefits of installed micro hydro power plants. The data has been collected from field observations, questionnaires, and interviews with all relevant stakeholders. The research study determined overall sustainability of a 100 kW and 70 kW plant in Rajwal and Khainian village. This research consists of 28 indicators including economic, social, and environmental parameters. The average indicator score is between 1 and 4. The results revealed that the percentage of dimensions evaluated was 97% for economic, 89% for social, and 78% for environmental while the study found that the economic parameter is the highest score at 3.75 followed by social 3.5 and environmental 3.0. The installed MHPs have a significant contribution to the improvement of the economic and social conditions of the selected study area. The results demonstrated that the research study can serve as a basis for sustainability assessment both quantitatively and qualitatively. This model provides a simple way to conduct comparative studies on MHPs that will lead to efficient decision-making.

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ADB	Asian development bank
AE	Alternative energy
AEPC	Alternative energy promoter center
EU	European union
GWh	Giga watt hour
IRENA	International renewable energy agency
kWh	Kilo watt hour
LPG	Liquefied petroleum gas
MHP	Micro hydropower plant
MW	Mega watt
NEECA	National energy efficiency & conservation authority
NEPRA	National electric power regulatory authority
NMHPDA	Nepal micro hydro power development authority
PEDO	Pakhtunkhwa energy development organization
PPDB	Punjab power development board
PPIB	Private power and infrastructure board
RE	Renewable energy
UNDP	United nation development program
WAPDA	Water and power development authority
WB	World bank

CHAPTER 1

INTRODUCTION

1.1 Micro hydropower plant

Micro hydropower plant MHP is a power plant that has the capability of electricity generation between 1 kW and 100 kW (Hoseinzadeh et al., 2020). The MHP is the most reliable and cost-effective for remote areas. This technology is more suitable for developing countries. There are thousands of plants have been installed in China, Nepal, Sri Lanka, Pakistan, Vietnam, and Peru. The MHPs provide constant electricity for small communities and businesses. The investment on MHP is in range and has a quick payback period. The MHP has immediate and direct benefits for rural communities that could not connect to national grids.

Here is the basic component of a micro hydropower plant MHP. Following is present the basic component used in our proposed micro hydropower plant MHP.

1.1.1 Plant layout

The water from the river shall be drained using random rubble shaped structures. The power lines are 1800 feet long. The masonry is cemented for the protection of water. With a width of about 2 feet and a depth of about 4 feet, the flow of water is maintained. There are approximately 6 cases of diversion water. For the power channel and the engine, a PCC 1:3:6 plum structure is proposed. Desidementation had been performed by the flashing gate. The water from the inlet valve to the penstock through X flows to the turbine for power generation. The generator and turbine are coupled with a belt drive mechanism. The location for the plant has been selected as per site requirements.

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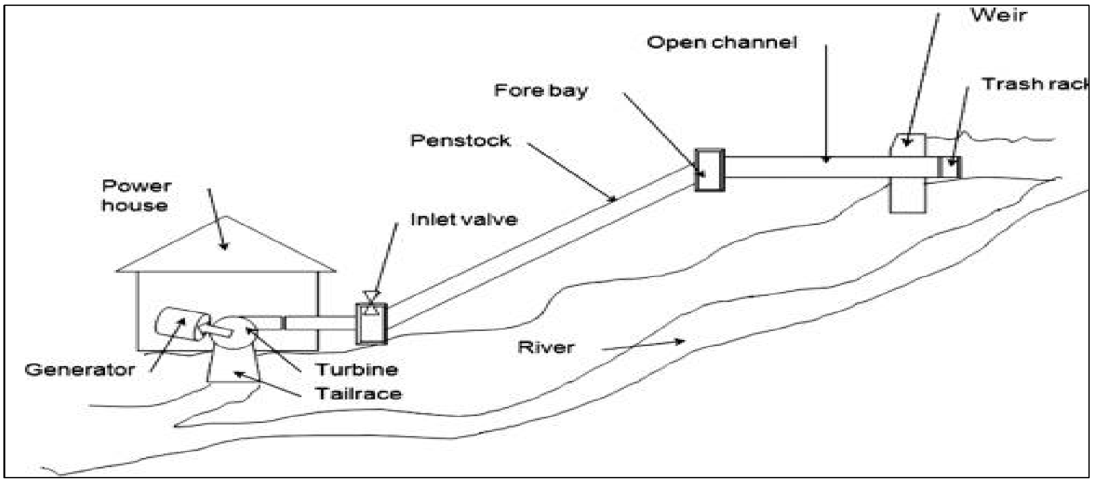
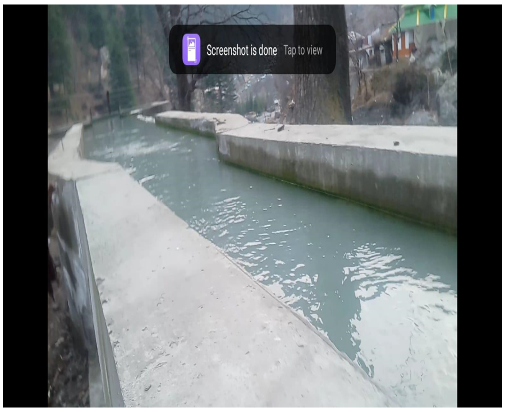


Figure 1.1 Layout of micro hydro power plant.

Power house (a)

Fore-bay (b)

Turbine (c)



Concreted masonry (d)

Figure 1.2 Powerhouse (a) fore bay (b) turbine (c) concreted masonry (d)

1.1.2 Fore-bay

The fore-bay serves as a reservoir for the turbine. The fore-bay tank is joined with a penstock pipe by nut blots to supply water regularly. The function of the fore-bay is to store water and ensure a constant supply of water to the turbine. The movement of the turbine depends on water intake from the fore-bay. The influx of water increased through the concrete wall of the fore-bay to serve as a settling area for water.

1.1.3 Penstock

The penstock is a pipe to connect the fore-bay to the turbine. The penstocks serve as a carrier of constant water flow from the fore-bay to the moving turbine. The diameter of the penstock is 12 inches. It is made of mild steel which is fixed with nut bolts.

1.1.4 Powerhouse/tailrace channel

The power of Khanian and Rajwal MHPs were constructed on the left bank of the Kunhar river. The powerhouse provides space for a turbine, generator, and controller. The roof of the powerhouse has been concreted to make secure the power system from any rain, flood, and land sliding. The water used by the turbine is discharged into the Kunhar river. The way of discharged water has cemented to throw into river safely.

Powerhouse (a)

Trail race (b)

Figure 1.3 Powerhouse (a) Trail race (b)

1.1.5 Turbine and generator

The T 15 turbine assembled and made locally, with a unit generation of 100 kW has been installed. The water level is controlled by constructing a short weir-type structure, through the tailrace. The following design is a single unit of a turbine. The net head rate output is 1*100 kV with 5 cusecs water discharge rate and efficiency is 80%.

The generated would be rated at 1* 100 kV capacities with a power factor is 0.85. The frequency of the generator is 50Hz. The voltage of the generator is constant at 400 volts, and the speed at 50Hz is 1500rpm.

1.1.6 Power potential

The hydro project is based on the rated head and design discharge value. The power potential can be calculated by following the given formula:

$$P = Q*H*g*n$$

1.1.7 Butterfly/sluice inlet valve

The water is stopping penstock through the butterfly valve when it is required for repair or otherwise. The Inlet valve is used to isolate the penstock to the unit.

1.2 Background

In 1880s, the first Hydropower plant was built in France.(Pang, Zhang, Wang, & Liu, 2015). In France, the production of electricity by small hydro plants is Europe's leading producer. In 2010, there was a generation capacity of 6820 GWh. (Larinier, 2008; Pang et al., 2015). Hydro power is biggest renewable energy source in the world. From the mega project to pico watt, hydropower plants are available. The small or micro hydropower plants MHPs is reliable and environmental friendly technology. Which is a quick solution to rural electrification in the Developing Countries. (Azimov & Avezova, 2022).

There is no internationally agreed definition for small, mini and micro hydro projects. The definitions differ from one State to another. In India, these small hydro power plants have been classified as ranging from 2.5 to 25 MW. (Hossain et al., 2018). The European Commission, on the other hand, classified small hydro installations as those below 10 MW. According to the 2006 Pakistan Renewable Energy Policy, projects less than 50 MW are considered smaller hydro power plants. According to the World Bank, 100kW-1MW is considered a mini-hydro project (Sharif et al., 2018).According to the World Bank, 100kW-1MW is considered a mini-hydro project (Sharif et al., 2018).

MHP is a renewable technology for generating electricity from water. Renewable energy (RE) or alternative sources of energy are considered all energy sources that can be renewed, produce energy again and again, and are inexhaustible. Renewable energy source includes solar, wind, bioenergy, geothermal, hydro, and ocean energy, and can be used for energy production, transportation, home use, and district heating (Rahman et al., 2022).

Renewable energy RE was included in the sustainable goal signed by 179 countries in 2017. A target of 100% Renewable Energy has been proposed for 57 countries (Tkáč, 2018). In 2020, the European Union is committed to 20 % of its energy consumption coming from renewable sources (Zahraoui, et al., 2021). The German government plans to develop a plan for renewable energy by 2035. In the period up to 2035, government energy transition will amount to 60% (Ren et al., 2021). According to The United Kingdom UK 13th five years plan, UK is switching from fossil fuels to renewables, with 40% of the UK's current energy production coming from renewable sources.

Developing countries like China, India, Bangladesh, Japan, Malaysia, and Indonesia are big economies in Asia. The technological revolution increased dependency on electricity for growth. It has been estimated that 50% of world electricity is needed by Asian developing countries (I. Khan, 2019)

China's RE utilization should reach approximately 730 million tons of equivalent standard coal by 2020, and RE electricity should make up 27% of the total electricity generation. China is producing 88% of its electricity from fossil fuels but China is the world's largest economy which is filling its energy demand gap with renewable energy. In parallel, India is also a diverse economy that they are bringing its renewable energy sources into an energy form. In Asia, resources are pressurized by huge population densities (Ren et al., 2021).

In South Asian countries, the population is increasing but resources are shrinking. Instead of the availability of abundant resources in South Asia, transparency and financial crisis is considered a barrier (Ul-Haq et al., 2020).

In Nepal, the MHPs have a significant impact on the economic condition of remote areas. Access to electricity from MHPs enables the people of remote areas to establish small businesses such as weaving, woodworking, and metalworking in Nepal. This has created employment opportunities and generated income for local communities. Access to electricity from MHPs increased the use of food processing appliances and promoted food safety. Micro electricity is used in Nepal for small-scale irrigation. MHPs are helping in tourism activities such as guesthouses and eco-lodges, creating employment opportunities, and generating income for local communities. Hence, MHPs can improve economic conditions in remote areas by creating new opportunities for income generation, improving the productivity of existing economic activities, and providing access to electricity for businesses and households.

Pakistan is considered a developing country. Pakistan is facing the worst energy crisis and economic stability. The energy depicts in Pakistan is the key barrier to socioeconomic development. Pakistan is producing 66% energy from fossil fuels. Pakistan is fulfilling the need for energy from thermal. The cost of electricity is too high due to thermal operated power plants (Arshad et al., 2019).

The required energy is based on fossil fuel (37.5% oil, and 30.17% gas). These fossils are imported from Saudi Arabia, Indonesia, and China. The current gap energy has an augmentation of 68% per annum. Most of the urban and rural population is faced with electricity offloading for 10-12 hours. More than 140 million people remain without access to electricity. It is anticipated that energy demand in Pakistan will be three times higher by 2050. The electricity demand in Pakistan will increase to 49, 078 MW in 2050 (Kamran, 2018).

Pakistan produces only 6% hydroelectricity. However, Pakistan has the potential to generate 60,000 MW of hydropower (Brown et al., 2019). Geographically, the mountainous areas of Pakistan are rich in water. Khyber Pakhtunkhwa, Gilgit Baltistan, and Azad Jammu Kashmir are focused areas for hydropower. Hydroelectricity can generate from large-scale (MW) to micro-scale (kW). People in hilly areas are still not connected to the national grid for electricity. The main objective is to access people to electricity as a basic right. However, the installation of mega projects is not feasible in remote areas due to financial assistance and population density (Elgarahy et al., 2022)

Hydroelectricity is considered renewable energy which is an environmentally friendly and reliable source of energy. However, large Hydropower needs a huge dam for the storage of water. Whereas it harms the environment and society. The large dams need infrastructure for construction and cover millions of hectares affecting biodiversity and stressed to people for migration. However, Micro hydropower plants are small in size and do not require the construction of large dams or reservoirs, which can have a significant impact on the environment (Durrani, et al., 2019).

Micro hydro power plants are a renewable energy source that does not deplete natural resources, unlike fossil fuels. Fossil fuel-based power plants emit greenhouse gases such as carbon and methane which contribute to climate change but MHPs do not cause greenhouse gases. MHPs have low operation and maintenance costs which make them a cost-effective source of renewable energy (Sharif et al., 2018).

Micro hydropower plants are socially acceptable and beneficial to the communities. It can provide reliable access to electricity which can improve the quality of life for communities in remote areas. This can have significant social benefits, such as improved access to information, combination, and entertainment (Hussain et al., 2019).

This technology promotes social cohesion within the community and can help to ensure that the technology is culturally appropriate and acceptable. Access to electricity provided by micro hydropower plants can also have significant health and education benefits for local communities. For example, electricity can be used to power medical equipment, provide lighting for schools, and improve access to clean water. It can also promote gender equality. It is providing opportunities for women to participate in the planning, implementation, and management. It can reduce the burden of work on women and children. Hence, technology has a great influence in society to promote quality of life by using the latest technology, education, and health facilities.

1.3 Global scenario of renewable energy

Energy is a basic need for supporting industrial, transportation, and agricultural activities. These are key sectors to shape the world economy (Shafie et al., 2012). According to research, every country is adopting renewable technologies as their available resources. Europe and especially Germany's transformation towards wind and Photovoltaic (Jung et al., 2009). As a developing country, China has replaced the United States as the biggest energy user globally China is consuming about 20.3 % of world energy (Wang et al., 2018). The primary source of China is fossil fuel where coal is dominating in China at 77%, Indonesia at 70%

and oil in Japan at 28%, and natural gas in Malaysia at 61%. China is producing the highest renewable energy for primary production (Sharvini et al., 2018). While the energy policies of Malaysia focus on environmental conversation and sustainable development. High-quality services are the primary aim of all stakeholders (Selvaraj et al., 2018). Iran has identified over 3000 spots to install micro hydropower plants. Iran has a 50000MW potential of hydro energy in which 7670 MW is operational and about 6600 MW is under construction (Mohammadi et al., 2011).

Central Asia has established targets for renewable energy generation. Central Asia has the potential for small and micro-scale hydro energy. Asian Development Bank (ADB) is providing funding to increase relay on sustainable energy to Central Asian countries. Central Asian countries are taking advantage of hydro energy without disturbing the political balance (Azimov & Avezova, 2022). In 2011, the contribution of nuclear (12%), solar (2%), geothermal (2%), hydropower (16%), and fossil fuel (68%) while in 2021, the contribution of nuclear (10%), solar (10%), geothermal (3%) hydropower (15%) and fossil fuel 62% (REN21 International report- 2022).Figure 1.1. is showing Production of renewable energy of big economies.

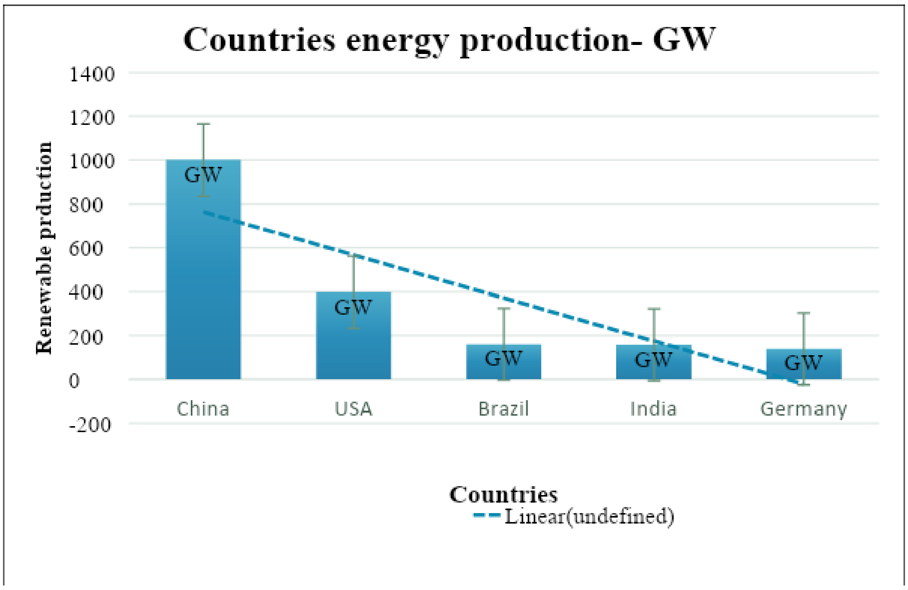


Figure 1.5 Production of renewable energy of big economies.

1.4 Hydro power electricity in Pakistan

The renewable energy contribution is only 1% in 2010. The government planned to increase the contribution of renewable energy by up to 5% in 2030. The economy of Pakistan is impacted due to a lack of sufficient and cheap energy. Rapid urbanization and technological advancement pressurized the recent production of electricity which is the cause of a huge deficit in demand and supply. The attention to production of renewable energy like hydro in Pakistan is expected to meet effective energy to commercial and industrial sectors(A. A. Khan, Khan, Zahid, & Rizwan, 2013).

The suitable sites for hydropower potential areas are Khyber Pakhtunkhwa, Punjab, Gilgit Baltistan, and Azad Jammu Kashmir. These regions are capable of generating up to 6000MW (PPIB and Board 2011). Numerous stations have been identified for the installation of mega-scale power programs (Li et al., 2021). In the northern areas of Pakistan, proudly 1200 MW has hydropower capacity. The first small turbine was built by Sir Ganga Ram in 1925 in Punjab, with a potential of 1.1 MW (Uddin et al., 2019).

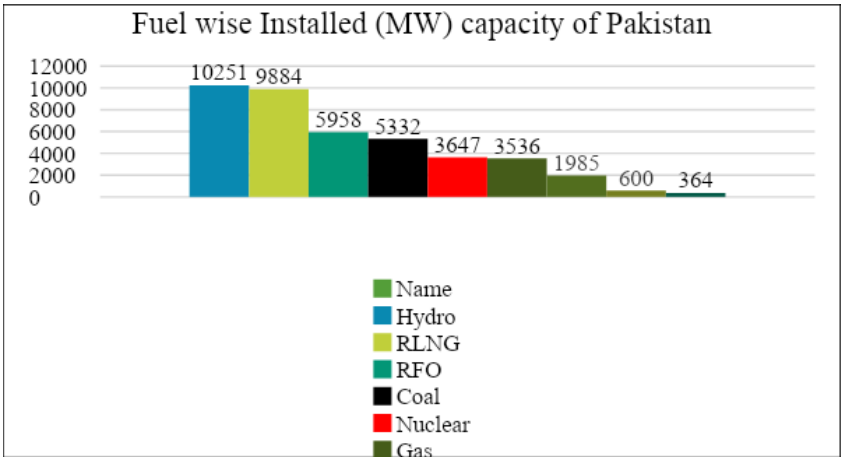


Figure 1.6 Electricity generating from different source in Pakistan.

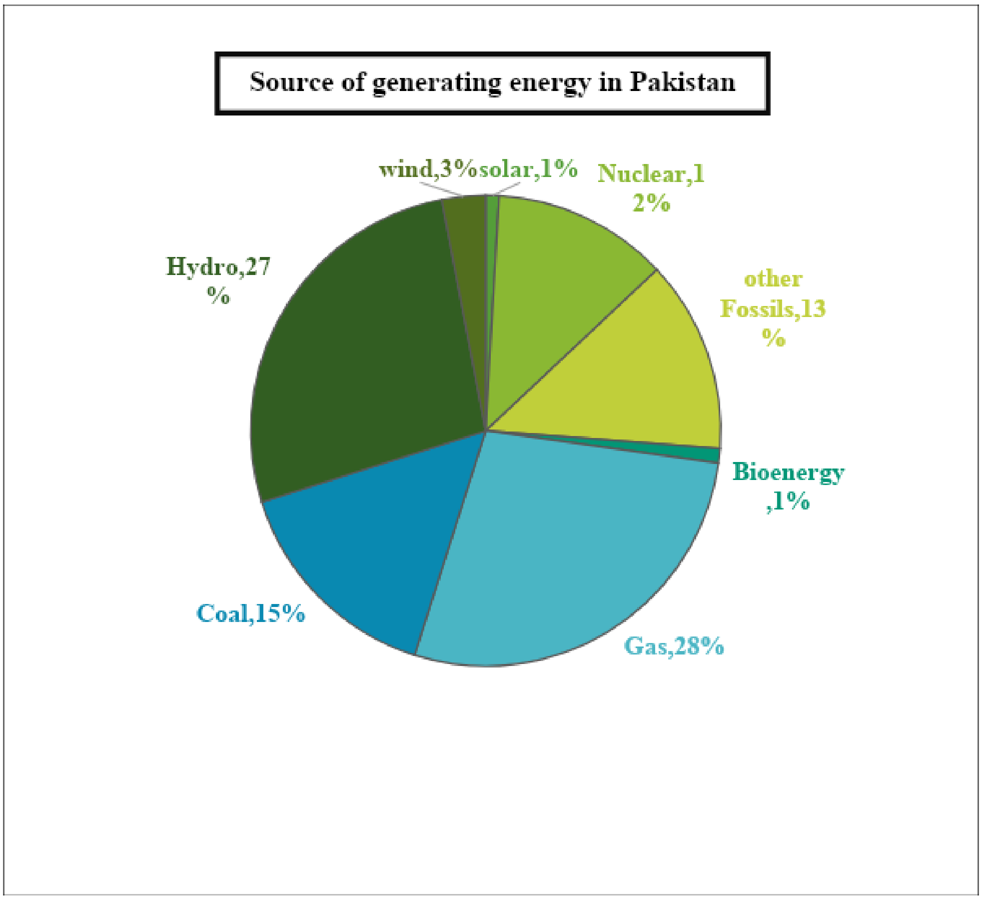


Figure 1.7 The contribution of hydro and different sources for generating electricity in Pakistan.

1.5 Literature review

The United Nations' Sustainable Development (UNDP) Goals for 2030 have energy targets, but there are still 840 million people living without access to electricity. (UNDP, 2022). It is predicted that end-use sectors will consume over 87,000 terawatt hours (TWh) more electricity by 2050, compared to 2020. The generation of renewable energy for total electricity will be 68% and 91% in 2030 and 2050, respectively. By 2030, the total installed renewable generation capacity will need to double (11174 GW) and triple (33216 GW) from 2020 level. The current decade will see an average addition of around 1000 GW in renewable energy capacity. The installed renewable capacity will increase by three times in 2022 and will reach 1100 GW by 2050. The share of renewable energy in new capacity was 83% in 2022 (IRENA, 2023). Figure 1.4. .is showing Increasing percentage of renewable energy as globally.

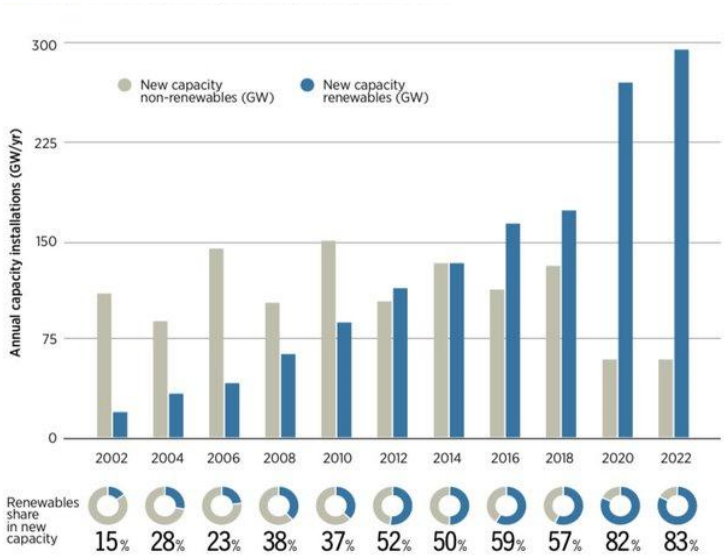


Figure 1.8 Increasing percentage of renewable energy as globally.

In terms of installed capacity, hydropower is still the largest renewable power source. The installed capacity of global hydropower reached 1256 GW in 2022 as shown in Figure 1.5 which is 37% of total renewable capacity. The combined installed capacity of other renewable energy sources will be 171GW in 2022 (IRENA, 2023). By 2030, the global installed hydropower capacity is expected to grow to 1465 GW Figure 1.5 which is almost 21% growth from the level in 2022 level. The global installed capacity of hydropower is expected to double and surpass 2500 GW by 2050 (IRENA, 2023). Hydropower generated 4250 TWh of clean energy, which is equal to one and a half of Europe's total electricity consumption (International hydropower status Report-2022). By The installed capacity of global hydropower will double from 2020 to surpass 2500 GW in 2050 (IRENA, 2023). Figure 1.5 predicts the global hydro energy and Figure 1.6

shows energy installed capacity and ongoing generation. Figure 1.5 is Predicting the global hydro energy up to 2050.

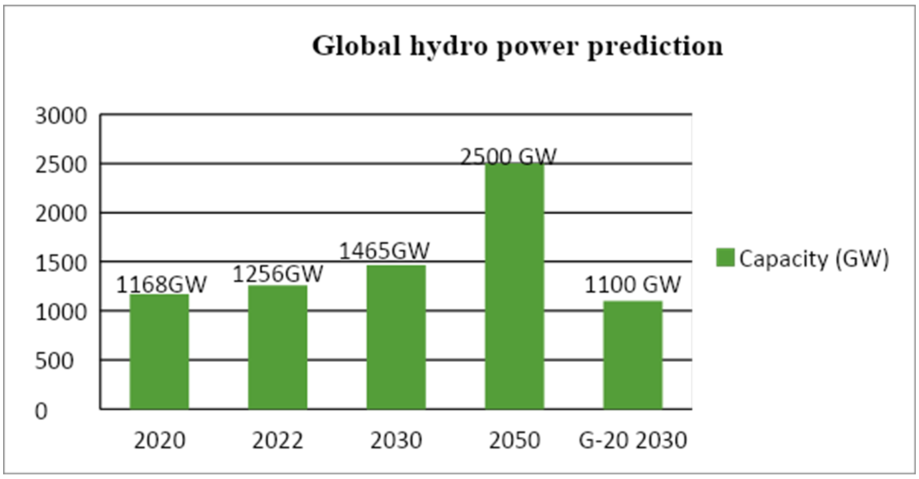


Figure 1.9 Global hydro energy up to 2050.

Table 1.1 Energy installed capacity and ongoing generation of different continents.

Continent	Total Installed Capacity (MW)	Generation (TWh)
Africa	38,469	146
South and Central Asia	162,313	538
East Asia and Pacific	522,891	1639
Europe	254,901	689
South America	176,773	614
North and Central America	205,058	702
Total World	1,360,405	4328

Rural areas, which are characterized by remoteness and sparse population density, lack access to electricity for approximately 87% of people worldwide. The extension of national grids is often technically difficult, costly, and inefficient (Ashish et al., 2023). Rural electrification is a challenge that is still ongoing. The lack of infrastructure, high cost, resources, conflicts and political instability are typical problems (Butchers et al. 2022). Rural electrification is the process of providing electrical power to rural and remote areas without any grid expansion (Ashish et al., 2023). This is national government responsibility to make decision based upon the technical, environmental and socio-economic viability of the range of available technologies (Butchers et al. 2022).

The Himalaya is a huge mountainous range where Nepal is located. The population is dispersed across a wide range of mountains. It is a challenge for the government to ensure that every citizen has access to electricity. The 95% of electricity in Nepal is generated from hydro. But it is difficult to connect every region to the national grid. The mountains and forests are barriers for electricity access. Therefore, MHPs are option for rural electrification (Nepal economic survey 2021/22). Development of MHPs in Nepal Government of Nepal recognizes the hydropower plants ranging from 5kW to 100kW as MHPs. Mostly, MHP is of 'run of river' type plants; which means that the plant uses the flow of the river and there is almost no storage of water. Thus, this does not require construction of dams and other large civil structures. The civil structures, if present, contribute to conduct the water to the penstock and maintain the level of water at intake to the plant. MHPs are considered to be one of the most environmentally benign energy technologies as they do not have any adverse effect on the surroundings, like the large hydropower projects do (Paish, 2002).

In Nepal, Nepal Micro Hydropower Development Authority (NMHDA) is actively involved in the development of MHP manufacturing. Alternative Energy Promote Center (AEPC) is another government agency to provide technical and financial services. There 3300 MHPs have been installed in the country. There are 40 plants currently functioning, and a 12 kW plant constructed by locals on the Rumdi River in Manebhanjyang Rural Municipality-5 ten years ago is still functioning. Trial production has begun for the 13 MW Sikles Hydropower Project in Madi, Kaski district in western Nepal. Baglung and Gulmi districts, which are situated in Gandaki Pradesh and province No. 5, were recognized as areas with a high concentration of MHPs. In these districts, there is enough road access and a high population of MHPs (Bhandaria et al., 2023).

In Nepal, 1400kW of electricity is produced through pico/mini/micro hydro installation (APEC, 2022). A rehabilitation plan for incomplete and sick MHPs and an improved water mill (IWM) resulted in only 5 out of 15 being rehabilitated. The target for repairing, maintaining, and reconstructing Clean Development Mechanisms (CDMs) registered in International Water Management (IWM) and mini/micro hydro projects was achieved by 42%. Out of the 16 targets to connect the MHP, none were met during the reporting period regarding their grid connection. (AEPC Annual Report, 2022).In In Nepal, 94 percent of the population had access to electricity by mid-March 2022. The total installed power capacity has increased by 30.9% as compared to mid-July 2021, reaching 2205 MW by mid-March 2022. As of mid-March 2022, 398 kW of electricity has been generated from micro and small hydropower projects under alternative energy. The production was 955 kW in 2021. Similarly, out of 284 KW of electricity generated from solar and wind energy in 2021 (Nepal Annual Economic Survey, 2022).

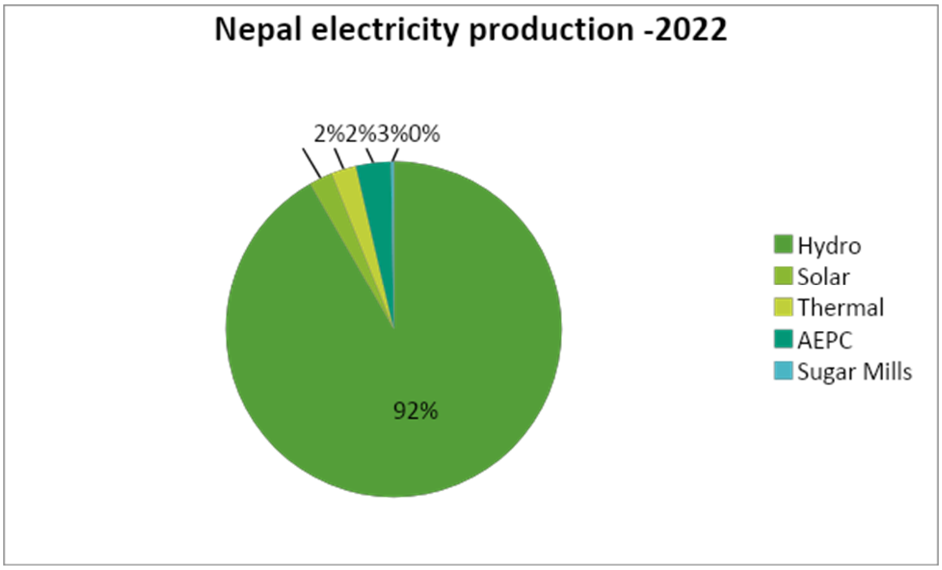


Figure 1.10 Source of electricity in Nepal

Indonesia the first generation of SHP was designed during the Dutch occupation in the 1800s (Widmer et al., 2001). The government of Indonesia took a step towards rural electrification by creating interest in MHP schemes in the mid-1970s. The mid-1970s saw a 10% rural electricity rate and 15% residential rate, making low electrification a significant motivation (Rospriandana et al., 2023). In Indonesia, there were almost 500 MHPs of 15MW built between 1980 and 2010. About 437 MHPs have capacities that are less than 100kW each. Between 2009 and 2017, 357 MHPs with 9.5 MW were constructed, producing energy to meet the needs of 38,000 households. The commercial projects of MHPs of the more than 1 MW capacity (Castlerock , 2012).

The Indonesian government is struggling to achieve a target of 23% share in primary energy by 2050 (Yadoo et al., 2012). The MHP is the fourth largest renewable source contributor in Indonesia with an estimated capacity of 486MW. From 1980 to 2017, a variety of MHPs were constructed by various organizations. The GIZ has a leading role in funding and providing services for MHP in Indonesia. Integrated micro hydropower development and application program integrated micro hydropower development and application program (IMIDAP) (Rospriandna et al., 2023) under the United Nations Development Program (UNDP) provided technical assistance and standardization for feasible capacity across Indonesia in 2000 (IMIDAP, 2020). Hundreds of examples of sustainable MHPs are supported by grant schemes. Five key dimensional sustainability risks can arise from the inability of communities to manage assets either technical, financial, social, environmental, and institutionally (Affah et al., 2016, Urmee et al., 2016).

Here is a case study of two installed MHPs in Indonesia. In 2011, Bakuhu, Sumba island was the location where the 37 kW MHP was installed. The MHP is supplying electricity to 100 households. Each house is being charged ($2) per month. In 2016, the study identified the remote hilly area of BaKuhau connected to the rest of the world through cell phones and television (Kumar et al., 2014). The second case study of 25 kW in 2010 and 40 kW installed in 2013 in Tepal Helmat in Sumbawa Island. The MHPs were installed to improve the community’s welfare under cooperatives. The 25kW MHP generates electricity for 279 households and 20 businesses. The 40 kW was installed after three years to support product activity along with 25 kW (GIZ report 2020, Rospriandana et al., 2023).

Indonesia is an archipelago state that consists of 17504 islands (Novitasari et al, 2023). In a recent scenario, hydro power potential is 75000 MW and only 9% is exploited in Indonesia (Pambidi et al., 2023). The mountainous area receive high rainfall which can be used as electricity, through large and Micro Hydro power plants. But, the hydropower generation in Indonesia is very low. The MHPs are only 1% of the total potential of 19385GW (Novitasari et al, 2023). The ratio of electrification is close to 100% but Indonesian people do not have access to cheap and sufficient electrical energy. The MHPs have the potential to generate enough electricity to cater to agricultural, residential, and plantation needs or even for small communities. Furthermore, MHP application is sufficient for mechanical processes like fabrication, cooling, textile, and drying (Pambidi et al., 2023).

Indonesia has immense hydroelectric potential. Indonesia's geography and socioeconomic challenges limit the possibilities that can be explored. The construction of a large-scale hydroelectric facility is often not possible due to the unsuitability of Indonesia's rivers. Despite the requirement for hydropower plants to supply renewable energy-based loads, hydropower can be enhanced in a variety of ways. One option is to enhance the capacity of the hydropower plant and install MHPs. Rural communities and agricultural areas will benefit greatly from the inclusion of MHP as community-based energy generators (Kusakana et al., 2008).

Pakistan is a rising nation in the energy sector in South Asia (Afzal et al., 2023). The government of Pakistan also pursuing a 60% target of electricity generation through indigenous clean energy technology by 2030 (Economic Survey Pakistan 20230). The average electricity generation from hydro is 6.75% and 85% is exploitable. The Hydropower potential (64000) in Pakistan can be divided into six sectorial regions according to different province locations: Gilgit-Baltistan (GB), Punjab, Azad Jammu-Kashmir (AJ&K), Khyber Pakhtunkhwa (KPK).

In Pakistan, 123 potential hydropower sites have been identified with high, medium, and small heads in Khyber Pakhtunkhwa. The capacity of these selected sites is about 27012.81MW. These sites are Indus, Tochi, Khurram, Ushu, Chitral, Gabral, and Pankkoora. In Punjab, 810 hydropower sites are identified according to Hydropower development studies. The hydropower location is situated on five rivers: The Indus, Jhelum, Ravi, Sutluj and Chenab. The estimated potential is about 7316.13 MV. Azad and Jammu Kashmir have 68 high, medium, and tiny hydropower sites. The combined potential is about 8295.79 MW. These sites are found on Jhelum and Poonch (Hydro Power Pakistan, 2022).

Table 1.2 Provincial potential and installed capacity of electricity of Pakistan.

Province	Potential (MW)	Installed (MW)
Khyber Pakhtunkhawa	27012.81	5789.22
Punjab	7316.13	2524.06
Sindh	208	0
Baluchistan	5.2	0
Gilgit Baltistan	21162.35	169.35
Azad & Jammu Kashmir	8295.79	2370.22
Total	64000.28	10852.85

Table 1.3. Installed capacity and generation of different source in Pakistan.

Source	Installed Capacity		Generation	
	MW	Share (%)	GWh	Share (%)
Hydro	10,592	25.8	26,937	28.6
Thermal	24,095	58.8	43,526	46.2
Nuclear	3,530	8.6	19,739	21
Renewable	2,783	6.8	3,919	4.2

Total	41,000	94,121

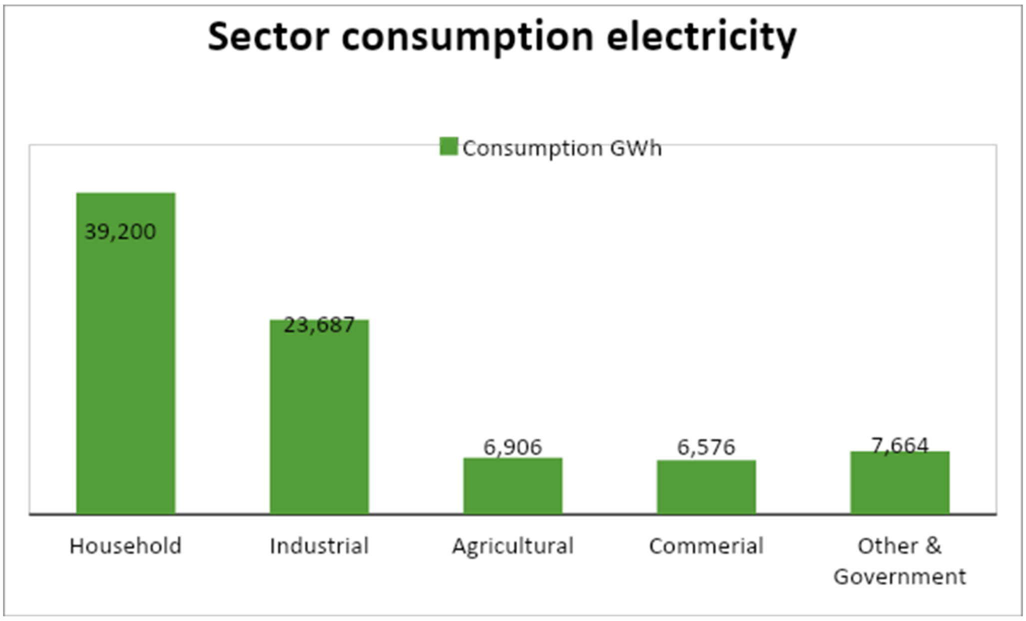


Figure 1.11 The sector wise consumption of electricity in Pakistan

Khyber Pakhtunkhwa has largest potential for hydro power in Pakistan. Pukhtunkhawa Energy Development Organization (PEDO) is a provincial government department to provide technical and financial assistance to small micro hydro power projects. The aim is to provide clean and green electricity to rural areas across the province. The PEDO initiated schemes with the financial assistance of the Asian development Bank ADB to improve the livelihood of the people. These are creating opportunities and discouraging deforestation. A total of 316 mini/micro hydro power plants with a total capacity of 28.5 MW were initiated under phase-I. The phase-I scheme aims to generate 140 GWh of electricity annually. Another Phase-II initiated 301 mini/micro hydropower plants of 50 MW. The annual generation capacity is 240 GWh (PEDO annual report 2022-2023)

Table 1.4 Installed projects with its capacity in different districts of Khyber Pakhtunkhawa.

Lot No.	Districts	No. of Projects	Capacity(KW)
1	Abbottabad Mansehera	38	3599
2	Torghar and Battagram	28	2647
3	Upper Kohistan (I & II)	21	8888
4	Lower Kohistan	20	3526
5	Chitral Lower	28	5775
6	Chitral Upper	28	5627
7	Swat	40	4658
8	Dir (U & L)	37	671o
9	Buner	3	649
10	Shangla	15	1114
	Total streams micro projects	258	43193

The hydropower is dependent on geography and climate conditions. The climate of Pakistan is varied in different regions. In July and August, the highest stream flow occurs in Punjab. Only in January did Punjab's rivers begin to decline because the stream flow decreased (Kamaran et al., 2019). The construction of Hydropower projects is installed carefully. These projects need strong assessment to illustrate all the strengths, weaknesses, opportunities, and threats (SWOT analysis) associated with the hydropower sector (Sibtain et al., 2021). Compared with the large-scale hydropower projects (electricity produced through Dams using conventional turbines), the Small/ Micro/Pico hydropower projects have also shown enormous potential for the progress of energy sectors in developing countries such as Pakistan (Bhutto et al., 2012)

Hence, MHP is a promising technology to generate sustainable energy for rural electrification. It has the potential to supply clean and reliable energy to promote local development. The MHPs are participating in improving the quality of village people. However, the participation of local communities is required for successful implementation. Effective management and governance strengthen these projects. The MHP is sustainable energy which is more suitable for rural areas where the electric grid is difficult to establish. The MHP systems suggested improving socio- economic and environmental sustainability with the cooperation of local communities.

p

Table 1.5 Summary of literature review

Sr	Study	Region	Period	Summary
1	PEDO annual report- 2022-2023	Pakistan	1992-2023	The PEDO conduct study to publish annual report on performance of department. The study evaluate the hydro power potential in Khyber Pukhtunkhawa. The study focus on small and micro hydro power plants project and provided enough data on complete, ongoing and future proposed project in province.
2	Ashish et al., 2023	Nepal	2015-2023	The study conducted in Kaernali province in Nepal. . This study summarizes the current electricity access status in Nepal and Karnali

				province specifically. The study investigate the feasibility of 200-kW solar plant and 100-KW of wind power plant. The study estimates an investment cost ranging from 7 to 9 million USD would be necessary for the installation of such distributed solar PV and wind turbines.
3	Bhandari, S. R. (2023)	Indonesi a	2021-2023	The study examines the technical and economic feasibility of micro hydropower in Gairibari Jharna, Kalika Municipality-08, Chitwan, Nepal. Through the qualitative and quantitative research, average p ower demand for each household was found to be 513.29 W leading to an average energy demand of 1.9 kWhr per day. Through the detail analysis of cost, budget for this project was Nepalese NRs 36,84,730 ($ 28,102.7) . After economic analysis of cost the payback period is calculated to be 15.37 years.
4	M. Sibtain, et al., 2021	Pakistan	2019-2020	This is review study to examine the potential benefits and projects of hydro power in Pakistan. The study used SWOT analysis technique. The strengths include high potential of resource and technology established,

				The capital investment, time taking completion projects and resources degradation, as considered as weakness. The SWOT analysis showed that despite having server issues, the hydro technology is still priority for energy
5	Khan et al., 2020	Pakistan	2016-2020	The study thorough analysis of Pakistan’s renewable energy potential and current practices, in trying to meet its energy demands. The study adopts qualitative means to investigate global trends and current practices in renewable energy. The study concludes by suggesting that there is an urgent need to follow the global trend in replacing conventional energy methods with the country's extensive RE resources in order to ensure sustainable economic security and growth
6	Kamran, et al., 2019	Pakistan	2016-2019	The study conducted on proposed micro hydropower system and design on run-of- canal on river Sutlej. The study examined the technical and economic feasibility of the proposed micro hydro power plants. The study analyzed the Net present Cost and Levelized Cost of Energy. The system is expected to recover all the

				costs in the 5th year of the lifetime of the project.
7	Butchers et al., 2022	Nepal	2020-2021	The study examine the cost analysis for selecting the right technology for rural communities, in Nepal. This paper attempts to address the current lack of publicly available costing information for locally manufactured micro-hydropower equipment. A methodology is presented where quotations are provided by micro-hydropower manufacturing companies in Nepal for randomly generated sites. The study estimate proposed costs of micro hydro power equipment.
8	AEPC report 2022-2023	Nepal	1978-2023	The study conducted by Ministry of energy, Nepal. The study covered all type of renewable energy source in Nepal, according to report, 92% energy comes from hydro power where all type of pico/mini/micro hydro power plants are contributing,
9	Bhuto at el., 2012	Pakistan	2010-2012	This paper investigates the progress and challenges for hydro power generation in Pakistan according to the overall concept

				of sustainable development and identifies the region wise potential of hydro power in Pakistan, its current status. Barriers are examined and Policy issue and institutional roles and responsibilities are discussed.
9	Rasheed et al., 2020	Pakistan	2016-2019	The comparative study of renewable energy potential in south Asia. The paper suggested to transfer the fuel based economy. The south Asia countries has big potential of renewable energy. It has been analyzed that Pakistan is naturally blessed with annual hydropower potential of 0.06 TW, highest after India i.e. 0.15 TW and Nepal i.e. 0.083 TW in South Asia. Pakistan has the highest average solar insolation potential of 2.5 $kWh/m^2/day$ in the South Asia and can generate about 2.9 TW solar energy annually. The comparative study of south Asian country will provide a factual roadmap to the decision makers
10	Hydropower development report by PPIB	Pakistan	1993-2022	The PPIB conduct feasibility studies and surveys to identify opportunities for power generation and other applications through conventional and alternative and renewable energy resources .The study Create

				awareness and motivation of the need to set up alternative and renewable energy projects for benefit of general public as well as evaluating concepts and technologies from technical and financial perspective make legislative proposals to enforce use and installation of equipment utilizing alternative and renewable energy.
11	Rospriandana etal.,2023	Indonesia	1961-2023	The study is review over a century of small hydro power plants. The method adopted for study is literature review, field interviews and survey. The study showed the various steps of modification and dimensions of MHPs in Indonesia.
12	Azimov U., et al., 2022	Uzbekistan	2017-2022	This is review study focuses on the broad and efficient of hydro power potential in Central Asia, use of these existing resources, which are still underutilized. This review covers the objectives to identify extensive and efficient use of existing resources in Central Asian region to develop small-and micro-scale hydropower solutions, which are currently either inefficiently used due to aging network and equipment or still unexploited. The value of this review

	is that it provides overall outlook on the small-scale hydropower development in Central Asian region.

1.6 Problem statement

- This study examines the benefits of micro hydropower for rural communities, focusing on its impact on socio-economic conditions and environmental aspects. The research provides insight into the viability and effectiveness of micro hydropower plants to address rural electricity challenges by means of a comprehensive analysis.

1.7 Justification of the study

- Provincial government involved stakeholders to improve economic conditions, social up-left and provide environmentally friendly electricity to remote areas where it is impossible to install a large grid stations.
- There is a geographical similarity in the northern area. By examining the sustainability performance of two installed projects within this research study. The sustainability of the proposed projects could be assessed easily.
- Hydro power is an important sector in Pakistan, but there is a lack of research in the sector, particularly small hydro power projects in remote areas.

1.8 Objectives of research

- Determine environmental and social benefits of installed micro hydropower plants in Khanian and Rajwal Villages in Kagan, Balakot, Mansehra.
- Evaluation of economic improvement by the installation of micro hydropower plants on residents of selected study area.

CHAPTER 2

METHODOLOGY

2.1 Introduction

This methodology provided a path to study the sustainability of micro hydropower plants. The research study determined the environmental, and social benefits of installed micro hydropower plants in the study area. The research also tries to evaluate the economic uplift of both villages due to installed micro hydropower plants. There are 28 indicators have been identified for research from three parameters of sustainability. The research study followed the Ilskog Method to establish a framework for the study of indicators. The interviews and surveys were conducted to collect data for both objectives of the research.

Environmental parameters determined that MHP is environmentally friendly and zero waste technology. Also, micro hydropower replaced fossil fuel consumption with renewable energy. The social parameters include safety concerns in the village due to the lack of electricity. The MHP enhances social interaction in village due to modern facilities. Economic parameters determined project benefits for the village to boost the economic conditions of the study area.

2.2 Study area

2.2.1 Description of study areas

The study area consists of two villages namely Khanian and Rajwal, union council Kaghan, tehsil Balakot. The MHPs are installed by PEDO in these two villages in 2018 and 2019 respectively.

2.2.2 Study area Khanian

Khanian is a village on the bank of the Kunar River, located in the Tehsil Balakot district Mansehra. The MHP was installed by Pakhtunkhawa Energy Development Organization (PEDO) in 2018. The stream water from the mountain is diverted through the Masonry canal to the fore-bay of MHP. There are 50 houses befitting micro hydropower plants. The MHP is providing electricity to houses, hotels, and business spots supported by Poles.

2.2.3 Study area Rajwal

Rajwal village is 30 minutes away from Khanian village.it is also located on the bank of the Kunar River. The micro hydro power plant was installed by PEDO in 2019. The stream water from the mountain is diverted through the Masonry canal to the fore-bay of MHP. There are 100 houses befitting micro hydro power plants. The MHP is providing electricity to houses, hotels, and business spots supported by Poles.

2.2.4 Study area map

The longitude 73.7478° E and latitude 34.8984° N of tehsil Balakot.

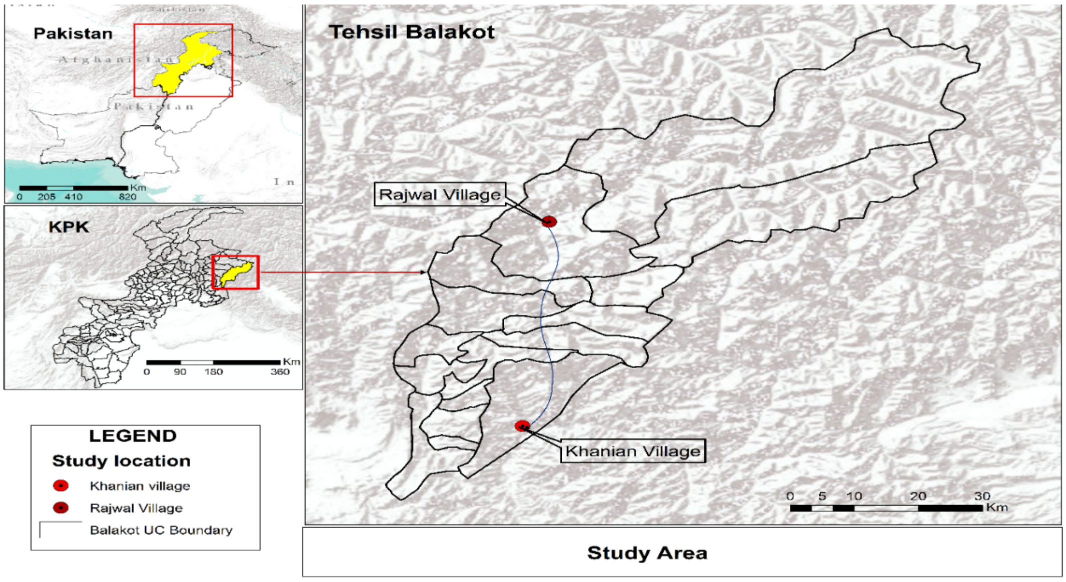


Figure 2.1 Map of study area.

2.2.5 Hierarchy of study area.

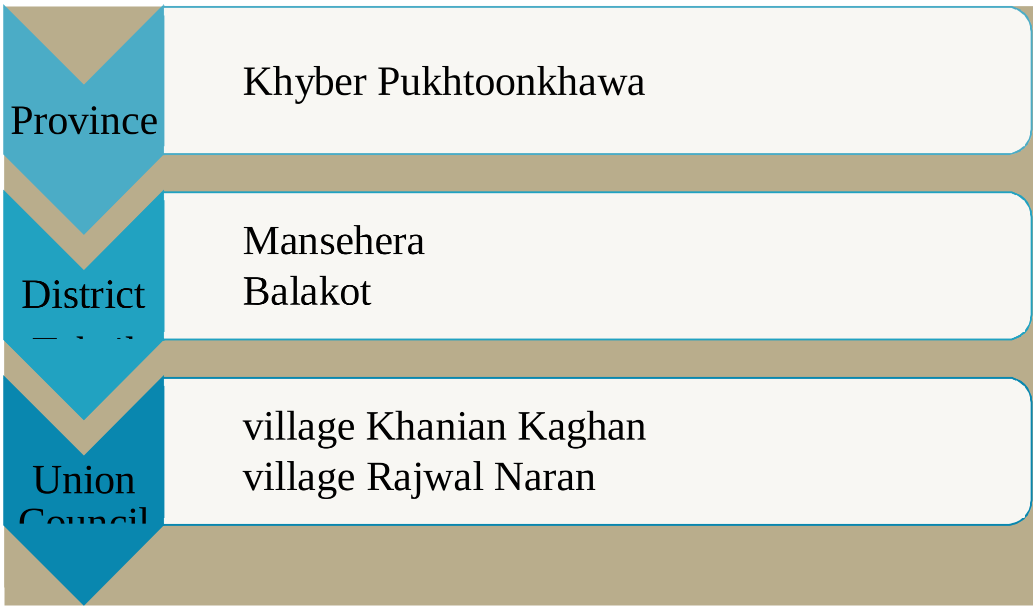


Figure 2.2 Hierarchy of study area.

2.3 Methodology flow chart

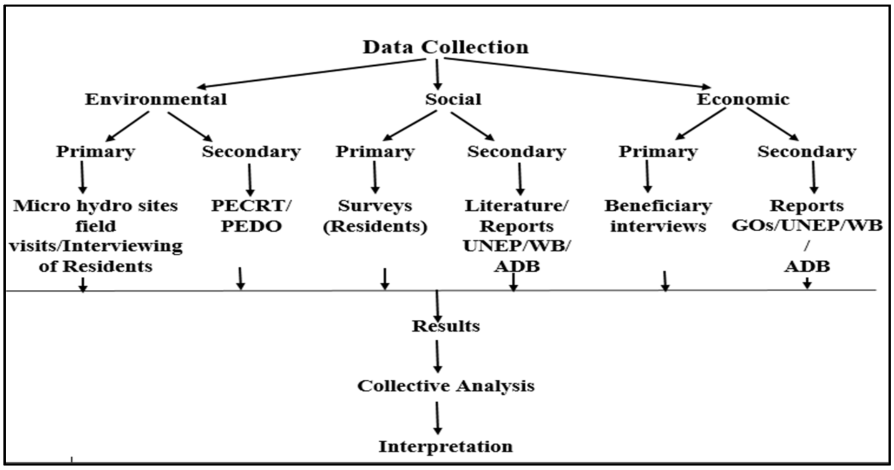


Figure 2.3 Research methodology for study.

2.4 Data collection

The data collected through field observations, interviews and questionnaires from residents of village and related stakeholders. The primary data was extracted through field observations and interviews to concern persons. The survey consist of structured and semi structured questionnaires. The secondary data on the hydropower energy trends, status, and its impact in the global scenario and international report on hydro energy.

2.4.1 Primary data

Primary data was collected through the field visits of the installed micro hydro power plants, personnel interviews with beneficiaries, experts and photography. The field surveys was baseline information source about installed plants. A sum of 40 interviews was held from selected households of the study areas and a sample size of 20 over each village was selected for the study area.

The questionnaire consisted of two parts. Both parts consist of baseline information about the beneficiaries of MHPs. The first part was conducted for the environmental source of information while the second part gathered data about socio- socio-economic impact of MHP on villagers. The questionnaire was explicit about the environmental and social benefits of installing a micro hydro power plant. Also, helps to identify the economic uplift of the study area.

2.5 Qualitative analysis of indicators

2.5.1 Code and score of indicators

During the interviews and surveys in the field, various questions have been asked. The interviews and survey questions are related to MHP performance and its impacts on the environment and society.

According to the following table of evaluation criteria, strongly agree shows that people in the study area are more satisfied with an indicator while Disagree is marked as 1. The code is given name and number to an indicator for analysis in a research study for example Environmental indicator (ENV1, 2, 3...), Economic indicator (ECO1, 2, 3...), and Social indicator (SCO1, 2, 3...).

Table 2.1 Options for evaluation criteria of indicators.

Sr. No	Options	Evaluation criteria	Target
A	**Strongly Agree**	**4**	●●●●
B	**Agree**	**3**	●●●○
C	**Partial Agree**	**2**	●●○○
D	**Disagree**	**1**	●○○○

2.5.2 Evaluation of sustainable development indicator percentage

The equations to determine the indicator values and their target levels which have been taken by literature review, specifically followed the sustainable indicator framework by Ilskog Method. The SDI score of each indicator was 100% if the indicator reached the target indicator's value.

Where:

SDI: score of the sustainable development indicator, Vi: the value of the indicator,

Vt: the value of the target level.

$$Sustainable\ developement\ indicator = \frac{value\ of\ the\ indicator\ score}{value\ of\ the\ target\ level}\ X\ 100\% \quad \ldots\ldots 2.1$$

$$SDI = \frac{Vi}{Vt}\ X\ 100\%$$

SDI will calculate social, economic and environmental sustainable development indicator percentage.

2.5.3. Dimensional average percentage of parameters

The research study calculated the average dimensional percentage for every selected parameter. The average is the sum of all percentages of parameters by a total number of parameters. The average percentage of parameters was calculated to compare the performance of all selected parameters

$$Dimension\ average\ percentage = \frac{sum\ of\ all\ percentage\ of\ perameters}{total\ Number\ of\ perameters}\ X\ 100\% \quad \ldots\ldots 2.2$$

2.6 Quantitative analysis of indicators

2.6.1 Estimate calculation of fuel consumption

The research study sought to determine the fuel types and consumption before and after MHPs. The research study determined the daily fuel usage and its expenses. Based on daily consumption, the monthly and annual fuel consumption and cost have been estimated. The following calculation formula has been used for the annual estimate.

$$Monthly\ fuel\ consumption = daily\ consumption \times 30\ days \quad \ldots\ldots 2.3$$

$$Annual\ fuel\ consumption = daily\ consumption \times 365\ days \quad \ldots\ldots 2.4$$

After the installation of micro hydropower plants, some fuels have been eliminated. The MHPs converted these fuel costs into saving for example by MHPs electricity replaced batteries for lighting.

2.6.2 Estimate calculation of saved trees

The research study identified the wood consumption by villagers as fuel. The wood consumption is the cause of deforestation. It has been estimated during the study that how much numbers of trees were saved due to installed MHPs**.**

$$Number\ of\ saved\ trees = \frac{sum\ of\ all\ household\ wood\ consumption}{estimated\ weight\ of\ young\ (6-7\ years)\ tree} \quad ....2.5$$

Table 2.2 Sustainability analysis parameters

Environmental				
Parameter	**Alternative Energy Source**	**Pollution**	**Water Availability**	**Technology**
Indicator	• Lightening • Ironing • Cooking	• Noise • Emissions	• Water Availability Annual	• Renewable Technology • Zero Waste
Social				

Parameter	Safety	Social Activities	Accessibility	Electric Appliances Usage	Work Burden
Indicator	• Wild Animal Threats • Theft Threats	• Family Gathering • Business services	• Electricity Percentage	• Men Business • Women Business • House Works	• Children • Women
Economic					
Parameter	**Investment**	**Affordability**	**Business Hours**	**Project Benefits**	
Indicator	• Loan • PEDO	• Electricity Bill • Cheap Electricity	• Increased Time • Electrical Assistance	• Savings Increased • Income increased • Employment	

Chapter 3

Results and Discussion

3.1 Environmental parameters

In table 3.1 the environmental assessment was obtained to visit the village of Khanian and Rajwal for field study. The observations and survey covered four main selected environmental parameters. These are environmental parameters - alternative energy source, pollution, water availability, and sustainable technology. Each parameter assessment is based on indicators. There are eight environmental indicators that have been studied during this study. The assessment tries to explore whether MHP electricity supports the selected indicator to solve the villager problems or not.

By using Equation 2.1 Sustainable Development Indicator (SDI) percentage has of environmental indicators have been calculated. The initial value Vi is score of evaluation criteria of survey and interviews in the field as mention in table 2.1 and Vt is target value of environmental indicator. The code is identify the indicator. The evaluation criteria selected by people during Survey as mention in Annexure C. The SDI average percentage is average percentage of all SDI percentage of environmental indicators by using Eq. 2 for calculation.

Table 3.1 Sustainability assessment of environmental parameter.

Parameter	SDI Average %	Code	Indicators	Score	Evaluation Criteria	SDI %
Alternative Energy Source	66.6%	ENV 1	▪ Lightening	4	Strongly Agree	100%
		ENV 2	▪ Ironing	3	Agree	75%
		ENV 3	▪ Cooking	1	Disagree	25%
Pollution	75%	ENV 4	▪ Noise	2	Partial Agree	50%
		ENV 5	▪ No Emissions	4	Agree	100%
Water Availability	100%	ENV 6	▪ Annually	4	Strongly Agree	100%
Sustainable Technology	88%	ENV 7	▪ Renewable Technology	3	Agree	75%
		ENV 8	▪ Zero Waste	4	Strongly Agree	100%
Total Average	78%			3		75%

3.1.1 Dimensional evaluation average percentage of parameters

In figure 3.1, the graph is evaluate the satisfaction of parameters during the study. The MHP as AES gain a 66.6% evaluation percentage. The percentage showed that MHP cannot generate enough electricity to replace cooking and other house requirements except lighting. The noise pollution generated by MHP is considered 50% during operation and 100% water available throughout can be considered as good natural resource management and better consumption of natural resources instead of wasting. The MHP is 88% sustainable technology but due to minor pollution generation (noise and technology impaction on water) and a 30 % difference between input and output reduces the evaluation percentage.

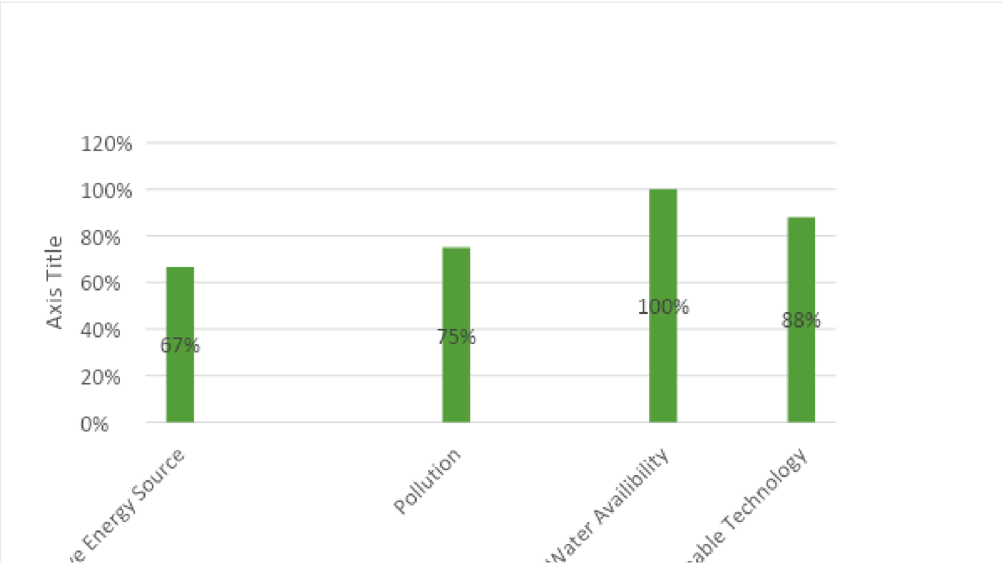


Figure 3.1 Dimensional evaluation average percentage of parameters of environment.

3.1.2 Code and score of indicators

In Figure 3.2, the bar graph shows the indicators of parameters. Each indicator has been named with a code and score of 4.00. The research study put

Lightening (ENV1), ironing (ENV2), and cooking (ENV3) in the domain of Parameter i.e., alternative Energy source. The research asked questions in the Field visit and survey that MHP has replaced the former conventional energy source with clean electricity. Noise (ENV4) and no emissions (ENV6) are indicators of pollution. Indicator ENV6 represents water availability. The indicator (ENV7) and ENV8 represent renewable and zero waste characteristics of MHP respectively.

The graph is showing scores of indicators. The score is marked under the survey evaluation criteria. Lightening (ENV1) scored 4.00 because the study found that MHP electricity solved 100% problem of village lighting in houses, hotels, and mosques. Along with that, reducing the fossil fuel (wood, kerosene, and LPG) impact on the environment. Cooking was not supported by MHP electricity and people disagreed. Therefore, the cooking score was 1. During the survey, it has been observed that noise (ENV4) scored 2. Because people of village are partially agree that MHP noise has an impact on the environment. Water availability and zero waste technology scored 4.00. The reason is water is available throughout year and MHP is clean technology.

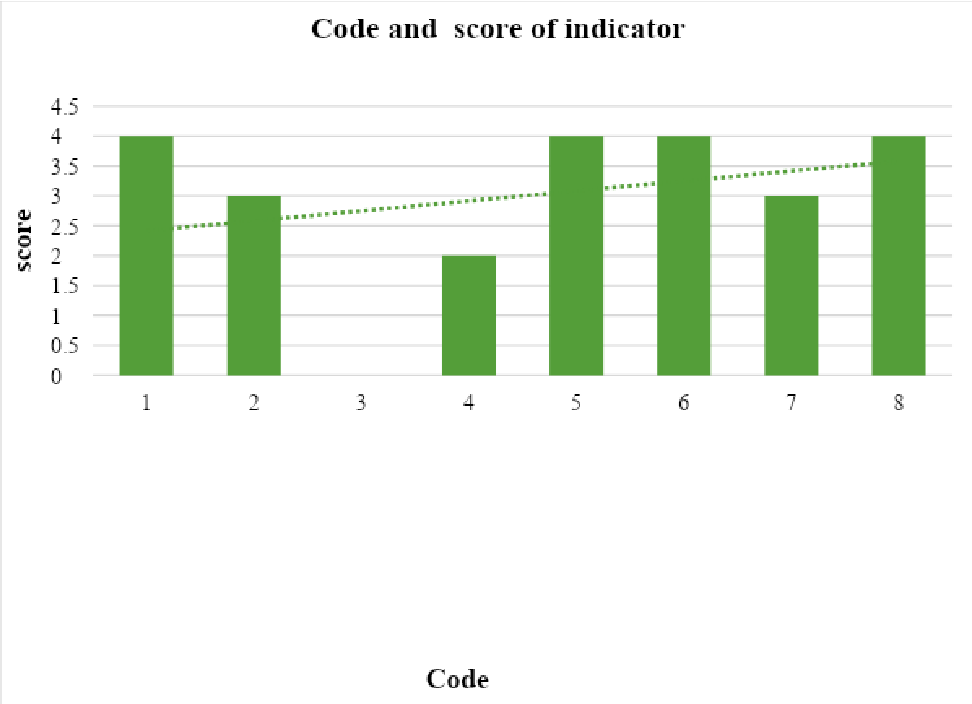


Figure 3.2 Code and score of indicators of environment.

3.1.3 Indicator evaluation percentage

In Figure 3.4, the indicator percentage has to be evaluated based on score and criteria. The indicator score of 4.00 got a 100% evaluation percentage as well and the 0-scored indicator is not supported by MHP. Each bar shows a different percentage according to score and evaluation criteria.

The indicators percentage shows how much the MHP electricity is sustainable for the community. In the graph, the indicator has 100% solved an identified problem of Khanian and Rajwal village or shows characteristics of MHP which is reliable and environmentally friendly technology.

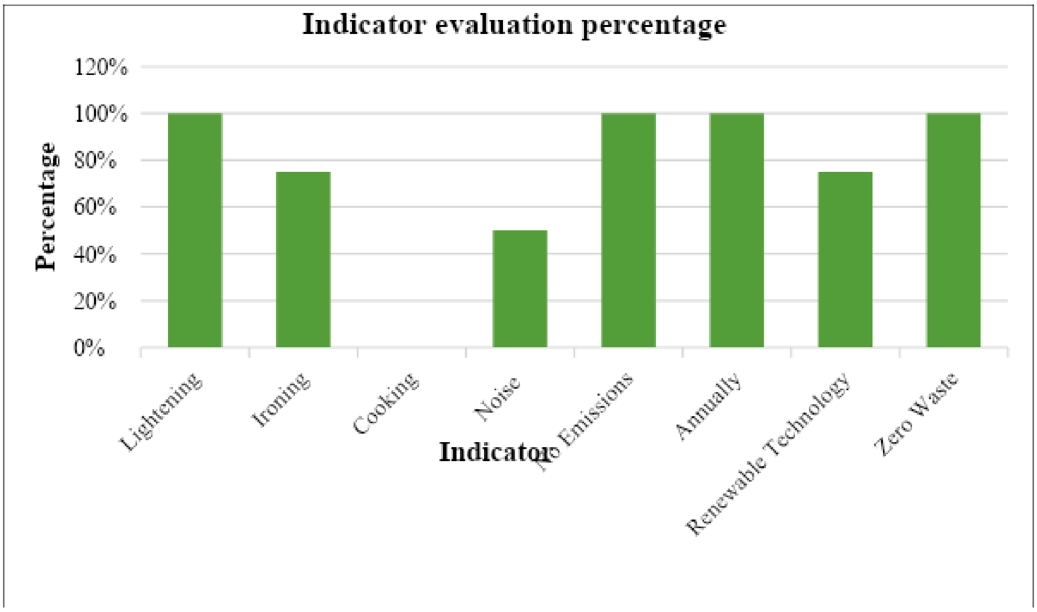


Figure 3.3 Evaluation percentage of indicators of environment.

3.1.4 Quantitative analysis of environmental indicators

According to field study, the inhabitants of both villages were using LGP and kerosene oil lighting (ENV1). Wood is still used for cooking (ENV3). The MHPs could not replace the wood as energy fuel for cooking but, the MHPs had made minor sustainable impact to saved cutting trees which were using to ironing and lighting purpose in house and hotels. People of both villages were using 162000 kg wood, 27000kg kerosene oil and 1296 kg annually. Therefore, lighting (ENV1) indicator of alternative source of energy scored 100%. The study calculated that MHPs saved 294 trees to replace the fossils fuel.

The daily fuel is primary data found through surveys and interviews in the field as mentioned in survey annexure C. The monthly and annual consumption of fuel has been calculated by using Equations 2.3 and 2.4. The complete calculations are mentioned for tress saved and fuel consumption by each house is mentioned in annexure A.

Table 3.2 Consumption of fossil fuel for lighting and ironing.

Household Consumption	Pre-MHP Wood (Kg)	Pre-MHP Kerosene (Kg)	Pre-MHP LPG(Kg)	Post-MHP Consumption
Average daily	3kg	0.25L	0.2kg	Zero
Average monthly	90kg	7.5L	6 kg	Zero
Average annual	1080kg	90L	72kg	Zero
Total fuel of 150 households	162000kg	13500 L	10800kg	All saved

Table 3.3 Trees saved by installation of MHPs.

Annual wood Usage	Tree age	Total wood usage	Trees saved
150 X 1080kg	6-7 years	162000kg	294

In Table 3.2 the consumption of wood was 162000kg. By using Equation 2.5, it has been calculated that 294 trees have been saved by installation of MHPs in both villages.

3.2 Social parameters

In table 3.4., the social assessment was obtained to conduct a survey and interview of the villagers of Khanian and Rajwal. The interviews and survey covered five main selected social parameters. These are social parameters - safety, social activities, accessibility, electric appliances, and work burden. Each parameter assessment is based on indicators. There are ten environmental indicators that have been studied during this study. The assessment tries to explore whether MHP electricity supports the selected indicator to solve the villager's problems.

The social life of both villages was affected by the unavailability of electricity. The interaction of people and social activities was limited to daytime. According to the survey, safety and social activities were two big problems that were faced by the community as well as the MHP's electricity accessibility enable the society to bring electric appliances in their daily work and businesses.

By using Eq.1 sustainable development indicator (SDI) percentage of social indicators has been calculated. The initial value Vi is the score of evaluation criteria of the survey as mentioned in Table 2.1 and Vt is the target value of the social indicator. The code identifies the indicator. The evaluation criteria were selected by people during the survey as mentioned in Annexure C. The SDI average % is the average percentage of all SDI % of social indicators by using Eq. 2 for calculation.

Table 3.4 Sustainability assessment of social parameter.

Parameter	SDI Average (%)	Code	Indicators	Score	Evaluation Criteria	SDI %
Safety	88%	SCO1	▪ Wild Animal Threats	4	Strongly Agree	100%
		SCO2	▪ Theft Threats	3	Agree	75%
Social Activities	75%	SCO3	▪ Family Gathering	3	Agree	75%
		SCO4	▪ Business Services	3	Agree	75%

Accessibility	100%	SCO5	▪	Electricity	4	Strongly Agree	100%
Electric Appliances Usage	92%	SCO6	▪	Men Business	3	Agree	75%
		SCO7	▪	Women Business	4	Strongly agree	100%
		SCO8	▪	House Works	4	Strongly agree	100%
Work Burden	88%	SCO9	▪	Children	3	Agree	75%
		SCO10	▪	Women	4	Strongly agree	100%
Total Average	89%				3.5		88%

3.2.1 Dimensional evaluation average percentage

In figure 3.4, the graph is showing the dimensional evaluation of selected parameters of social development. The big concern of the community was safety during nighttime from wild animal threats and theft activities. Safety has been enhanced by 88% by lighting in houses and streets. People of both villages agreed that MHP increased social interaction and family gatherings by up to 75%. Both villages have 100% accessibility to MHP electricity. The MHPs can support 92% of electric appliances like bulbs, wash machines, rechargeable torches, sewing machines, low-volt fans, and refrigerators. The electric appliance reduce 88% work burden on women and children.

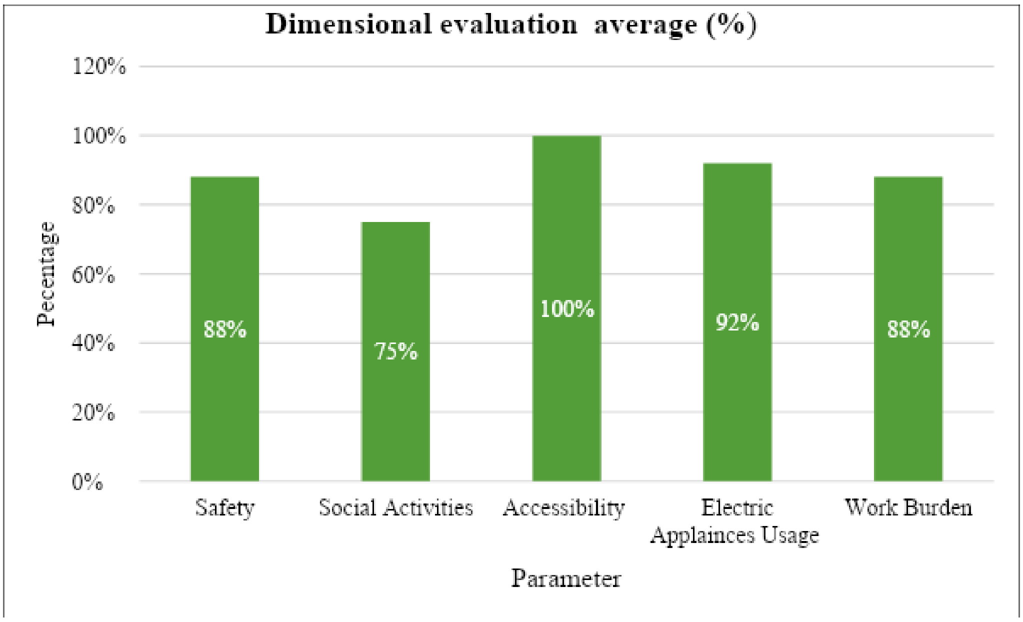


Figure 3.4 Dimensional evaluation of average percentage of social parameters

3.2.2 Code and score of indicators

In figure 3.5, the bar graphs show the indicators of parameters. Each indicator has been named with a code and score of 4.00. Wild animal threats (SCO1) and thefts (SCO2) have been studied under the safety parameters of both villages. The wild animal threat (SCO1) has a score of 4.00. It has been completely extinct due to lighting and rechargeable torches and batteries in houses and the theft threat (SCO2) also has been reduced. The family gathers (SCO3) and business services (SCO4) are considered indicators of social activities because the MHP electricity enhance the social interaction and activities up to last night in both villages, both scored 3.00 as well as people agreed with MHPs electricity increased business hours, and people of both villages to shops and hotel in last night. (SCO5) shows access to electricity in each house in both villages, the indicator (SCO5) scored 4.00 because all houses of both were connected to MHPs powerhouses. The appliance was used in both men's business (SCO6) and women's business (SCO7), the graph is showing a men's business (SCO6) score of 3.00 and a women's business (SCO7) score of 4.00. The (SCO6), (SCO7) and (SCO8) are indicators of electric appliance usage in businesses and homes. These appliances have reduced the work burden on children's duties (SCO9) and women's duties (SCO10). The graph is showing that MHP electricity increased society's standards by enhancing security, reducing work burden, and brought electric appliances in houses.

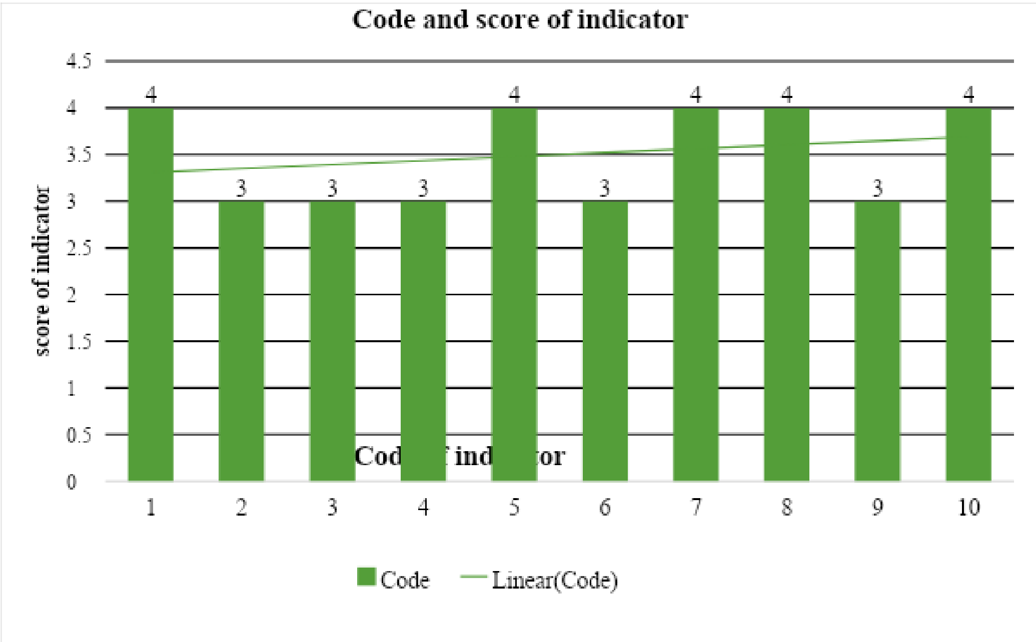


Figure 3.5 Code and score of indicators of social parameter

3.2.3 Indicator evaluation percentage

In Figure 3.6, the indicator percentage has to evaluate based on score and criteria. The indicator scores of 4.00 got a 100% evaluation percentage as well as 0 score has not had any impact. Each bar shows a different percentage according to score and evaluation criteria.

The social indicators percentage is showing that how much the MHP electricity is sustainable for the community. In the graph, the indicator 100% shows that the MHP has solved an identified problem in Khanian and Rajwal villages. While the percentage reduced according to the performance evaluation of the survey.

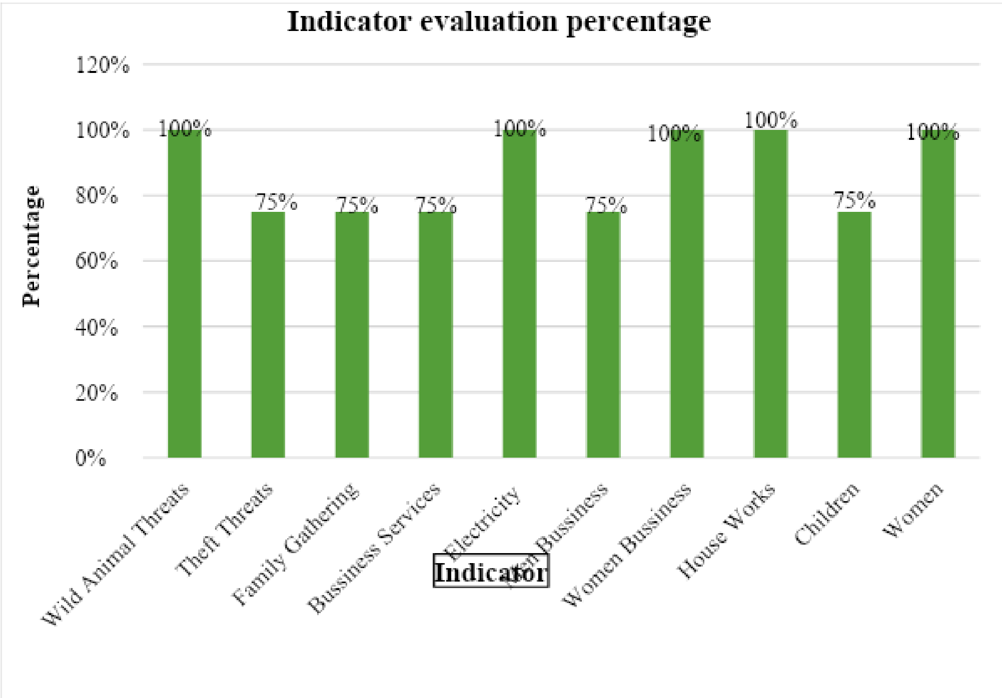


Figure 3.6 Evaluation of indicator in percentage of social parameter

3.2.4 Analysis of social indicators

The results are showing that wild animal threat (SCO1) threats overcome to provide electricity in their houses. During the survey, it has been complained by numbers beneficiaries that they were victimized by wild animal attacks like wolves, leopards and dogs while thieves snatch money and accessories in night. But, electricity enlightened (SCO5) the streets and houses of both villages. The villagers visit shops to buy grocery and stayed outside from home to late night.

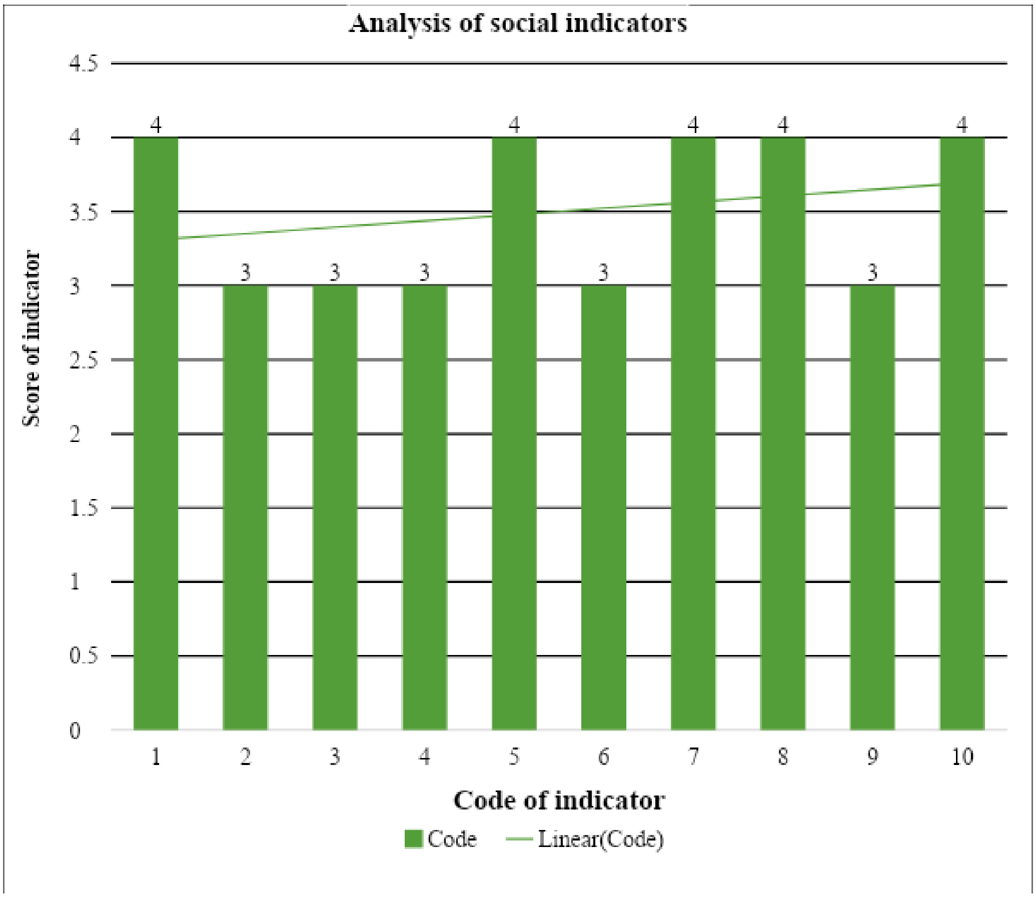


Figure 3.7 Analysis of social indicators

The electricity made social interaction (SCO3) among people. Television and radio became a part of each family due to electricity accessibility (SCO5). During a survey, the beneficiaries expressed that "we send our electric appliance like rechargeable torch and cell phone to near village or relatives for charging. But, now, it does not anymore". The elder people were unable to go mosque for Fajr, Maghrib and Eisha prayers. The children also got time to play in daytime and study in night. Each light in every house of village brought real existence of community. The electricity was big issued during any family gathering (SCO3). Hence, MHPs brought the villagers very close to each other.

In the study area, women (SCO9) and children (SCO10) are spending much of time to collecting wood for firewood and bring water from remote point. The MHPs cannot replace firewood for cooking (ECO3), but it can help to women to save time in many other tasks. These duties are the real cause to keep girls away from education. Wood is needed for cooking but MHPs help to children to study in night. Women who are working in home for earning some money. The electricity helps to reduce time for other duties. Hence, the social indicators included in this were major problems before MHPs. Buts, these problems were solved by installing MHPs. The studied has found that the MHPs pushed society toward socio-economic development.

3.3 Economic parameters

In Table 3.5, the economic assessment was obtained to conduct interviews of the beneficiaries of the MHP of the villages of Khanian and Rajwal. The interview covered four main selected economic parameters. These are economic parameters –Investment for the installation of plants for both villages, affordability of electricity, and impact on business hours and project benefits. There are nine economic indicators that have been studied during this study. The study found economic improvement in both villages of Khanian and Rajwal village.

The MHPs of both villages expanded income growth by creating opportunities and increased income saving on fossil fuel expenditure for energy needs. The inhabitants of villages spend a large amount of their income on buying wood, kerosene oil, batteries, and LPG as well as relying on conventional sources of energy for income.

By using Equation 2.1 sustainable development indicator (SDI) percentage of economic indicators has been calculated. The initial value Vi is the score of evaluation criteria as mentioned in Table 2.1 and Vt is a target value of the economic indicator. The code identifies the indicator. The evaluation criteria were selected by people during the survey as mentioned in annexure C. The SDI average

% is the average percentage of all SDI % of economic indicators by using Eq. 2 for calculation.

Table 3.5 Sustainability assessment of economic parameter.

Parameter	SDI average (%)	Code	Indicators	Score	Evaluation Criteria	SDI %
Investment	100%	ECO1	Loan	4	Strongly Agree	100%
		ECO2	PEDO	4	Strongly Agree	100%
Affordability	100%	ECO3	Electricity Bill	4	Strongly Agree	100%
		ECO4	Cheap Electricity	4	Strongly Agree	100%
Business Hours	88%	ECO5	Increase Time	4	strongly Agree	100%
		ECO6	Electrical Assistance	3	Agree	75%
Project Benefits	100%	ECO7	Savings Increased	3	Agree	75%
		ECO8	Income increased	4	Strongly Agree	100%
		ECO9	Employment	4	Strongly agree	100%
Total Average	97%			3.75		94%

3.3.1 Dimensional evaluation average percentage of parameters

In figure 3.11, showing the dimensional evaluation average percentage of parameters the project was 100% funded by Asian Development Bank (ADB) and installed by PEDO (ECO2). The construction of plants and transmission lines was constructed by PEDO (ECO2). The PEDO (ECO2) is charging only PKR 400 for each house for the electricity bill. The electricity bill was fulfilled only technical assistance and the salary of an operator. Hence, the MHP electricity was 100% affordable for every house. The MHP helped to increase business hours, especially for local businesses like shops, hotels, and small businesses. The study observed that MHPs are benefiting the beneficiaries to save and increase their income and enjoying employment opportunities.

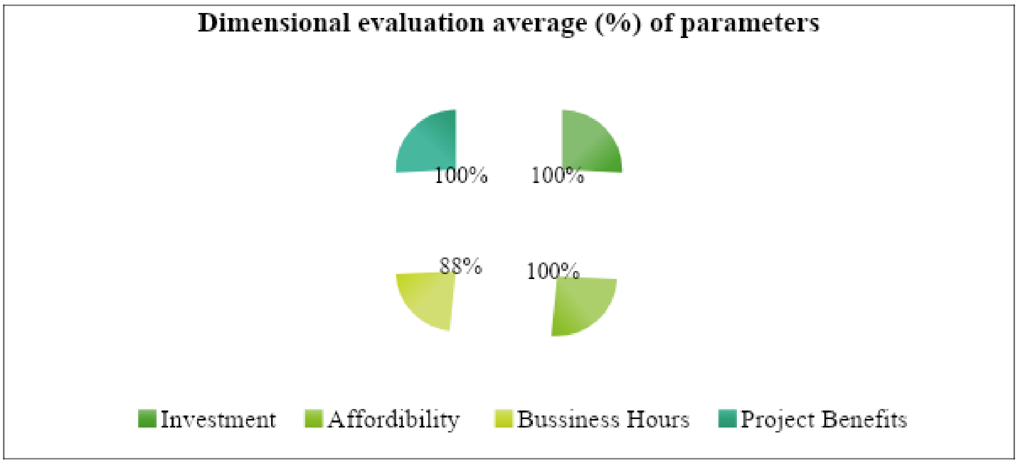


Figure 3.8 Dimensional evaluation average percentage of economic parameters

3.3.2 Code and score of indicator

In figure 3.12., there are nine indicators of economic parameters. The Asian Development Bank (ADB) loaned (ECO1) to PEDO (ECO2). Both indicators (ECO1) and (ECO2) scored 4.00 because the projects were completed on time and operated for villages. PEDO (ECO2) has monitored the project and delivered it in its given timeframe. Hydro is considered a renewable energy and the people of both villages were benefiting from affordable electricity bills (ECO3) and cheap electricity (ECO4) against WAPDA, hence both indicators scored 4.00. The MHP electricity increased business hours (ECO5) scored 4.00 and boosted the business by using electronic appliances (ECO6) scored 3.00. The indicator of project benefits saving increased (ECO7) scored 3.00 due to replace of expensive lighting fuels like non-rechargeable torches and batteries, LPG, and kerosene oil, income increased (ECO8) by using the latest electric appliances in small businesses and also producing employment (ECO9) opportunities in tourism and hospitality sector, both indicators (ECO8) and (ECO9) scored 4.00.

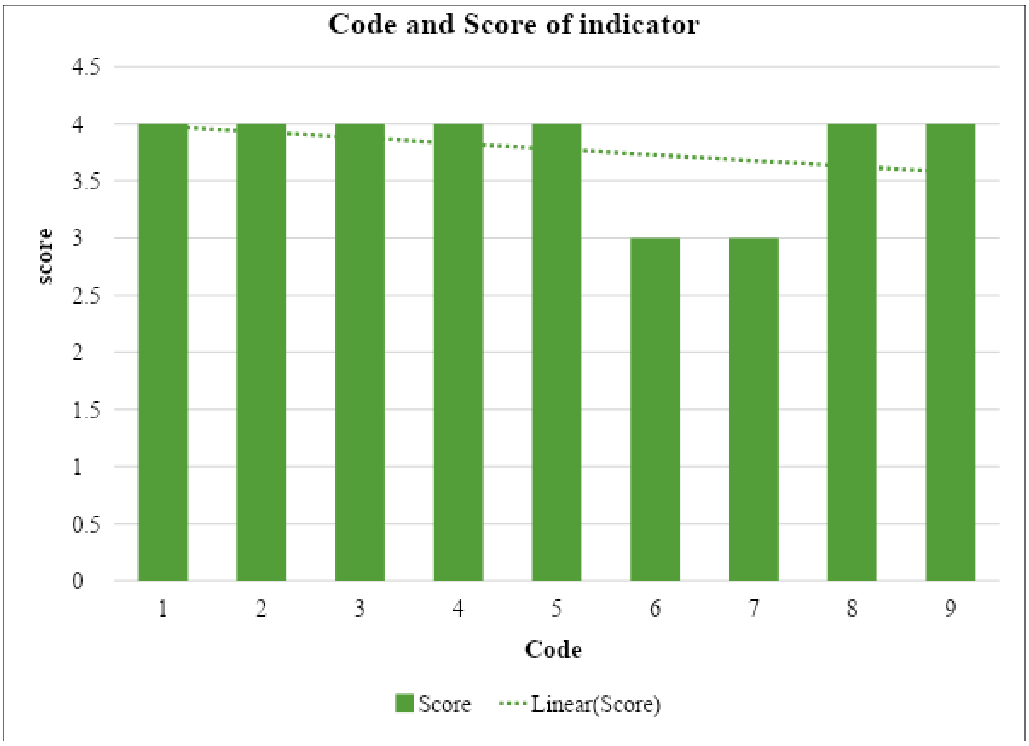


Figure 3.9 Code and score of indicators

3.3.3 Indicator evaluation percentage

In Figure 3.10, the indicator percentage has to be evaluated based on score and criteria. The indicator score of 4.00 got a 100% evaluation percentage as well as 0 score has not had any impact. The maximum indicators of the economic parameter have a 100% evaluation percentage. The MHP boost the economic conditions of both villages. The beneficiaries of both villages increase their income and save money to cut expenditures on energy fuels.

Each bar shows a different percentage according to score and evaluation criteria. The Economic indicators percentage shows how much the MHP electricity is economically sustainable for the community. The MHPs are providing cost-effective and cheap electricity to each house in both villages.

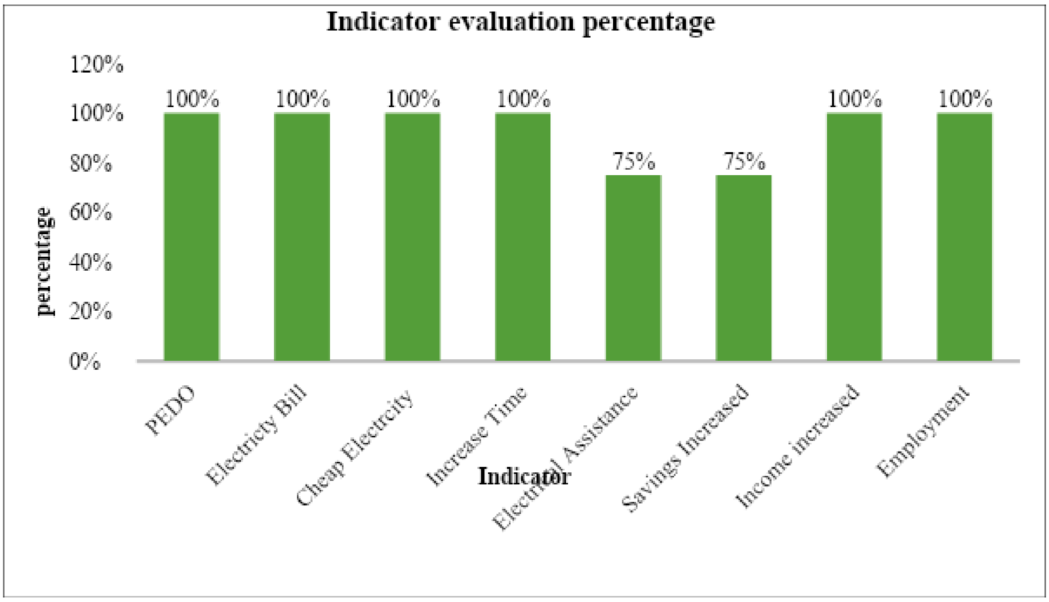


Figure 3.10 The evaluation of indicator percentage of economic indicators

3.3.4 Economic indicators analysis

Pukhtunkhawa Energy Development Organization (PEDO) (ECO2) costs 200,000 PKR for one kV of installed MHPs for both communities as according to PEDO (ECO2) project manager during interview. The projects aimed to develop the community instead of payback. Each household is charging only 500 PKR for electricity bill (ECO2) which is more cost-effective than Water and Power Development Authority (WAPDA). The project has been satisfied to provide cheap electricity (ECO3) to consumers.

Equation 2.5 is using to calculate annual fuel expense as according to recent rates. The saving of amount is mention in Table 3.6. The complete energy and fuel calculations are mention annexure B.

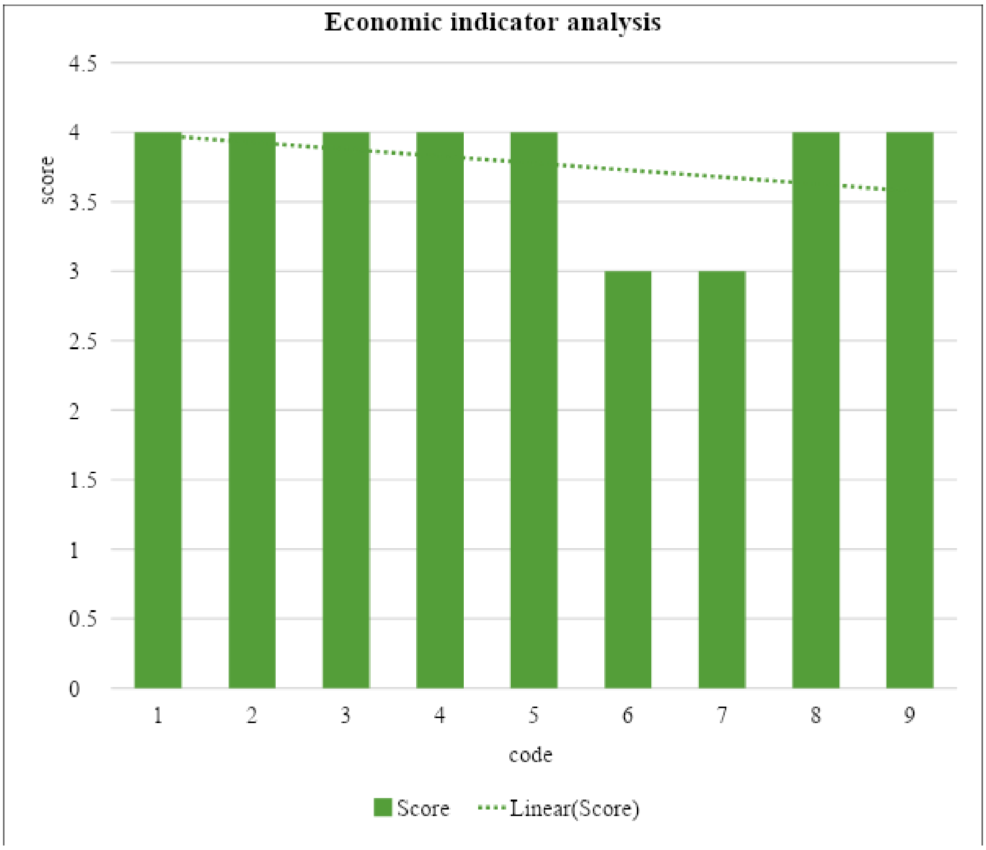


Figure 3.11 Analysis of economic indicators.

Villagers transformed from battery cells to MHPs electricity helped users increased saving (ECO7) save 7200 PKR annually. The battery cells torch replaced to rechargeable torch due to electricity. The people increase their income (ECO6) due to saving on buying battery cells.

The villager was using fossil fuel for as energy before MHPs. The monthly estimated cost of household consumption was of wood 900 PKR, kerosene 2250 PKR and LPG 1800 PKR. All these expenses on buying energy fuel have been saved (ECO7) and increased income ECO8 for standard life.

Table 3.6 Saving of household on energy fuel.

Household	**Wood**	**Kerosene**	**LPG**	**Total fuel Cost**
Monthly saving	900 PKR	2250 PKR	1800 PKR	4950 PKR
Annual	10800 PKR	27000 PKR	21600 PKR	59400 PKR

Villagers transformed from battery cells to MHPs electricity helped users increase saving (ECO7) save 7200 PKR annually. The battery cells torch was replaced with a rechargeable torch due to electricity. The people have increased income (ECO6) due to saving on buying battery cells.

The MHPs users were using fossil fuels for consumption. The annual estimated cost of household consumption was of wood 10800 PKR, kerosene 27000 PKR, and LPG 21600 PKR according to recent price of Pakistan. All these expenses on buying energy fuel have been saved (ECO7) and increased income ECO8 for standard life.

Table 3.7 Business hours pre and post installation of MHPs.

Business	Days	Pre- MHPs Days	Post –MHPs
Hotels	Morning – Sun	Generator Using	5:00 am 01:00 am
Shops	Morning – Sun	Sunset	7:00am to 10:00pm
Tailors	Morning – Sun	Sunset	10:00am to 11:00pm
Barbershop	Morning – Sun	Sunset	10:00 am to 11:00pm

The analysis of economic indicators shows that the user is satisfied with the installation of MHP. All indicators satisfied the economic condition of both villages. The result showed the economic situation has got better in both villages.

3.4. Comparative analysis of sustainability parameters

3.4.1 Average dimensional percentage of sustainability parameters

In Figure 3.12, each sustainability parameter has a different dimensional evaluation percentage. The percentage of the economic parameter has a high-performance dimensional percentage. The results calculated that the economic parameters performed a high percentage due to the high rate of satisfaction of MHP beneficiaries. The investment is 100% funded by ADB whereas both have been installed free of cost in villages. The affordability of electricity was also 100% due to cheap electricity bills. The project was highly beneficial for both villages which enlighten houses, increase business hours, increase electric appliance usage, and create job opportunities.

The study showed that the social impact of MHP on society improved. Both beneficiaries of both villages were living in the absence of electricity. Therefore, they were facing many challenges like a lack of social interaction, disconnected from the recent world. But, MHP electricity has a positive impact on society to improve family gatherings, ease of work, living standard, etc.

Comparatively, the impact of MHP on the environment is lower than economic and social parameters. The results showed that MHP is a 58% alternative source of energy. As alternative energy, the MHP replace fossil fuel, and ironing sources but could not replace the cooking sources which come mostly from wood use. MHP was little but important role to save the deforestation in the study area.

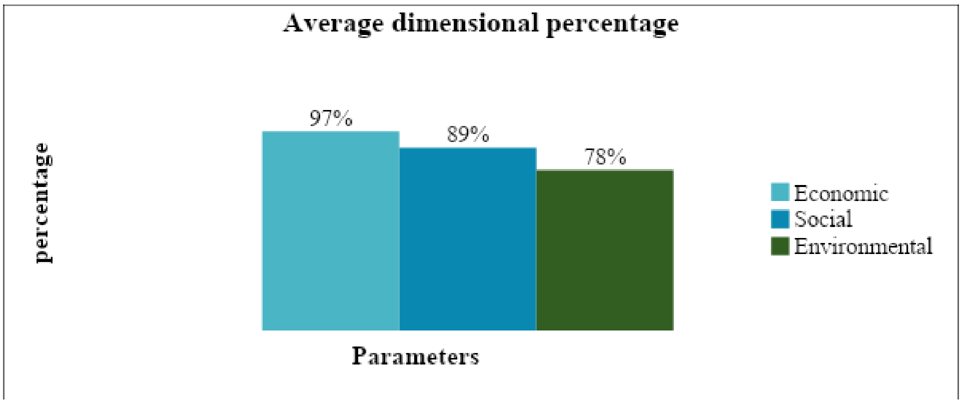


Figure 3.12 Average evaluation percentage of sustainability parameters.

3.4.2 Average dimensional percentage of Sustainability Parameters

The results showed that the installed MHPs have a high average economic indicator score. The economic parameter has covered nine different indicators, all indicators performed at maximum due to high project benefits to the beneficiary. Beneficiaries of both villages were identified very satisfactorily. The beneficiary commented that PEDO (ECO2) as institutional delivered 100%. The completion of the project on time enabled the people to get connected with MHP to improve their economic conditions. Due to the first-time installation of MHP in both villages, economic indicators of sustainability scored high.

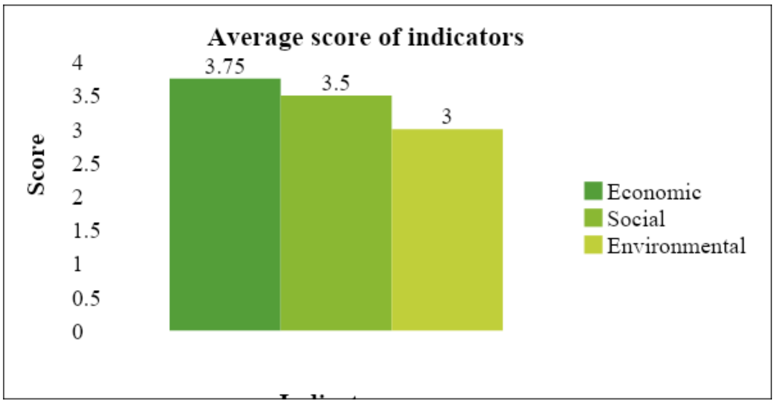


Figure 3.13 Average score of indicators

Conclusions

The study was conducted for sustainability analysis of village micro hydropower plants. The research studied the high and most vulnerable sustainability dimensions of MHPs. By analyzing the data, the findings showed that the economic indicators are the strongest in terms of the sustainability of MHPs, while the environmental dimension was the weakest. The strong commitment of the community to sustain the MHPs is the primary source of electricity in houses. In the mountainous areas, MHPs have a high socio-economic impact due to evacuating many challenges of the community but create fewer environmental benefits due to the low capacity of a generation that is unable to replace things like using wood for cooking. The technical and operational costs of the community were paid with goodwill. The MHP marked the beginning of progress and development for the two villages. That turned black into light, creating employment opportunities and attracting tourism. The MHPs had brought a change in the livelihood of village people. Hence, the micro hydropower plant has a role in improving the quality of life in remote areas

Recommendations

- People have benefited economically from the capacity of MHPs. They have not deterred deforestation activities, but future projects could replace wood by improving capacity. While the long-term operation sustainability of MHPs is a major problem. To maintain the infrastructure of MHPs, creating awareness within the community is important.
- There are serious risks and complications in the operation process. The PEDO shall have responsibility for the monitoring and provision of appropriate training to operational managers.
- The community is concerned about safety. To reduce risks and hazards during operation or in an emergency, the monitoring organization shall conduct public trainings for the creation of awareness.
- The construction company should follow proposed environmental assessment studies to fulfill post-construction protocols.

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Annexure A

Survey finding

i. Consumption of Fuel for Lighting and Ironing:

Household Consumption	**Pre-MHP Wood(Kg)**	**Pre-MHP Kerosene(Kg)**	**Pre-MHP LPG(Kg)**	**Post-MHP Consumption**
Average daily	3kg	0.25L	0.2kg	Zero
Average monthly	90kg	7.5L	6 kg	Zero
Average annual	1080kg	90L	72kg	Zero
Total fuel of 150 households	162000kg	13500 L	10800kg	All saved

ii. Trees saved by installation of MHPs:

Consumption of each household annually = 1080 kg

Annual wood Usage	**Tree age**	**Total wood usage**	**Trees saved**
150 X 1080kg	6-7 years	162000kg	294

iii. Saving amount after installation of MHPs

Household	**Wood**	**Kerosene**	**LPG**	**Total fuel Cost**
Monthly saving	900 PKR	2250 PKR	1800 PKR	4950 PKR
Annual	10800 PKR	27000 PKR	21600 PKR	59400 PKR

Annexure B

i. Energy calculation of MHP:

Annual energy is calculated by the following given formula:

Daily Energy:

$$ED = Pa*h$$

Where

Pa = Average Daily Power (MW)

ED = Daily Energy Output (MWh)

h = Nos. of Hours in a Day = 24

Annual Energy

$$EA = ED* d$$

Where

ED = Average Daily Output (MW)

EA = Annual Daily Energy output (MWh)

D = Nos. of Days in a Year = 365

ii. Calculation of wood consumption:

Wood cost = 10PKR/KG

Monthly consumption = 3kg* 30 days= 90kg/Month

Monthly cost= 90kg* 10 PKR = 900 PKR/Month

Annual cost = 900PKR * 12 Months = 900 PKR * 12 = 10800 PKR/Year

Annexure C

Research Survey

Personal Information

Name of Beneficiary: ________________

Village: ________________

Tehsil: ________________

Age (Years): ________________

Mantel status: ________________

Education: ________________

House-hold characteristics:

Family size: ________________

Occupation: ________________

Gender: ________________

Union council: ________________

District: ________________

Environmental

1. Micro Hydro Power plant (MHPP) is completely renewable energy source for lightening in the village:
    a) Strongly Agree
    b) Agree
    c) Partially agree
    d) Disagree
2. Each household has been reduced dependency on fossil fuel (Wood/LPG/Kerosene) after installation of MHPP in the village:
    a) Strongly Agree
    b) Agree
    c) Partial agree
    d) Disagree
3. I think MHPP plant is not more sustainable technology?
   Note: Water is source of renewable energy.
    a) Strongly Agree
    b) Agree
    c) Partial agree
    d) Disagree
4. Which one is most using fuel for lighting purpose in the Village?
    a) Wood
    b) LPG
    c) Kerosene oil
    d) candle
    e) battery cells

Socio – Economic

1. The village was protected from wild animals and theft threats by MHPP's lighting in streets and houses:

a) Strongly Agree
b) Agree
c) Partially Agree
d) Disagree

2. MHPP increased family gathering, wedding and funeral ceremony in village at night:
   a) Strongly Agree
   b) Agree
   c) Partially Agree
   d) Disagree
3. MHPP provides access to use electric appliances such as washing machines, TVs, and radios:
   a) Strongly Agree
   b) Agree
   c) Partially Agree
   d) Disagree
4. Do you think MHPP empowered women to access electric appliances for businesses:
   a) Strongly Agree
   b) Agree
   c) Partially Agree
   d) Disagree

5. Do you think MHPP increased the income of each household:
   a) Strongly Agree
   b) Agree
   c) Partially Agree
   d) Disagree
6. Do you think that installing MHPPs in remote mountainous regions has the capability to create job opportunities in the hospitality and tourism sector?
   a) Strongly Agree

b) Agree

c) Partially Agree

d) Disagree

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