Study Report
"Multiple Use of Solar Energy in Agriculture"

Government of Nepal
Ministry of Agriculture And Livestock Development
Prime Minister Agriculture Modernization Project
Project Management Unit
Khumaltar, Lalitpur
FY 2080/81

Publisher
Prime Minister Agriculture Modernization Project
Project Management Unit
Khumaltar, Lalitpur

Published Year
2081(2024)

© Copyright
PMAMP, PMU, Khumaltar, Lalitpur

Layout
Dr Jeet B Chand, PMAMP, PMU
Er Sameer Shrestha, PMAMP, PMU

Printing Press
Offset Print Solution
Balkot, Bhaktapur

शुभकामना

नेपालको राष्ट्रिय अर्थतन्त्रमा कृषि क्षेत्रले ठुलो योगदान पुर्‍याउदै आएको छ तर परम्परागत खेती प्रणाली, उपयुक्त पूर्वाधार, प्रविधि एंव जनशक्तिको अभाव जस्ता कारणहरुले गर्दा नेपालको कृषि क्षेत्रले अपेक्षित गति लिन सकेको छैन। भौगोलिक परिवेशले उपलब्ध गराएका अवसरहरु, प्रयोगशालामा प्रमाणित प्रविधिहरु तथा श्रोत साधनहरुलाई एकीकृतरुपमा संयोजन गरी लागु गर्न सकेको खण्डमा नेपालको कृषिले युगान्तकारी परिवर्तन गर्ने प्रशस्त सम्भावना बोकेको छ।

सम्भावना र चुनौतीहरुलाई मध्यनजर गर्दै नेपाल सरकारले कृषि क्षेत्रको दिर्घकालिन सोच सहित २० वर्षे कृषि विकास रणनीति तर्जुमा गरी कार्यान्वयनमा ल्याएको छ। कृषि विकास रणनीतिको सहयोगी परियोजनाको रुपमा रहेको प्रधानमन्त्री कृषि आधुनिकीकरण परियोजनाले कृषिमा आधारित अर्थतन्त्रलाई यान्त्रीकरण, विशिष्टीकरण तथा आधुनिकीकरण गरि कृषिजन्य उद्योगमा रुपान्तरण गर्दै व्यवसायिक, दिगो एवं आत्मनिर्भर कृषि क्षेत्रको विकास गर्ने सोच लिएको र उक्त सोचलाई मुर्तरुप दिन कृषि उपादनको विशिष्टीकृत क्षेत्र निर्माण, निर्यातयोग्त कृषि वस्तुहरुको मुल्य अभिवृद्धि तथा प्रतिस्पर्धात्मक क्षमता वृद्धि र सम्बन्धित सबै सरोकारवालाहरुसँगको कार्यमुलक समन्वयलाई प्राथमिकता दिने जस्ता उदेश्यहरु लिएको छ। स्वदेशी सोच, श्रोत तथा उपलब्ध जनशक्तिबाट तयार गरीएको यो परियोजना कार्यान्वयनमा सबै सरोकारवालाहरु जिम्मेवारीबोधका साथ संलग्न रहन सके कृषि क्षेत्रको विकासले तिव्रता पाउने छ।

अन्तमा, राष्ट्रिय महत्व बोकेको रुपान्तरणकारी परियोजनाबाट प्रकाशित भएको **कृषिमा सौर्य ऊर्जाको बहुउपयोगसँग सम्बन्धित पुस्तक"** पढ्न पाउँदा खुशी भएको छु। पुस्तक तयार तथा प्रकाशन कार्यमा संलग्न प्रधानमन्त्री कृषि आधुनिकीकरण परियोजनाका कार्यवाहक परियोजना निर्देशक हिक्मत कुमार श्रेष्ठ, वरिष्ठ इन्जिनियर डा. जीत ब. चन्द, कृषि इन्जिनियर समीर श्रेष्ठ, नेपाल कृषि अनुसन्धान परिषद्का वैज्ञानिक डा. इन्जिनियर शिवकुमार झा एवं प्रकाशनको लागि महत्वपूर्ण भुमिका निर्वाह गर्नुहुने सम्पूर्णलाई विशेष धन्यवाद दिन चाहन्छु। वहुसंख्यक नेपाली कृषकहरुको आशा र धरोहरको रुपमा रहेको यस परियोजनाले नतिजामुखी परिणाम दिन सकोस भन्ने समेत कामना गर्दछु।

डा. राजेन्द्र प्रसाद मिश्र
सचिव (पशुपन्छी विकास)
कृषि तथा पशुपन्छी विकास मन्त्रालय

मन्तव्य

आन्तरिक संस्थागत जनशक्तिबाट दस्तावेज तयार भई नेपाल सरकारको आफ्नै स्रोतबाट सञ्चालन हुने गरी "कृषि विकास रणनीति" कार्यान्वयनको सहयोगी परियोजनाको रुपमा कृषिमा आधारित अर्थतन्त्रबाट कृषिजन्य उद्योगमा रुपान्तरित आधुनिक, व्यावसायिक, दिगो एवम आत्मनिर्भर कृषि क्षेत्रको विकास गर्ने सोचका साथ नेपाल सरकार, मन्त्रिपरिषद्को मिति २०७३/०९/२६ को निर्णयबाट आ.व. २०७३/०७४ देखि प्रधानमन्त्री कृषि आधुनिकीकरण परियोजना १० वर्षको लागि नेपालका सातै प्रदेश, ७७ जिल्ला र ७५३ पालिकाहरुमा सञ्चालनमा रहेको छ। कृषि उत्पादन र उत्पादकत्व वृद्धिका लागि आवश्यक प्रविधि, पहुँच तथा उत्पादन सामाग्रीको व्यवस्था, बाली/वस्तुको उत्पादन लागत घटाउनको लागि यान्त्रिकरण एवम् पूर्वाधार विकास लगायतका क्रियाकलापमार्फत प्रशोधन तथा बजारीकरण गरी उत्पादनको मूल्य अभिवृद्धि गर्ने स्पष्ट मार्गचित्रका साथ नेपालको कृषि क्षेत्रको आधुनिकीकरणको परिकल्पना यस परियोजनामा गरिएको छ। कृषि क्षेत्रको समग्र विकासका लागि सरोकारवाला समुदायकै नेतृत्वले सहजीकरण गरी आधुनिकीकरणको प्रक्रियालाई तीव्र गति दिने सोचाई राखिएको यस परियोजनामा मुख्यतः चारवटा सम्भागहरुः साना व्यवसायिक कृषि उत्पादन केन्द्र (पकेट) विकास कार्यक्रम, व्यवसायिक कृषि उत्पादन केन्द्र (ब्लक) विकास कार्यक्रम, व्यवसायिक कृषि उत्पादन तथा प्रशोधन केन्द्र (जोन) विकास कार्यक्रम र वृहत व्यवसायिक कृषि उत्पादन तथा औद्योगिक केन्द्र (सुपरजोन) विकास कार्यक्रमको व्यवस्था गरी उत्पादन, प्रशोधन तथा औद्योगिकीकरणमार्फत कृषिमा आत्मनिर्भरताको दिशामा अगाडी बढ्ने अपेक्षा गरिएको छ। परियोजनाको दस्तावेजमा उल्लेख गरिएको अपेक्षित उपलब्धीहरुको हालसम्मको प्रगतिको अवस्था हेर्दा आ.व.२०७३/०७४ देखि देशभर ७७ जिल्लामा विशिष्टीकृत बाली वस्तुहरुमा पकेट, ब्लक, जोन र सुपरजोन स्थापना भई कार्यक्रम सञ्चालन भइरहेका छन्।

नेपालको कृषि विकासमा अथाह सम्भावना हुँदा पनि कृषकहरुले अपेक्षित लाभ लिन नसकेको कुरा सर्वविदितै छ। यसको पछाडी विविध कारणहरु छन् जसमध्ये उपयुक्त, नयाँ र प्रमाणित प्रविधीहरु कृषकस्तरमा पुर्याउन नसक्नु पनि एक हो। नेपाली कृषिको उत्पादकत्व कम हुनुको एउटा कारण कृषिमा ऊर्जाको कम प्रयोग हो । नेपालमा सौर्य ऊर्जाको प्रचुर सम्भावना छ र हामीले हाम्रो कृषिलाई जलवायु-स्मार्ट बनाउन त्यसलाई प्रवर्द्धन गरिरहेका छौं। तसर्थ सौर्य ऊर्जासँग सम्बन्धित विभिन्न विषय/पक्षहरु समेटेर तयार गरिएको यो पुस्तक महत्वपूर्ण छ। यस पुस्तकलाई साकार रुप दिन प्रत्यक्ष संलग्न हुनुभएका पूर्वाधार विकास शाखाको वरिष्ठ इन्जिनियर डा. जीत ब. चन्द, कृषि इन्जिनियर समीर श्रेष्ठ, नेपाल कृषि अनुसन्धान परिषद्का वैज्ञानिक डा. इन्जिनियर शिवकुमार झालाई विशेष आभार व्यक्त गर्दछु। यसैगरी पुस्तक छपाईको कार्यभार पुरा गर्ने अफसेट प्रिन्ट सोलुसन तथा कृषि विकासका क्षेत्रमा योगदान गर्नुहुने सबैलाई हार्दिक धन्यवाद प्रकट गर्दछु।

हिक्मत कुमार श्रेष्ठ
कार्यवाहक परियोजना निर्देशक

Study Team
अध्ययन टोली

Dr. Jeet B Chand
Senior Agricultural Engineer
Prime Minister Agriculture Modernization Project
Project Management Unit
Khumaltar, Lalitpur

Dr. Shiva Kumar Jha
Scientist (Agricultural Engineering)
Nepal Agricultural Research Council
National Agricultural Engineering Research Centre
Khumaltar, Lalitpur

Sameer Shrestha
Agricultural Engineer
Prime Minister Agriculture Modernization Project
Project Management Unit
Khumaltar, Lalitpur

Executive Summary

Various energy sources have been used in agriculture from land preparation to production and post-harvest engineering unit operations. The major power sources in Nepalese agriculture currently practiced are: human, animal, mechanical, electrical, solar and biomass. The level of modernization and advancement of an agricultural farm is indicated by how much energy is utilized there in agriculture purpose. In bitter reality, Nepalese farms have been identified as the least-energy users in world where energy use per ha is below one kW, whose value, however, in developed countries is around 8-10 followed by India 2.5 to 3 kW per ha. Energy use in agricultural production and subsequent productivity has directly proportional relationship. Hence, to modernize and industrialize the agriculture profession in Nepal, it is essential to improve power use in farm which not only attracts youth in farming but also makes this black-colored job profession attractive and lucrative. Also, because of climate change, new situation has been raised in agriculture where availability and use of energy and water should be integrated, climate-smart and efficient enough. Different studies and literatures demonstrate that Nepal has tremendous potential of renewable and rural energy as it contains above 300 sunny days in a year. In the context of importing huge amount of diesel/petrol and gas from foreign countries, development and proper use of renewable energy in Nepal has paramount importance. Renewable Energy Technology (RET) is a synonym for new, renewable and non-conventional forms of energy i.e. the technologies, which use local energy resources (other than commercial fuels) and biomass fuel (firewood, agricultural residues and animal wastes) in traditional forms. The main sources of these alternatives are biomass, water, sun and air.

Three millennia ago, a Greek philosopher, Thales of Miletus had claimed that “best of everything in this universe is water”. UN conference 1977, first time declared water as a basic need of living being which was sealed by UN Resolution Act 64/292. Undoubtedly, it is no surprise that access to water has been a global development priority since many decades. Despite priorities given, above two billion people are facing water scarcity by 2025 and annually 300 million cases of diseases related to water are reported with 5% deaths. Unplanned urbanization is expected to cause perennial water shortage to one billion people in poor nations by 2050. Also, as little as 30% of the global cultivated area is irrigated till now and is predicted that the availability of freshwater in agriculture will decrease globally by 17% in coming decades. In the context of changing climate, shooting population and the corresponding competition among users, FAO recommends to improve the understanding of global water supply and demand. Till date, around 35% of irrigable land in Nepal receives year-round irrigation with below 30% efficiency. To tackle these challenges associated with water, it is found some important solutions including technological advancement, identification of new sources and modernization of water management techniques in agriculture. Undoubtedly, using alternative sources of water and employing efficient irrigation strategies via sustainable technologies including water and energy smart micro irrigation/ solar-based lift irrigation are the two immediate remedies

in agricultural water. The literature evidences of this study highlight the importance of single drop of water, and managing it as a finite and scarce resources which needs to be rationalized its use in terms of productivity, efficacy and access.

Nepal is an agrarian economy where the agriculture sector contributes around one-fourth of the national GDP. The majority of the farmers in Nepal are smallholders who rely on traditional rain-fed agriculture. Most of the irrigated land in Nepal lies in the Tarai, where the topography is flat. Farmers who use groundwater rely on diesel pumps because grid electricity is not available everywhere. Irrigation using diesel pumps is both expensive and harmful to the environment. The agriculture sector (including irrigation) alone accounts for around 10.5% of the total diesel consumption in the country. Nepalese agriculture makes up 2% of the national energy consumption. Diesel is the most relied upon fuel at 90.9% of the fuel mix, other fuels being electricity (7.4%), Petrol (1.4%), followed by solar as 0.3%. The Government of Nepal has been supporting the promotion and development of Renewable Energy Technologies (RETs). To date, Nepal has approximately 1,600 solar irrigation projects (SIP), 75% of which have been financed and installed by Alternative Energy Promotion Centre (AEPC), and the remainder by a number of GOs including local municipalities, Agriculture Knowledge Centre (AKC), province level Agriculture Development Directorate and Prime Minister Agriculture Modernization Project (PMAMP), and non-government sector such as IDE, ICIMOD, Winrock, and Practical Action. Hence, making agriculture more productive and sustainable, the inputs of agricultural production including energy and irrigation services can contribute significantly.

In its 15th plan, National Planning Commission has defined Prime Minister Agriculture Modernization Project (PMAMP) as one of the game changer projects of Nepal Government. Ministry of Agriculture and Livestock Development has been implementing the PMAMP since fiscal year 2073/74. PMAMP is working throughout the country via four departments: pocket, block, zone and super zone. This project aims at self-reliant economy through modernization, specialization, mechanization and industrialization of the agriculture sector. Currently, the federal component of PMAMP has been implemented in 16 specialized agriculture production and industrial centers (Superzone) and 177 Commercial agriculture production and processing centers (Zone) in 77 districts of the country. Commercial agriculture production centers (Block) and agriculture production centers (Pocket) components of the projects are being implemented by provincial and local government. The project aims at implementing 21 super zones, 300 zones, 1500 blocks and 15000 pockets by the end of project by the end period of the project.

PMAMP is investing a significant amount of budget in construction, repair/maintenance and modernization under small irrigation program which includes development and commissioning of solar irrigation in technically suitable locations. Particularly, in mid-hill and Terai region of Nepal, solar-based lift irrigations are under operation. However, the systematic study about effectiveness, usage and sustainability of these solar projects has not been carried out yet. In this circumstance, this study has been undertaken to study solar projects established from economic and technical support of PMAMP. In addition, similar type solar lift irrigations established in PMAMP zone/super zone area by other organizations have also been included in this study. The specific objectives of this study were to:

a. Document and review solar irrigation projects in working area of PMAMP throughout the country,
b. Evaluate key effects of solar irrigation in agricultural production and productivity in study locations,
c. Examine the impacts of solar projects in gender issues, particularly focusing women farmers, d) explore the possibilities of converting solar energy tapped from panels into multipurpose agricultural operations,
d. Examine gaps and issues concerning economic and technical efficiency of solar irrigation projects, and thereby recommending suggestions and future courses of action to be adopted by government for sustainability and profitability, and
e. Recommend generic guidelines for improved efficiency and application of solar irrigation in agricultural farm to sustainably manage the water-energy and climate inter-linkages.

As one of the strategies of PMAMP is promotion of climate-smart technologies in agriculture, the selected study is convergent with overall aim of the project. The findings of the study will contribute in agricultural production and water management via the sustained development of energy and water-smart solar projects. It is important to conduct systematic study of lift irrigation projects in plain as well as hilly region to minimize the constraints and make it cost-effective among farming communities. Huge energy costs, more frequent breakage and wear and tear of electro-mechanical components, and the unwillingness of the farmers to share the operation and management costs have been the key constraints to dependable irrigation services in the earlier developed lift irrigation schemes in Nepal.

This study targeted to include locations from different agro-ecological zone of Nepal to know the conceptual variation among the solar energy users of Terai, Mid-hill and High-hill in utilizing the solar lift irrigation technology. The study pursued to understand that, from which region and what kind of perception the solar lift irrigation user has. As explained in the objective of this study, we have targeted to study the current status of existing solar lift irrigation and how the user are exploring the technology in the field of agriculture. Do the users are aware about the multiple use of solar energy and are they applying their knowledge to get multiple benefit from the same solar panel using for the lifting water or not. Also, the physical observation sampling study could make us understanding about the existing capacity of the solar system, their edge of application and real demand as well as future possibilities in making it multiple use in the field of agriculture sector.

To achieve this target, total 30 number of randomly selected sites with the coordination of PMAMP, unit in-charge of different districts. The sampling within the sampling area was carried out using a multi-stage sampling method. In which, the first stage of sampling carried in Madhesh Province at Sarlahi, Dhanusha, Siraha, Saptari, Rautahat and Parsa district. The second phase of sampling was conducted in Gandaki Province (Kaski and Lamjung district). Similarly, in the successive phase of sampling was planned to conduct at Ramechhap, Sindhupalchowk and Chitwan district of Bagmati province. Also, Jhapa and Morang district of Koshi Province and Surkhet district of Karnali province.

Observation checklist was developed to attain quantitative data on the studied solar lift irrigation system. Alongside quantitative data, qualitative data was retrieved through Key Informant Interview (KII) with all 30-sample site. The Focal Group Discussions (FGD) were carried out at Kachankawal rural municipality of Jahapa district at Koshi province representing the Terai sites and Polingtar, Rupa Rural Municipality of Kaski district at Gandaki province representing the hill sites. FGD was also conducted in Karnali province. KII Guidelines were developed to collect qualitative data to: know the current status of existing solar lift system, identify the exact location, available of infrastructure (Specifically, electricity GRID and road connections), local suppliers information, source of water lifting, major uses of lifted water, from how long the system is running or getting damaged, what are the most repaired component of the system, who are the contributor or supporting for installation of the solar system, and are the system owned by individual or community.

Likewise, the questionnaire includes the technical information which has prepared to collect the input and output supply as well as power generated by the solar system, water lifting head of pump, the energy required by pump set, type of pump set used for the purpose etc. which, on analysis could support the available power, currently utilizing power and possibilities to make the system power for the other purpose than that of water lifting. The KII questionnaire form focus to understand the farmers perception on the solar lift technologies they had installed where the impact of this technology on the farmers cropping pattern, income generation and its effectiveness were studied and at the end the physical observation and farmers need were evaluated to find the further possibilities making the existing solar system as multipurpose use in the agriculture production or agri-business system. The details of the sample format of Questionnaire used for KII and FGD is provided in Annex I. As a final tool, PMAMP organized the technical working group meeting with the experts of this field invited from AEPC, ICIMOD, IOE Pulchowk Campus, Nepal Electricity Authority and expert team of PMAMP where, all the information collected during the KII and FGD were discussed and a conclusion of the study were drafted.

After introduction of diesel and petrol engine with irrigation pump, it's become crucial for Nepalese farmers. Such pumps rapidly adopted for pumping either ground water, especially from shallow tube wells (STWs) and/ or surface water like running river, ponds, channels waters to irrigate their field and feel very relief as compared to the traditional irrigation system where, traditional hand pump, Dhanki Pump, Don or Swing buckets etc. were used for the purpose. Such farmers, either using surface water or groundwater for irrigation, rely on diesel pumps because grid electricity is not available everywhere and have no any alternative source of energy. Irrigation using diesel & petrol pumps is both expensive and harmful to the environment. The agriculture sector (including irrigation) alone accounts for around 10.5% of the total diesel consumption in the country. In this regards Solar-powered Irrigation Pumps (SIPs) have emerged as a viable alternative to diesel pumps. The SIP technology makes it suitable for rural farms which are far away from the NEA electric grid. Such, SIP technology sustainably manages the water-energy and climate inter-linkages. The GoN agencies like AEPC, DOI, Krishi Gyan Kendra, PMAMP etc. with different INGOs, and NGOs, are found supporting the individual farmers or farmer's groups for the installation of such solar lift irrigation (SLI) technologies in their farms. Many projects have lunched and had found updating the time wise scenario of SIP through case study of particular areas only and never had thought about its sustainability, its optimum uses and its impacts on agriculture as well as user's status.

This study aimed to document the existing status of solar lift irrigation technology installed at farmer's field. The main objective of this study is to understand the need of agricultural machineries and possibilities to make the existing solar powered lift irrigation multifunctional to operate the agricultural machines for the SPI users' farmer. With this aim, the study team visited the selected site of different agro-ecological zone of Nepal and developed observation checklist to perceive the quantitative data. Alongside quantitative data, a qualitative data was retrieved through Key Informant Interview (KII), Focal Group Discussion (FGD), local suppliers' information, and finally conducted the technical working group meeting with the experts of this field.

This report presents a brief analysis of the current status of SLI technologies in Nepal in terms of its functioning, current application in agriculture, impact on production and economic status of farmers, social benefits and future possible ways to make it sustainability through multiple uses of existing solar energy. The study data showed that 63% of SLI has been owned by individual farmers and 37% has group ownership where 86.7% SLI was found in working conditions. Though globally panel costs have declined rapidly, standalone off-grid SIPs still remain expensive from small and marginal farmers in Nepal. The GoN has been gradually increasing the budget allocated for subsidizing SIP. In 71% of total installed SLI, different government organizations like AEPC, Department of Irrigation, PMAMP etc., as well as NGOs & INGOs had shared 80-90% of the installation cost whereas, 100% installation cost has been supported by those organization in 25% of existing SLI users farm. Even, the GoN and support organization are investing huge cost for farmers, 70% of them are using it only for irrigating field and 16.7% are lifting water for livestock, fishing along with irrigation. This concluded that the farmers are not utilizing SLI technology efficiently, on the other hand farmers need huge energy for other farm operation like threshing, chaff cutting, winnowing, drying etc. which can be achieved from existing solar panel installed for SLI system. The study and expert group discussion concluded that since, about 87% of existing SLI had NEA grid nearby its site, it is possible to connect all those SLI system to NEA grid line to make the existing SLI system multifunction benefiting those farmers both in electric bill for supplying unused energy to NEA and can make the system applicable for broad areas of using agriculture machinery or any other farm operations.

In addition, this study explored opportunities for use and application of solar energy on agricultural ecosystems, sustainability and rights-based approaches to irrigation water management in the context of climate change. Particularly, how the multiple use of energy collected in solar panels could be made possible from same motor in different unit operations of agriculture was the main agenda. Three alternatives discovered includes;

i. Use of hybrid model,
ii. Conduct extensive research to understand what type of agricultural machineries can be operate from the existing SLI system and
iii. Upgrade the existing system for grid-connected SLI system.

Among these three alternatives, grid connection to NEA mains is found to be the most viable, sustainable and cost-effective to farmers because it works on the principle of Energy Bank which, not only uses produced solar energy but also sells the excess one. As it is a crystal clear proven fact that agriculture is one of the most energy-intensive profession, priority of clean energy in that sector could be the mild-stone in climate change management. The study also concluded that in stationary unit operations like drying, threshing, winnowing and etc., solar energy collected on the same panel could be utilized relatively easier compared to other operations.

The current strategy of solar energy application in lift irrigation could not be successful if favorable plan and policy will not be developed to bring the investment for its optimal output. This study thus, would like to recommend that the existing policy need to be improved in such a way that the users will be motivated to connect the SIP into the NEA grid line and subsidies the SIP based on the possible application by them so that the investment will be justified based on the productive uses of solar panel and also contribute national energy supply system. Grid-connected solar system could be the best option. However, a more systematic research about multiple use of solar power in different activities of agriculture from land preparation to post-processing has urgent need for sustainability of water and energy.

Table of Content

1

INTRODUCTION

1.1 Background

Different types of power source have been used in global agriculture since time immemorial from production to post-harvest engineering operations. The major power sources are: human, animal, mechanical, electrical, solar, biomass and wind. The level of modernization and advancement of farm is indicated by how much energy the particular farm uses in agriculture purpose. Nepalese farms have been identified as the least-energy users where energy use per ha is below one kW, whose value, however, in developed countries is around 8-10 kW (PMAMP 2023). India uses nearly 2.5 to 3 kW per ha. Energy use in agricultural production and subsequent productivity has directly proportional relationship (Michaeal & Ojha 2014, Singh 2014). Hence, to modernize and industrialize Nepalese agriculture, it is essential to improve power use in agriculture sector which not only attracts youth in farming but also makes this black-colored job profession attractive and lucrative. In addition, other parameters including technology, seed, fertilizer and water are equally important for prosper and modern agriculture. Nowadays, because of climate change, new situation has been arrived in agriculture where availability and use of energy and water should be integrated, climate-smart and efficient.

Three millennia ago, a Greek philosopher, Thales of Miletus had claimed that "best of everything in this universe is water" (Biswas & Tortajada 2009). UN conference 1977, first time declared water as a basic need of living being which was sealed by UN Resolution Act 64/292 (Koumpli & Kanakoudis 2022). Undoubtedly, it is no surprise that access to water has been a global development priority since many decades (Riazi et al. 2023). Despite priorities given, above two billion population are facing water scarcity by 2025 and annually 300 million cases of diseases related to water are reported with 5% deaths (Susnik et al. 2023). Unplanned urbanization is expected to cause perennial water shortage to one billion people in poor nations by 2050 (Enqvist et al. 2022). Also, as little as 30% of the global cultivated area is irrigated till now (ICID 2023) and is predicted that the availability of freshwater in agriculture will decrease globally by 17% (Chand et al. 2023). The Global Water Security Assessment 2023 alarming that world is out of track to meet its SDG goals in water resources. In the context of changing climate, shooting population and the corresponding competition among users, FAO (2019) recommends to improve the understanding of global water supply and demand. These literature evidences highlight the importance of single drop of water, managing water as a finite and scarce resources which needs to be rationalized its use in terms of productivity, efficacy and access. To tackle these challenges associated with water, Mishra (2014) recommended some important solutions including technological advancement, identification of new sources and modernization of management techniques. Furthermore, Hashem et al. (2018) added that using alternative sources of water and employing efficient irrigation strategies via sustainable technologies are the two immediate remedies in water sector.

Agricultural irrigation represents the main water use sector accounting for about 70% of the global freshwater withdrawals and 90% of consumptive water uses (Pulido-Bosch et al. 2018; Montazar 2019). Nearly 70% of freshwater is used in agriculture globally compared with 20% and 10% for the industrial and domestic sectors, respectively (Lea-cox et al. 2013; Du et al. 2015; Francaviglia & Bene2019). However, competitive users of water in different fields have put pressure on agriculture to use water as the most scare resources (Montazar 2019). Water is expected to be a major constraint for agriculture, particularly in developing countries and the countries located in arid and semi-arid regions (Stikic et al. 2009; Prazeres et al. 2016). Insufficient supply of water for crop production will be the norm rather than the exception, and irrigation management will shift from emphasizing production per unit area towards maximizing the production per unit of water consumed (Zhang et al. 2017). According to Djurovic et al. (2016), modern agriculture has faced with two tasks: (1) to produce enough food for a growing population, and (2) to ensure satisfactory crop quality while using water resources efficiently.

Agriculture is the backbone of national economy in Nepal which depends largely on monsoon rains (Gyawali & Khanal 2021). The majority of arable area has some sort of irrigation facilities but below 35% of irrigated land gets year-round water (DoI 2023). For the agricultural transformation from subsistence-based to a sustained industry, the crop parameters including production and intensity have important role (Liu et al. 2021). One of the major challenges in Nepalese agriculture sector is to increase 50% yield per unit of land which can only be fulfilled through the improvement of cropping intensity and introducing high yielding hybrid varieties that subsequently demands more water. In another side, water availability in Nepalese farm continues to remain a barrier for production of cereals and horticultural commodities resulting millions dollars outgoing in food import (Chand et al. 2023). Despite huge potential of freshwater resources in Nepal, we are unable to transform our agriculture into a profitable and sustainable enterprise. For making agriculture more commercial, cost reduction including water, energy and nutrients should be made possible. Increasing irrigation efficiency makes farm operations more economically viable whereas conserving water saves money through reduced pumping cost. As agriculture is the base of Nepal, innovative and practical measures for higher productivity in irrigation including integrated crop-water management and exploration of new sources in irrigation has utmost importance. Mishra (2014) warned that food security issues will not be managed until water availability, water efficiency and efficacy in agriculture will be improved.

Nepal is an agrarian economy where the agriculture sector contributes around one-fourth of the national GDP. The majority of the farmers in Nepal are smallholders who rely on traditional rain-fed agriculture. Of the estimated 2.6 million hectares of arable land in Nepal, only 70% of it is irrigable, and 16 lakh ha is actually equipped with basic irrigation infrastructures (Department of Water Resources and Irrigation 2023). Most of the irrigated land in Nepal lies in the Tarai, where the topography is flat. Both surface water and groundwater are used for irrigation. Farmers who use groundwater rely on diesel pumps because grid electricity is not available everywhere. Irrigation using diesel pumps is both expensive and harmful to the environment. The agriculture sector (including irrigation) alone accounts for around 10.5% of the total diesel consumption in the country (Shrestha & Upreti 2021). Moreover, despite employing 64% of the population in the agriculture sector, Nepal is not self- sufficient in food and hence imports from other countries. Hence, making agriculture more productive and sustainable, the inputs of agricultural production including energy and irrigation services can contribute significantly.

The Government of Nepal has been supporting the promotion and development of Renewable Energy Technologies (RETs). To date, Nepal has approximately 1,600 solar irrigation projects (SIP), 75% of which have been financed and installed by Alternative Energy Promotion Centre (AEPC), and the remainder by a number of GOs, NGOs and INGOs such as IDE, ICIMOD, Winrock, and Practical Action (International Water Management Institute 2024). Until the start of the 13th Plan (2013-2016), the use of solar energy for irrigation and drinking water was limited to hilly and remote areas. The 13th Plan incorporated ideas for solar energy for irrigation in the Terai. In the 2018-19 budget, the central government allocated NPR 350 million (~USD 3.5 million) as grants for SIPs and pledged additional support to renewable energy production if initiated by cooperatives and local communities in collaboration with the local government. The 14th Plan initiated a subsidy for solar drinking water and irrigation systems at the individual, community, and institutional (i.e., private sector) levels. The AEPC is the main institution responsible for the implementation of the Renewable Energy Subsidy Policy, 2016. Guided by Renewable Energy Subsidy Policy (2016) and Subsidy Delivery Mechanism Guidelines (2016), Alternative Energy Promotion Center (AEPC), the government's nodal agency for renewable energy, started promoting SIPs in 2016 by providing a 60% subsidy. The majority of AEPC-subsidized SIPs are installed in the Tarai districts (Pandey et al., 2020). In addition to the AEPC, a number of government organizations including local municipalities, Agriculture Knowledge Centre (AKC), province level Agriculture Development

Directorate and Prime Minister Agriculture Modernization Project (PMAMP) are working to promote and implement SIP projects in Nepal.

1.2 Overall Aim, Objectives and Questions of the Study

In its 15th plan, National Planning Commission has defined Prime Minister Agriculture Modernization Project (PMAMP) as one of the game changer projects of Nepal Government. Ministry of Agriculture and Livestock Development has been implementing the PMAMP since fiscal year 2073/74. PMAMP is working throughout the country via four departments: pocket, block, zone and super zone. This project aims at self-reliant economy through modernization, specialization, mechanization and industrialization of the agriculture sector. Currently, the federal component of PMAMP has been implemented in 16 specialized agriculture production and industrial centers (Superzone) and 177 Commercial agriculture production and processing centers (Zone) in 77 districts of the country. Commercial agriculture production centers (Block) and agriculture production centers (Pocket) components of the projects are being implemented by provincial and local government. The project aims at implementing 21 super zones, 300 zones, 1500 blocks and 15000 pockets by the end of project by the end period of the project.

PMAMP is investing a significant amount of budget in construction, repair/maintenance and modernization under small irrigation program which includes development and commissioning of solar irrigation in technically suitable locations. Particularly, in mid-hill and Terai region of Nepal, solar-based lift irrigations are under operation. However, the systematic study about effectiveness, usage and sustainability of these solar projects has not been carried out yet. In this circumstance, this study has been undertaken to study solar projects established from economic and technical support of PMAMP. In addition, similar type solar lift irrigations established in PMAMP zone/ super zone area by other organizations have also been included in this study. The specific objectives of this study were to

a. Document and review solar irrigation projects in working area of PMAMP throughout the country,
b. Evaluate key effects of solar irrigation in agricultural production and productivity in study locations,
c. Examine the impacts of solar projects in gender issues, particularly focusing women farmers, d) explore the possibilities of converting solar energy tapped from panels into multipurpose agricultural operations,
d. Examine gaps and issues concerning economic and technical efficiency of solar irrigation projects, and thereby recommending suggestions and future courses

of action to be adopted by government for sustainability and profitability, and

e. Recommend generic guidelines for improved efficiency and application of solar irrigation in agricultural farm to sustainably manage the water-energy and climate inter-linkages.

As one of the strategies of PMAMP is promotion of climate-smart technologies in agriculture, the selected study is convergent with overall aim of the project. The findings of the study will contribute in agricultural production and water management via the sustained development of energy and water-smart solar projects. It is important to conduct systematic study of lift irrigation projects in plain as well as hilly region to minimize the constraints and make it cost-effective among farming communities. Huge energy costs, more frequent breakage and wear and tear of electro-mechanical components, and the unwillingness of the farmers to share the operation and management costs have been the key constraints to dependable irrigation services in the earlier developed lift irrigation schemes in Nepal (ADB 2016).

Study Questions:

1. What is the status of solar irrigation projects within PMAMP Zone and Super zone region?
2. What are the major effects of solar irrigation in agricultural production and productivity in selected locations?
3. How GESI issue is supported by solar irrigation in study locations?
4. Does it possible to make solar energy multifunctional for various agricultural unit operations?
5. Does it possible to recommend generic guidelines for sustainability of solar irrigation in agriculture sector?

1.3 Scope of the study

This study covered two topographical regions of Nepal: Terai and mid-hill under supoerzone and zone regions of PMAMP. The solar irrigation projects from FY 2073/74 were included for the study purpose. Major activities included:

a. Desk-top based literature review and selection of study areas
b. Questionnaire survey
c. Field observation
d. Focus group discussion
e. Key informants interview
f. Expert group consultation
g. Report writing and publication

2

LITERATURE REVIEW

2.1 Renewable Energy Technologies, Potential and Importance in Nepal

Different studies and literatures demonstrate that Nepal has tremendous potential of renewable and rural energy as it contains above 300 sunny days in a year. In the context of importing huge amount of diesel/petrol and gas from foreign countries, development and proper use of renewable energy in Nepal has paramount importance. Renewable Energy Technology (RET) is a synonym for new, renewable and non-conventional forms of energy i.e. the technologies, which use local energy resources (other than commercial fuels) and biomass fuel (firewood, agricultural residues and animal wastes) in traditional forms (Devkota 2007). The main sources of these alternatives are biomass, water, sun and air.

Biomass as a source of energy mainly consists of fuel wood, agricultural residue and animal dung. At present, the bulk of biomass energy comes from wood i.e. stem, branches, twigs, barks, saw dust and scrap of wood. Fuel wood and other biomass fuels are burnt in traditional stoves of various kinds. Agricultural residue can be converted into briquettes that burnt directly for energy purpose. Conversion of biomass technology into other efficient and convenient energy forms include biogas, improved cooking stoves, briquettes and gasifier.

Mini and micro- hydro technology has enormous potential to promote environmentally sound and sustainable development in the hills of Nepal. At present about 15 companies manufacture and install micro-hydro plants in Nepal. So far about 17 MW of both mechanical and electrical power has been generated from about 2410 micro-hydro plants including peltric sets. Most of these turbines are installed solely for agro processing. Some of the units are for rural electrification and some are also coupled with electric generators. Micro-hydro plant consists of civil and electro-mechanical components. Civil structure consists of intake, canal, desilting basin, forebay tank, support piers, anchor blocks and powerhouse. Similarly electrical components consist of generator, control panel, ballast heater, transmission distribution system, earthing, poles, stay sets, insulators and load limiting devices. Likewise, mechanical components of a micro-hydro scheme consist of penstock pipe, turbine, valve, drive system and expansion joints.

Wind is still one of the unharnessed energy sources in Nepal. Its countrywide potential has not been assessed yet. Some studies have indicated that wind potential for power generation is favorable in Tansen of Palpa, Lomangthang of Mustang and Khumbu regions of Nepal. However, wind monitoring and mapping data are not available for many places. Windmill consists of a turbine, blade, roater, pole and so on.

Solar energy is radiant light and heat from the sun that is harnessed using a range of technologies such as solar power to generate electricity, solar thermal energy (including solar water heating), and solar architecture. It is an essential source of renewable energy, and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power, and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible, and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming which advantages are global. The earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest, 122 PW, is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. Most of the world's population live in areas with insolation levels of 150–300 watts/m2, or 3.5–7.0 kWh/m2 per day. The total solar energy absorbed by earth's atmosphere, oceans and land masses is approximately 122 PW year which is equivalent to 3,850,000 exajoules (EJ) per year. In 2002 (2019), this was more energy in one hour (one hour and 25 minutes) than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass.

The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet because factors such as geography, time variation, cloud cover, and the land available to humans limit the amount of solar energy that we can acquire. In 2021, Carbon Tracker Initiative estimated the land area needed to generate all our energy from solar alone was 450,000 km2 — or about the same as the area of Sweden, or the area of Morocco, or the area of California (0.3% of the Earth's total land area). In 2023, solar power systems generated 5% of the world's electricity, compared to 1% in 2015, when the Paris Agreement to limit climate change was signed. Along with onshore wind, in most countries, the cheapest levelised cost of electricity for new installations is utility-scale solar. Almost half the solar power installed in 2022 was rooftop. Much more low-carbon power is needed for electrification and to limit climate change. The International Energy Agency said in 2022 that more effort was needed for grid integration and the mitigation of policy, regulation and financing challenges.

Solar technologies are categorized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on the distance from the Equator. Although solar energy refers primarily to the use of solar radiation for practical ends, all types of renewable energy, other than geothermal power and tidal power, are derived either directly or indirectly from the sun. Active solar techniques use photovoltaic, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful output. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternative resources and are generally considered demand-side technologies.

In 2000, the United Nations Development Programme, UN Department of Economic and Social Affairs, and World Energy Council published an estimate of the potential solar energy that could be used by humans each year. This took into account factors such as insolation, cloud cover, and the land that is usable by humans. It was stated that solar energy has a global potential of 1,600 to 49,800 exajoules (4.4×1014 to 1.4×1016 kWh) per year.

In Nepal, Utilization of solar energy using modern equipment began in the early seventies through the introduction of domestic solar water heaters. Solar photovoltaic (PV) is not a new technology to Nepal. During 1981 solar cookers and dryers were also developed and propagated for some time in the country. The development of modern solar energy technology in Nepal is gradually growing up. Uses of solar energy is constantly increasing due to the growing scarcity of other sources of energy and increased awareness among the people. Mainly, two types of solar energy technologies (solar thermal and solar photovoltaic systems) are available in the country. Solar thermal systems include solar water heaters, solar dryers, and solar cookers. Similarly solar PV systems include solar communication systems, solar electrification systems, and solar pumping systems.

Devkota (2007) has stated the importance of RETs as:

"Renewable Energy Technology can play the role of a catalyst in rural development by providing a modern form of energy. Micro-hydro installation both at individual and community levels has contributed to the local economy; institution building and dissemination of skills and setting industrial enterprises. Similarly, uses of biogas reduce fuel wood and kerosene consumption. Likewise, agricultural productivity has increased with the application of slurry. Due to toilet attachment to most of the biogas plants it can be said that awareness among the local people regarding their health and sanitation has increased. Wind and solar are considered as clean energy and are all environment friendly. Thus, renewable energy is a clean fuel and its uses for cooking and lighting reduce the pollution and health hazards associated with fuel wood and kerosene. Solar energy technology helps in reducing the cost of electricity or otherwise for water heating. Hence the importance / advantages of RETs on rural development are of many folds. These include:

- Help in reducing the drudgery of rural population;
- Provide better cooking and lighting environment especially to rural women;
- Save foreign currency by substituting imported fuel;
- Improve health and living conditions;
- Reduce greenhouse gas emissions;
- Have potentials to create rural employment and to increase agricultural productivity; and
- Contribute towards the sustainable economic development of the country

Also, in case of environmental impact: When the potentials of the biogas plants are explored there will be substantial increases in the forest cover. Use of night soil in toilet attached plants help in environmental sanitation. Similarly, micro-hydro brings changes in the natural environment such as change in hydrological regime of the stream; vegetation clearing activates, soil erosion and landslides. Solar PV systems are associated with lead acid battery, the disposal of which is a serious environmental concern. However, solar dryers minimize the uses of firewood and kerosene. Wind energy is a clean energy but creates noise; further research should be carried out in making wind energy more environmentally friendly".

Agriculture sector seek to optimize the capture of solar energy to optimize the productivity of plants. Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows and the mixing of plant varieties can improve crop yields. While sunlight is generally considered a plentiful resource, the exceptions highlight the importance of solar energy to agriculture. During the short growing seasons of the Little Ice Age, French and English farmers employed fruit walls to maximize the collection of solar energy. These walls acted as thermal masses and accelerated ripening by keeping plants warm. Early fruit walls were built perpendicular to the ground and facing south, but over time, sloping walls were developed to make better use of sunlight. In 1699, Nicolas Fatio de Duillier even suggested using a tracking mechanism which could pivot to follow the Sun.

Applications of solar energy in agriculture aside from growing crops include pumping water, drying crops, brooding chicks and drying chicken manure. More recently the technology has been embraced by vintners, who use the energy generated by solar panels to power grape presses. Greenhouse convert solar light to heat, enabling year-round production and the growth (in enclosed environments) of specialty crops and other plants not naturally suited to the local climate. Primitive greenhouses were first used during Roman times to produce cucumbers year-round for the Roman emperor Tiberius. The first modern greenhouses were built in Europe in the 16th century to keep exotic plants brought back from explorations abroad. Greenhouses remain an important part of horticulture today. Plastic transparent materials have also been used to similar effect in poly tunnels and row covers.

2.2 Agricultural Water Management in Access and Food Security

Water is a valuable resource and is fundamental for human life, the economy and the natural environment (Valipour 2015; Du et al. 2018). It is estimated that 57% largest aquifers in world have been seriously overexploited, as water consumption is increasing by 1% every year (Garcia-Caparros et al. 2017). Projections for future population and consumption trends indicated that demand for water of enough quantity and good quality for various uses will present serious problems into the future (Montenegro et al. 2010; Giuliani et al. 2018). Drivers including urbanization, population growth and industrialization, and corresponding increases in the demand for food, energy and environmental sustainability have seriously impacted the existing water planning, management and allocation processes (Biswas &Tortajada 2009; Hooshmand et al. 2019). The 2030 Agenda of the United Nations was approved in 2015, consisting of 17 sustainable development goals, with overall aim to “End hunger, achieve food security, and promote sustainable agriculture” (Duque-Acevedo et al. 2020).

The water bodies are regarded as the strategic catalysts for development and life of any nation (Chand et al. 2023) and hence, water is becoming a national security issue for powerful countries. Availability of water indorse food production and nutrition, urban development and industrialization, income generation and livelihood, and human health and hygiene. Food security is the first priority of every government in which water plays a detrimental role. The World Food Summit (1996) defined food security as “when all people , at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs for a productive and healthy life”. The country having enough water means it has secured the future which is directly associated with national security. one of the UN general secretaries and many other scholars and pointed that due to geo-hydro politics, the conflict between states and countries is inevitable in future (Hossain et al. 2023) which indicates that water is directly/ or indirectly related to the national security.

In a global context, the FAO (2019) believes that there is a world food shortage which can only be alleviated if agricultural productivity can be increased in significant and sustainable fashion via expansion of irrigation coverage and improvements in water management. Agriculture consumes almost 70% of the global freshwater withdrawals, however, in many areas of the world, municipal, industry and environment sectors putting pressure to constrain the share of water in irrigation (Chand et al. 2023). In such situations, food security is only possible if a) the current productivity level of agricultural water is improved and, b) introduction of new and non-conventional sources of water and drought-resistant crop varieties come into sustainable practice (Hashem et al. 2018). In recent years, agricultural farms throughout the world have been subjected to increasing water constraints. Major droughts in Chile and the US have affected crop production while diminishing surface and groundwater reserves.

In the drum of global available water, less than 3% is freshwater and nearly 1% of that is readily available (NASA 2023). The annual renewable water resources throughout the world amount to nearly 50,000 km^3 and currently 70% of the available freshwater is being used (IWA 2023) where rule is rate of water use should be maintained at a lower than the renewable rate for sustainability. Also, climate change is becoming a threat putting pressure on water, its quantitative availability and quality for nature-positive agriculture/ economic development (Khatun *et al.* 2022). One of the global problems in irrigation water is repair, maintenance and modernization of the old infrastructures which needs huge financial investment (Prasad 2014). In this context, private sector participation could be one of the approaches to help achieving UN targets in water-SDGs (Root 2020). The PPP concept in the water was initiated from the French historical model of public service delegation and currently it serves water to 5% of the world's population, and private financing in WATSAN accounts for 10% of the sector's total investment (Koumpli & Kanakoudis 2022). Undoubtedly, developing countries throughout the world including Nepal are giving priority to PPP in their sectorial policy of water (irrigation, hydropower, drinking water and environment). The World Water Council's Vision 2025 assumes that around USD 3000 billion needs to be invested over a 25-year period in water sector which anticipated 70% private sector's contribution to meet the target.

Seven out of 17 SDGs (1, 2, 3, 6, 13, 15, and 17) of UN Agenda 2030 are directly or indirectly related to water which are forcing us to conclude that water is the key factor for the economic prosperity because any developmental activities demands water as a main component of hardware. It is said that earth contains enough water for living being but there is water insufficiency, primarily due to mismanagement, bureaucratic inertia and limited financial and human resources. Water is an indispensable ingredient to agricultural production and without water, growers would not be able to produce crops and feed their animals. Therefore water insecurity reflects food insecurity. A shift towards more nutritious and healthier diets will have repercussion on water consumption that cannot be ignored. Some of the healthy food we need, particularly fruits and vegetables, requires a sufficient amount of good quality water to be produced. Government policies need to tackle water risks to make water available for food production and to ensure that agricultural production does not pollute water sources. Also, the current and the foreseeable trend indicates that water problems will continue to become increasingly complex and more intertwined among competitors. So, these authors believe that water should not be viewed in isolation by one organization which demands IWRM strategy, applying knowledge from various stakeholders to devise and implement efficient, equitable and sustainable solutions to improve water productivity. In such condition only, a balance can be established between personal and economic needs which not only ensures the sustainability of ecosystems but also helps achieving the slogan of FAO 2023: “water is life, water is food. Leave no one behind”.

2.3 Issues and Challenges in Agricultural Irrigation Sector of Nepal

Irrigation is defined as the manipulation of soil moisture content (SMC) to achieve desired plant responses that can be fulfilled through application of the right volume of water,at the right time,and delivered by the right method (Davies et al. 2002; Meron 2007; Scherer 2017). Irrigation influences many important processes essential for crop growth, including soil organic matter decomposition, microbial activity, soil aeration and nutrient turnover (Huang et al. 2007; Scheer et al. 2013). However, globally the level of irrigation services provided to date has not been very successful because of poor irrigation efficiency and haphazard agricultural water management (Corcoles et al. 2012; Jha et al. 2017; Lu et al. 2019). Lovelli et al. (2017) identified the following three key reasons necessary to improve agricultural water productivity: a) sustainability in use of environmental resources, b) food security, and c) grower’s income increment due to judicial use of water. In the view of increasing water demand by other sectors, and expected reduction of water availability in the future, it is necessary to adopt water management strategies aimed at water saving while maintaining satisfactory levels of production (Costa et al. 2007; Montesano et al. 2015).

Irrigation is the strategy of artificial water supply to maximize crop production and improve resilience against climate change which is generally achieved by applying an appropriate volume of water at the right time and delivered by the right application method (Das *et al.*, 2018, Gao *et al.*, 2023; Koo-Oshima 2023). The spatial and temporal variability in rainfall and on-farm water shortage calls for the development of irrigation to feed the increasing population of the world (Allamine *et al.*, 2023;

Dantas *et al.*, 2023). Water use within crop production system accounts for almost 70 to 80% of global water withdrawals and efficient irrigation is critical for managing scarce water resources (Dhungel *et al.*, 2023; ICID 2023). However, the irrigation services provided throughout the world have not achieved the targeted objective of agricultural productivity despite huge investments in irrigation projects has been made (Chand *et al.,* 2023). The economic return per unit of water from the agricultural sector is less compared to service and manufacturing industries indicating the judicial and economic use of water from the planning to implementation stage (Corcoles *et al.,* 2012; Chand *et al.*, 2021). The reasons of acquiring less irrigation water productivity could be technical, socio-economic and/or managerial.

The irrigation in Nepal is broadly divided into two geographical regions: a) irrigation in plains/ flat regions, and b) hill irrigation (Pradhan & Belbase 2018). The hill irrigation system taps water from small streams/ rivers and consists of narrow, deep, and long canals with steep slopes or lift irrigation projects (Gautam et al., 2016; Dhakal et al., 2018). The lift irrigation system in the mid hills of Nepal has been identified as one of the high-priority projects for social and economic transformation (ADB 2016). The design constraints in hill irrigation systems are different from those in the plains. Typically, a sufficient hydraulic head is available in hill irrigation, and losses through structures can be tolerated (Gautam 2012). Steeper gradients in the canal are possible, allowing for a smaller cross-section.

Constructing large irrigation schemes takes a huge amount of resources and a long time, but a distributed energy approach with local pumping using hydropower and solar power irrigation schemes could provide immediate benefits. Three major energy options for powering farmer-led irrigation exist in Nepal – diesel, electric grid, and solar – each with its limits and opportunities. Around 80% of shallow tube wells are powered by diesel pumps (Nepal et al., 2019). Nepal has a solar potential of 50,000 terawatt-hours per year, which is 7,000 times more than the country's current energy consumption and 100 times larger than its hydro resource (AEPC, 2021). All of Nepal's future energy needs can be easily met by solar. Today, switching to higher-value crops and altering the subsistence and smallholder farmers' means of sustenance have made solar power a necessity. Nepal has already installed 1,600 solar irrigation systems throughout the nation as of August 2019, totaling eight million dollars (AEPC, 2021). Since investment and construction of lift irrigation schemes are increasing demand for new technology to provide irrigation to agricultural land has been rising where there is unsuitability of surface irrigation. Thus, the evaluation of constructed lift irrigation seems imperative.

Development of irrigation is a complex socio-technical phenomenon. Despite considerable investments in infrastructure development & a well-trained cadre of technicians, the public sector irrigation schemes have been performing below expectations. The irrigation efficiency is around 30%, the crop productivity is stagnant or declining & the problem of system management still remains a challenging job.

Some key issues (Constraints) in the irrigation sector of Nepal can be summarized as:

1. Reorientation of the supply-driven approach
2. Poor performance of irrigation schemes
3. Farmer's dependency syndromes
4. Sustainability of irrigation structures
5. Problems of river management
6. Weak institutional capability
7. Legal status of WUA & clarity of their roles & responsibilities
8. Symbiotic relationship between line agencies (Department of Agriculture and Irrigation)
9. Appropriate water sector planning
10. Urbanization of irrigated agricultural area & industrial problem
11. Resolution of disputes between the riparian countries
12. Effective transformation of policy to field level
13. Stringent covenant associated with donor's loan agreement
14. Skewed land distributions with very small land holdings

Challenges in irrigation development

Despite considerable investments in infrastructure development & a well-trained cadre of technicians, the public sector irrigation schemes have been performing below expectations. The irrigation efficiency is around 30 %, the crop productivity is stagnant or declining & the problem of system management still remains a challenging job.

The reasons are of several folds, which are discussed below:

1. Lack of clear-cut guideline in both the policy & implementation defining irrigation

   There is lack of clear-cut guideline in either the policy & implementation defining whether irrigation water is a social or an economic good. Although the policy hints that irrigation water is an economic good, neither there are mechanisms for collecting water taxes from the users, nor there exist any legal enforcement for this. As a result, irrigation water has been treated as a social good in practice. This policy dilemma has hampered effective maintenance of irrigation systems, which in turn hampering irrigation services to farmers.

2. Non-availability of water during lean period

   Most of the surface irrigation systems in Nepal are fed by medium or small rivers, with limited water resources available during the lean season insufficient for year-round irrigation. Development of year-round irrigation through these systems is not possible unless storage reservoirs are developed.

3. Resource constraints to develop irrigation systems

   Although Nepal has ample opportunities in developing year-round irrigation by utilizing water either from major river systems or through inter-basin transfer, actualization of such projects in Nepal has remained so far. Many of these river systems need to be developed as multipurpose projects. Sunkoshi-Kamala Diverison, Bheri-Babai Diversion, Kankai& West Rapti Projects are some of the identified projects of this kind. Despite these opportunities, many of the donors are reluctant to fund these projects due to riparian concerns. Large amount of resources is required to develop such projects combined with long gestation period add another constraint in the process.

4. Unsatisfactory people's participation in sharing capital cost of irrigation infrastructure

   People's participation has remained one of the key policy tools in the development of country's irrigated agriculture. Nepal's irrigation policy demand people's participation in planning, design & also in sharing capital cost for infrastructure development. However, past experiences show that people's participation in sharing capital cost in infrastructure development has not been satisfactory. As poverty alleviation has remained one of the national goal of irrigation development, raising a part of capital cost from the local community who already live below the poverty line does not seem socially justifiable.

5. Removal of subsidy on development of shallow tube well (STW)

   APP emphasizes development of groundwater (GW) for year round irrigation, especially in Terai. Despite great effort in this line, the GW development has not been satisfactory. The reasons are 2 folds. First, removal of subsidy on development of GW might have de-accelerated the demand for tube wells. Second, the high operating cost of TW mainly due to price hike of diesel & electricity has made the farmers reluctant for its development.

   In order to minimize the operating cost of TW, GW needs to be developed along with the present surface irrigation systems by utilizing the existing infrastructures & institutions. By doing so, the operating cost of TW could be reduced to a level acceptable to farmers, & at the same time year-round irrigation can be assured.

Policy-level Major Challenges

1. Lack of clear-cut guideline in both the policy & implementation defining whether irrigation water is a social or an economic good
2. No extensive development in the past 3 decades; improving existing systems emphasized.
3. Donors not interested in perennial streams & extensive irrigation
4. APP emphasized GW use

   APP is unable to achieve its GW irrigation target. Analyses show that a tube well irrigation project generally becomes economically viable only if the TW runs more than 1800 hours per year, whereas present utilization rate of the TWs is in the range of 200 to 400 hours per year. It seems that planners have ignored the fact that farmers would run a TW only when no alternative is available. Withdrawal of subsidy from the STW irrigation has also drastically slowed down the progress of STW, though it is another debatable issue as to whether or no subsidy is to be provided.
5. Fragmentation is in rise.

   Land consolidation is emphasized by the irrigation policy, but there is no sign of its implementation. In fact, land consolidation is costly as well as complicated & it is very difficult in current social & political environment.

2.4 Solar Lift Irrigation in Nepal

Agriculture makes up 2% of the national energy consumption. Diesel is the most relied upon fuel at 90.9% of the fuel mix, other fuels being electricity (7.4%), Petrol (1.4%), followed by solar as 0.3% (Energy Sector Synopsis Report 2021/2022, WECS). Lamsal (2024) states the status of solar lift irrigation as:

"The first solar-powered pumping system in Nepal, a 4KW system, was constructed at Sundharighat, Kathmandu, in 1993. In the following years, a few bigger Solar irrigation pump (SIP) schemes of 40-60kWp were constructed, but adoption was limited. Several isolated initiatives deployed SIPs using Government of Nepal (GoN) subsidies or development partner incentives. Solar-powered pumps surfaced as a promising option for drinking water and irrigation in rural Nepal in 2015. Because of the decentralized nature of the technology, it was great for reaching farmers who did not have grid connections. Winrock International conducted the USAID Accelerated Commercialization Solar Photovoltaic Water Pumping (AC-PVWP) three-year initiative in 2015 to enhance PVWP commercialization and acceptance (Foster et al., 2017). This project was implemented in two phases in the first phase, 69 PVWP schemes were piloted in 16 districts with a combined capacity of 53.15kWp benefiting 392 farmer groups. An additional 120 schemes were installed in the second phase in 2017 (Shrestha & Uprety, 2021).

In 2016, AEPC began marketing SIPs by the Renewable Energy Subsidy Policy 2016 and the Subsidy Delivery Mechanism Guidelines 2016. Since then, there has been a high demand for SIPs, particularly in Nepal's Terai area. AEPC has already deployed over 1900 subsidized SIPs, with AEPC providing 60% of the subsidy and farmers paying the remainder. AEPC received demand several times the number of SIPs it was able to award, demonstrating that there is significant unmet demand, particularly in the Terai. According to the 15th periodic plan, the GoN intends to boost SIPs to around 6500 cumulative installations through AEPC from 2021 to 2024 (NPC, 2020). Although regulatory efforts are increasing demand for solar irrigation pumps (SIPs), diesel and grid-connected electric pumps continue to dominate the market. Due to greater running costs, unpredictable fuel supply, and environmental unfriendliness, diesel pumps are the least sustainable technology. SIP and grid-connected electric pumps, on the other hand, are regarded as the most environmentally friendly technology in Nepal (Dhital et al., 2014).

The largest lift irrigation schemes established in Nepal are the Narayani, Marchwar, Battar, and Western Koshi Pump Canal. Many small to medium-lift irrigation schemes are currently in operation as part of the Medium Irrigation Project and the New Irrigation Technology Project (NITP). A total of 451 numbers of NITP schemes have been constructed irrigating 5478 ha of land (DWRI, 2019). By using groundwater, the Bheri Corridor Irrigation Development Project (BCIDP) has completed 27 solar lift irrigation projects. Among the 195 identified BCIDP pumped schemes, it is recommended that 149 be powered by solar panels and 46 be powered by electricity (BBDMP, 2022). The Integrated Energy and Irrigation Special Program (IEISP) has prepared six lift irrigation master plans of different river basins (Arun Tamor, Trishuli, Sunkoshi Tamakoshi, Karnali, Madi Jhimrukh and Indrawoti in which it has identified more than thousands of lift irrigation Schemes and has completed more than 15 solar lift irrigation projects with head ranges from 50 to 150 m, command area ranges from 10 ha to 50 ha, and irrigates more than 200 ha area (IEISP, 2022)".

2.5 Solar or Electric-based Irrigation Pumps vs Diesel Pumps in Agriculture

In Nepalese farm, growers are using all three options: solar/electric and diesel pumps for irrigation purposes. Shrestha and Neupane (2023) have studied about solar or electric-based irrigation pump and compared those with diesel pumps for sustainable groundwater irrigation in Nepal Terai and stated that:

"Nepal Terai contains nearly 16 lakh ha of cultivated land, of which 60% received irrigation from the surface, groundwater, and conjunctive uses (Nepal et al., 2021) focusing on pathways to water security that originate in actions and policies related to other sectors. It identifies promoting development of Nepal's hydropower potential to provide energy for pumping as way to improve water security in agriculture. Renewable groundwater of Nepal reserves of 1.4 Billion Cubic Meters (BCM). Around 18% of the irrigable land in the Tarai region utilizes groundwater for irrigation. There is still another 600,000 ha of land in the region, which is the potential for groundwater irrigation. Diesel Pumps have been used for irrigation in the region since the 1970s (ADB, 2013). However, the real intensification of diesel pumps began with the implementation of the Agriculture Perspective Plan (APP) in 1995 (Nepal & Thapa, 2009). There were 120,000 pump sets in Nepal in 2010, and more than 80% were considered diesel pumps (Justice & Biggs 2013). Nepal is adding 4,000 pumps each year, considering a linear growth rate (Foster et al., 2021) levels of groundwater use and access in the EIGP lag far behind other areas of South Asia despite abundant available groundwater resources. A key reason for prevailing access constraints is the dependence on diesel pump sets for accessing groundwater, which are typically unsubsidized and therefore expensive to purchase and operate. To date, efforts to reduce access costs have focused almost exclusively on how to incentivize adoption of alternative electric or solar-powered pumping technologies, which are viewed as being cheaper to operate and less environmentally damaging due to their lower operational carbon emissions. In contrast, there has been little attention paid to identifying opportunities to make existing diesel pump systems more cost effective for farmers to operate in order to support adaptation to climate change and reduce poverty".

In their study, Shrestha and Neupane (2023) used evidence from 116 detailed in-situ pump tests along with interviews with pump set dealers, mechanics and farmers in the Nepal Terai to assess how and why fuel efficiency and operational costs of diesel pump irrigation are affected by farmers' pump set selection decisions. They claimed that costs of diesel pump set in agriculture could be reduced significantly by supporting and incentivizing farmers. Table 1 indicates the choices of irrigation technologies and their economic and environmental implications (Shrestha & Neupane 2023). In addition to low installation costs, diesel pumps have several drawbacks, such as high operating costs, environmental pollution, and dependence on fossil fuels (Table 1). Solar Irrigation Pumps (SIPs) and Electric Pumps (EPs) are emerging as climate-resilient technology for pumped irrigation around the world. These pumps also can be an alternative to diesel pumps (DPs) for sustainable groundwater irrigation development and increased productivity in Nepal. According to Sarkar & Ghosh (2017), the optimal conditions for solar photovoltaic (PV found that replacing a single 1 kW diesel pump with a solar PV pump in Bangladesh has a net annual GHG reduction of 0.9 t CO_2.

Table 1: Irrigation technologies and their economic and environmental implications (Shrestha & Neupane 2023)

Technology	Precondition for the pumps	Potential economic and environmental Implications				
		GW exploitation	Emission	Upfront Cost	O&M Cost	Farm yield / income
SIP	Hour of solar radiation	Medium	No	High	Low	Medium to High
EP	Grid connectivity	Medium	Low	Medium	Medium	Medium to High
DP	Diesel availability	Low	High	Medium	High	Low to medium

Diesel pump is still predominantly used as a source of energy for groundwater irrigation in the plain area of Nepal, which is a major source of GHG emission in agriculture. Recently farmers started adopting SIPs and EPs due to the enabling policy environment and the initiation taken by the federal and provincial governments, Development partners, NGOs, and private sectors. A previous studies have indicated that SIP intervention significantly reduced diesel consumption in the agriculture sector of Nepal. However, diesel use was not completely reduced to zero, even with access to SIP. The best result is seen with the farmers with access to SIPs and EPs. It also infers that solar and electric-based irrigation pumps complement each other to address the GHG emission in the agriculture sector of Nepal. Since SIP has no operational costs and EP tariffs are heavily subsidized, there are concerns about over-abstraction. In their study 37% of the farmers from au sample had access to both SIP and EPs (Shrestha & Neupane 2023) which provides an opportunity for grid-connected solar irrigation allowing farmers to sell surplus solar energy to the grid. This incentivizes growers with secondary income opportunities and provides an incentive not to overuse ground water resources. SIPs and EPs in combination reduce diesel consumption and have the potential to regulate groundwater over-extraction. Therefore, the Government's future policy strategy should enhance access to SIP and EP together rather than promoting one technology in isolation. Their study recommends further analysis for quantifying GHG emissions in DPs and associated environmental costs, which gives a solid basis for subsidizing SIP and electricity tariffs for energy meters in agriculture purposes.

2.6 Grid Connected Solar System

A grid-connected photovoltaic (PV) system, also known as a grid-tied or on-grid solar system, is a renewable energy system that generates electricity using solar panels. The generated electricity is used to power homes and businesses, and any excess energy can be fed back into the electrical grid. Also, a grid-connected system allows you to power your home or small business with renewable energy during those periods (daily as well as seasonally) when the sun is shining, the water is running, or the wind is blowing. Any excess electricity you produce is fed back into the grid. Being grid-tied is beneficial because you don't have to buy an expensive battery back-up system to store any excess energy. Being off-grid means you are not connected in any way to your grid's power system or utility company. This is appealing because you are 100% self-sustaining your energy use. The main objectives of grid connected PV systems are to minimize distribution network losses, reduce node voltage offset, and lower access costs for the location and capacity of photovoltaic power supply.

Cost of an On-grid solar system is lower than other types of solar systems because there are no batteries. It also generates the highest amount of power compared to other types of solar systems. The minimal maintenance and reduction in monthly power bills ensure the customer gets an ROI of 25 – 30%. However, if the grid goes down, your system will shut off, leaving you without power. This is required to prevent energy from back feeding into the grid to keep utility workers safe. Also, the grid connection brings problems of voltage fluctuations and harmonic distortion.

The working principle of grid connected Solar PV system: The solar panels, installed on the user's home are 'tied' to the grid. The solar panels convert sunlight into electric energy, which is Direct Current (DC). This current is then sent to an inverter. The solar inverter then converts the DC to Alternating Current (AC), thus making it power the electrical items.

Solar powered PV systems can sometimes produce more electricity than is actually needed or consumed, especially during the long hot summer months. This extra or surplus electricity is either stored in batteries or as in most grid connected PV systems, fed directly back into the electrical grid network. In other words, homes and buildings that use a grid connected PV system can use a portion or all of their energy needs with solar energy, and still use power from the normal electrical mains grid during the night or on cloudy dull and rainy days, giving the best of both worlds. Then in grid connected PV systems, electricity flows back-and-forth to and from the mains grid according to sunlight conditions and the actual electrical demand at that time. The main advantage of a grid connected PV system is its simplicity, relatively low operating and maintenance costs as well as reduced electricity bills. The disadvantage however is that a sufficient number of solar panels need to be installed to generate the required amount of excess power. Since grid tied systems feed their solar energy directly back into the grid, expensive back-up batteries are not necessary and can be omitted from most grid connected designs. Also, as this type of PV system is permanently connected to the grid, solar energy consumption and solar panel sizing calculations are not required, giving a large range of options allowing for a system as small as 1.0kWh on the roof to help reduce your electricity bills, or a much larger floor mounted array that is large enough to virtually eliminate your electricity bills completely.

When installing a PV system, if net metering is available by your local electricity company, you may be required to install a new second electrical meter instead of using a single electricity meter that spins in both directions. This new meter allows for a measurement of net energy consumption, both entering and leaving the system and would be used to reduce your electricity bill. However, each electrical utility company has its own policy regarding the buying back of energy generated by your own small solar power station. While net metering is the ideal way to resell your solar generated excess power, some companies buy-back energy at a lower wholesale rate than the electricity you consume from the same power company. This means that you may need to generate more solar power than you would normally consume just to break even.

Grid connected PV systems always have a connection to the public electricity grid via a suitable inverter because a photovoltaic panel or array (multiple PV panels) only deliver DC power. As well as the solar panels, the additional components that make up a grid connected PV system compared to a standalone PV system are:

Inverter – The inverter is the most important part of any grid connected system. The inverter extracts as much DC (direct current) electricity as possible from the PV array and converts it into clean mains AC (alternating current) electricity at the right voltage and frequency for feeding into the grid or for supplying domestic loads.

It is important to choose the best quality invertor possible for the budget allowed as the main considerations in grid connected inverter choice are: *Power* – Maximum high and low voltage power the inverter can handle and *Efficiency* – How efficiently does the inverter convert solar power to AC power.

Electricity Meter - The electricity meter also called a Kilowatt hour (kWh) meter is used to record the flow of electricity to and from the grid. Twin kWh meters can be used, one to indicate the electrical energy being consumed and the other to record the solar electricity being sent to the grid. A single bidirectional kWh meter can also be used to indicate the net amount of electricity taken from the grid. A grid connected PV system will slow down or halt the aluminum disc in the electric meter and may cause it to spin backwards. This is generally referred to as *net metering*.

AC Breaker Panel and Fuses – The breaker panel or fuse box is the normal type of fuse box provided with a domestic electricity supply and installation with the exception of additional breakers for inverters and/or filter connections.

Safety Switches and Cabling – A photovoltaic array will always produce a voltage output in sunlight so it must be possible to disconnect it from the inverter for maintenance or testing. Isolator switches rated for the maximum DC voltage and current of the array and inverter safety switches must be provided separately with easy access to disconnect the system. Other safety features demanded by the electrical company may include earthing and fuses. The electrical cables used to connect the various components must also be correctly rated and sized.

The Electricity Grid – Finally the electricity grid itself to connect too, because without the utility grid it is not a Grid Connected PV System.

Shisher Shrestha made a virtual presentation in the Asia Sector-specific Meet (Sustainable Agriculture and Food Security) on March 31, 2023. Titled Opportunities and Challenges for Grid-connected Solar Irrigation in Nepal – Lessons from SoLAR Pilot Project, he highlighted the emissions due to diesel irrigation pumps and mentioned the findings that diesel pump consumes 13,870 m3 (kl). Shrestha presented the summary of findings from the impact evaluation studies conducted as part of the SoLAR-SA project. The evaluation study found that the impacts were mostly positive for SIP farmers since there was a strong reduction in the use of diesel pumps for SIP farmers compared to non-SIP farmers; SIP owners tend to devote more land to vegetables and SIP farmers earn 10% more revenue compared to non-SIP farmers. The presentation focused on opportunities that exist for grid-connected Solar irrigation – a) reduces e-waste by utilizing out-of-warranty and abandoned systems b) is a dual source of clean energy for improved irrigation for farmers c) improved Capacity Utilization of SIPs d) potential to increase energy consumption in the agriculture sector for NEA d) localized generation from Solar will improve the grid voltage, reduce strain on the grid's infrastructure and minimize transmission loss. The hurdles for implementing the grid-connected solar irrigation pilot were identified so the implementation process is not clear; and, there is a lack of policy for grid-connected solar irrigation, hence, awareness and capacity-building is needed at the local level (LG and NEA), etc. Also, no clear-cut direction on who should lead the implementation of grid-connected SIP projects – NEA, AEPC, Local government or the Farmer User Group – is there.

2.7 Major Barriers in Scaling Solar Irrigation in Nepal and Solution

Practical Action (2023) has pointed 10 major barriers for scaling solar based irrigation system in Nepalese farm. They are:

a. Technological knowledge and understanding

b. Awareness about climate change and its impact on water resources
c. Prioritisation
d. Lack of demonstrated business case
e. Lack of easy availability of solar technology
f. Lack of availability of skilled persons at local levels
g. Lack of awareness about financial support
h. Lack of business linkage and networking with service providers
i. Lack of capacity among civil society organisations
j. High instalment and maintenance costs

To overcome these challenges and barriers, at first, we must increase awareness of local governments, institutions and communities about benefits of this technology, subsidies offered by the government and showcase good practice to all stakeholders to encourage adoption of the technology. To do that, local authorities, local not-for-profit and private sector organisations and farmers need to be involved in the entire process – from demand identification to construction, supervision, monitoring, and preparation of water management plan.

With solar pump, farmers get access to a reliable and cost-effective irrigation solution. Proper irrigation promotes healthier plant growth, leading to higher-quality produce and increased harvests. Moreover, the transition to solar pumps promotes sustainable farming practices and reduces the effect of carbon emissions on the crops and the environment. In addition, these systems are integrated with smart IoT device like "Krishi Meter' which records real-time farm data, helps farmers optimize their farm operations and enhance productivity. Essentially, solar-powered water pumps work by converting the sun's rays (photons) to electricity that will operate the water pump. It uses solar panels to collect the photons (units of light) from sunlight, producing the direct current (DC) that provides the energy for the motor to pump water out from its source. In another words, solar irrigation system works when the pumps used for transporting the water are equipped with solar cells. Here, the solar energy absorbed by the cells is converted into electrical energy that then feeds an electric motor driving the pump. Also, when the sun shines onto a solar panel, energy from the sunlight is absorbed by the PV cells in the panel. This energy creates electrical charges that move in response to an internal electrical field in the cell, causing electricity to flow.

3 METHODOLOGY SECTION

3.1 Sample Area and Size of Sampling

The project has targeted to include the study area from different agroecological zone of Nepal (Fig. 3.1) to know the conceptual variation among the solar energy users of Terai, Mid-hill and High-hill in utilizing the solar lift irrigation technology. The study pursues to understand that, from which region and what kind of perception the solar lift irrigation user has. As explained in the objective of this study, we have targeted to study the current status of existing solar lift irrigation and how the user are exploring the technology in the field of agriculture. Do the users are aware about the multiple use of solar energy and are they applying their knowledge to get multiple benefit from the same solar panel using for the lifting water or not. Also, the physical observation sampling study could make us understanding about the existing capacity of the solar system, their edge of application and real demand as well as future possibilities in making it multiple use in the field of agriculture sector.

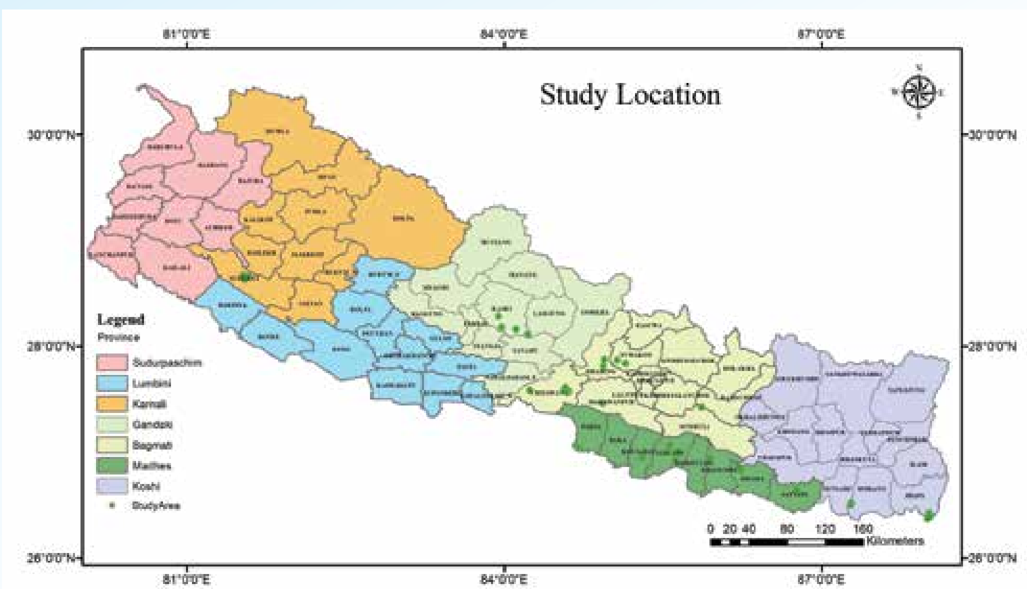


Fig. 3.1 Location of Study Area Representing the Province and Different Agro-ecological Zone of Nepal

To achieve this target, total 30 number of randomly selected site with the coordination of PMAMP, unit in-charge of different districts. The sampling within the sampling area was carried out using a multi-stage sampling method.

In which, the first stage of sampling carried in Madhesh Province at Sarlahi, Dhanusha, Siraha, Saptari, Rautahat and Parsa district. The second phase of sampling was conducted in Gandaki Province at Pokhara of Kaski and Lamjung district. Similarly, in the successive phase of sampling was planned to conduct at Ramechhap, Sindhupalchowk and Chitwan district of Bagmati province, likewise, Jhapa and Morang district of Koshi Province. The sampled area is shown in fig 3.1 pointing the exact location of study area whereas the expanded image of the study area shown in the figure 3.1 (a), 3.1 (b) and so on successively. Also, annex II, illustrate the details with latitude, longitude and elevation of the site location. The sampling size were selected based on the characteristic of different agro-ecological zone.

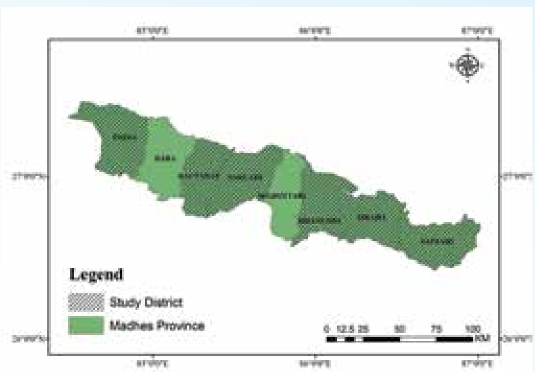


Fig. 3.1 (a) Madhesh Province Study Area

Fig. 3.1 (b) Gandaki Province Study Area

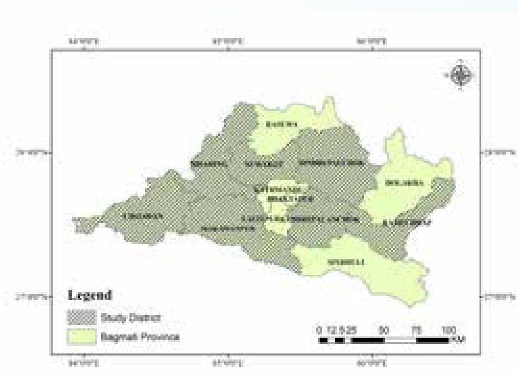


Fig. 3.1 (c) Bagmati Province Study Area

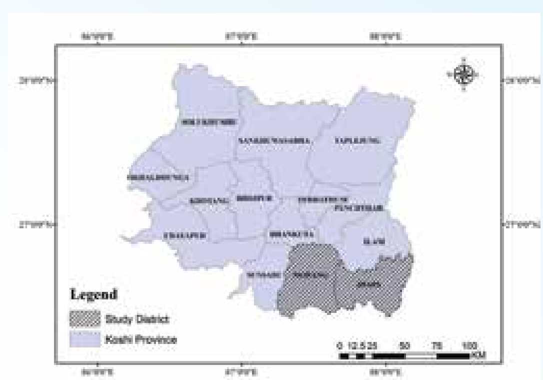


Fig. 3.1 (d) Koshi Province Study Area

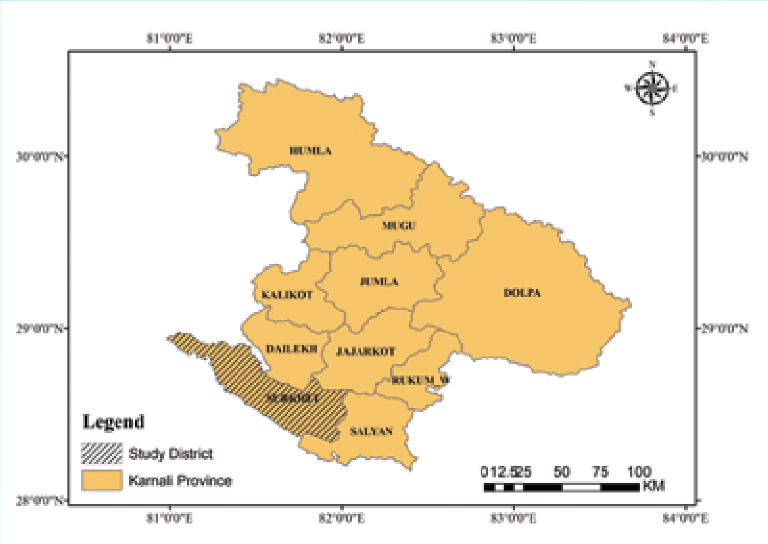


Fig 3.1 (e) Karnali Province Study Area

3.2 Tools Developments

Observation checklist was developed to attain quantitative data on the studied solar lift irrigation system. Alongside quantitative data, qualitative data was retrieved through Key Informant Interview (KII) with all 30-sample site. The Focal Group Discussion (FGD) were carried out at Kachankawal rural municipality of Jahapa district at Koshi province representing the Terai sites and Polingtar, Rupa Rural Municipality of Kaski district at Gandaki province representing the hill sites. KII Guidelines were developed to collect qualitative data to: know the current status of existing solar lift system, identify the exact location, available of infrastructure (Specifically, electricity GRID and road connections), local suppliers information, source of water lifting, major uses of lifted water, from how long the system is running or getting damaged, what are the most repaired component of the system, who are the contributor or supporting for installation of the solar system, and are the system owned by individual or community.

Likewise, the questionnaire includes the technical information which has prepared to collect the input and output supply as well as power generated by the solar system, water lifting head of pump, the energy required by pump set, type of pump set used for the purpose etc. which, on analysis could support the available power, currently utilizing power and possibilities to make the system power for the other purpose than that of water lifting. The KII questionnaire form focus to understand the farmers perception on the solar lift technologies they had installed where the impact of this technology on the farmers cropping pattern, income generation and its effectiveness were studied and at the end the physical observation and farmers need were evaluated to find the further possibilities making the existing solar system as multipurpose use in the agriculture production or agri-business system. The details of the sample format of Questionnaire used for KII and FGD is provided in Annex I.

As a final tool, out study team members organized the technical working group meeting with the experts of this field invited from AEPC, ICIMOD, IOE Campus, Pulchowk, expert team of PMAMP where, all the information collected during the KII and FGD were discussed and a conclusion of the study were drafted.

3.3 Data Collection and Analysis

Field visit was organized to collect the primary data as well as to enrich and validate the secondary data collected through literature review. Different tools like: KII, FGD and observation checklist were used to collect the primary data. Observation checklist was mainly focused on technology evaluation related data and KII attempted to collect qualitative data based on interaction and in-depth discussion. Alongside, qualitative information received from KIIs was translated before structuring and grouping, to identify recurrent themes and patterns in data. After Stakeholders' perception on different models were assessed through qualitative data analysis approach using data obtained from KII, FGD, and stakeholder interviews. Quality and consistency of data were checked and segregated for further analysis. The comparative cost for different types of pumping systems were calculated using life cycle cost (LCC) approach over 20 years per considering initial upfront cost, operating costs, repair and maintenance cost, and replacement cost. The analyzed data has been discussed in details on finding and discussion section as well as in conclusion section.

4 TECHNICAL REPORT SECTION

4.1 Current Status of Existing Solar Lift Irrigation System in The Study Area

In this section the detail description of individual studied solar lift irrigation system has been illustrated to justify the current status of existing solar lift irrigation system

4.1.1 Kothi Khola Solar Pumping System, Hariwan, Sarlahi

The Kothi Khola Solar Pumping System, is located at an altitude of 142.95 m from msl., belongs to Kothi Khola Drinking Water Users Group of Hariyon-1, Sarlahi ($27^{o}03^{/}58^{//}$, $85^{o}33^{/}57^{//}$). The public of the Kothi Khola Drinking Water Group, has demand of 35000 liter of drinking water per day. The source of water is ground water, for this purpose, a well has dug near the bank of Kothi Khola and the water is lifting for drinking by the solar system installed by supporting organizations: Government of Japan, Alternative Energy Promotion Center (AEPC), United Nations Development Programme (UNDP), as well as the 20000 liters of cement concrete reservoir tank has been constructed by the Hariwan, Municipality, Department of Drinking Water Supply and Sewage Management (DWSSM), Sarlahi. The system has installed in June 2023 and the user groups are unknown about the total investment of the pumping system. The location of site has been shown in fig. 4.1.

Fig. 4.1 Site location of Kothi Khola Solar Pumping System

4.1.2 Chandranagar, Ga. Pa., 1, Sarlahi, Jagat Narayan Tharu

In the same district, Sarlahi, the solar lift irrigation installed at agricultural field of Chandranagar Gaupalika-1 ($26^{o}55^{/}23^{//}$N, $85^{o}37^{/}04^{//}$E) was visited on 2080/11/13. The solar lift irrigation is located at 117.65 m from msl owned by Mr. Jagat Narayan Tharu has been installed in Jestha, 2079. The location of site has been shown in fig 4.2. The site is near by the rural road and have NEA electrification grid. The solar system is functioning well and is using for lifting irrigation water from the sallow tube-well. This lifted water is using for irrigating 1.5 ha of his agricultural land. The system was installed with total investment of NRs 375000 which is supported by one of the NGO's that's the farmers fail to remember that's NGO name.

Fig. 4.2 Site location of Solar Pumping System owned by Jagat Narayan Tharu

4.1.3 Ishworpur Municipality -10, Babarganj, Sarlahi, Jagat Narayan Tharu

The solar lift irrigation installed at agricultural field of Ishworpur, Municipality - 10, Babarganj, Sarlahi was visited on 2080/11/13. The solar lift irrigation is located at $26^{o}59^{/}58^{//}$N, $85^{o}38^{/}25^{//}$E at an elevation of 146.30 m from msl owned by Mr. Upendra Mahato, has been installed in Jestha, 2080. The location of site has been shown in fig. 4.3. He has two number of soar lift irrigation system installed about 1 km apart in his two different farms. One of the sites is very near to the highway road and have NEA electrification grid and is not functioning because the thieves had stolen his control panel. Farmers had plastered the pump with mud to keep safe from thieves (fig 4.3.a). Another solar irrigation system (fig 4.3.b) has installed in another farm which is not facilitated with NEA grid electricity and have to walked about 200 m along the narrow field bund from the rural road. This solar system is functioning well and is using for lifting irrigation water from the sallow tube-well. This lifted water is using for irrigating 1.5 ha of his agricultural land. The system was installed with total investment of NRs 3,00,000, which is supported by one of the Gangamai Sinchi Yajona contributing NRs 2,40,000 whereas farmers has to invest NRs 60,000 during the installation.

Fig. 4.3 (a) Location of Solar Pumping System owned by Mr Upendra Mahato (Water pump plastered with mud to keep safe from thieves)

Fig. 4.3 (b) Location of Solar Pumping System owned by Mr Upendra Mahato (Fully working)

4.1.4 Site 4: Mithila Solar PV Power Project, Janakpur, Dhanusha

The Mithila Solar PV Power Project is located at 26o56/16//N, 85o56/42//E at an elevation of 195.07m from msl in Dhalkebar, Janakpur of Dhanusha district was visited on 2080/11/14. This solar PV project is one of the Nepal's first privately owned 10 MW solar power plant. This plant is developed by ECO Power Development Company Pvt Ltd and is owned by EPC Contractor, Kushal Projects Nepal Pvt. Ltd. as well as financed by Prime Commercial Bank Ltd., which, has brought in operation from February, 2021. Total 88504 solar panel has been connected in this project to produce 12 MW DC power converted to 10 MW AC current through 3 numbers of inverter, 3 numbers of transformer (Two number of 5 MVA and 1.5 MVA of one transformer) as well as same capacity of inverter. The location of site has been shown in fig. 4.4. The site is very near to the Mahendra highway road and have NEA electrification grid. This solar PV power project is functioning well and is generating electricity of 10 MW, which has been connected to NEA grid electricity for supporting NEA by supplying electricity in day time. This project has transmission line of 630 m. It is injected electricity to the Dubahi NEA electricity grid of 400 by 220 by 132 by 33, that is feeding at 33 KVA.

We visited this solar power plant and conducted a meeting with the project engineers to share their idea that how can we make the multiple use of solar energy installed at the farmers field, mainly installed for irrigation purpose. This is an example to convince farmer that the unutilized solar power which remains wastage after lifting required irrigation or drinking water, can be supply to NEA grid in day time, support NEA in adding the electrical energy of their use and in return can get income or get discount in their electrical bill which they had used either for lighting in night or making use of NEA electricity in any agricultural machine operation or in used of their farm operation.

Fig. 4.4 Site location of Mithila Solar PV Power Project, Dhalkabar, Janakpur

4.1.5 Site 5: Karjanaha, Magarwasha, Siraha (Mr. Keshab Prasad Koirala)

The solar lift irrigation installed at agricultural field of Karjanaha, Magarwasha, Siraha was visited on 2080/11/14. The solar lift irrigation is located at $26^{o}51^{/}33^{//}$N, $86^{o}12^{/}39^{//}$E at an elevation of 146.30 m from msl owned by Mr. Keshab Prasad Koirala, has been installed in 2079. The location of site has been shown in fig. 4.5. The soar lift irrigation system installed in his vegetable farm land is very near to the rural road but need to walk about 200 m, through narrow field bund and have NEA electrification grid. The system is currently not functioning because the control panel switch is not working, but has called the technician to make it repair the switch which may be in function after simple repair maintenance. This solar system is using only for lifting irrigation water from the sallow tube-well installed in his field near the solar system. This lifted water is using for irrigating 1ha of his vegetable farmland. The system was installed with total investment of NRs 3,25,000, which is supported by one of the AEPC and Provincial Government, contributing NRs 2,60,000 whereas, farmers has shared NRs 65,000 during the installation.

Fig. 4.5 Location of Solar Pumping System at Karjanaha, Magarwasha, Siraha site (Owned by Mr Keshab Prasad Koirala)

(***Note: The study site location, of other existing Solar Lift Irrigation System site, their current status has been summarized in the Table 1 in the ANNEX II.***)

4.2 Technical Specification of Installed Solar System

This section has briefly described the technical specification (Table 2) of installed solar panel, solar water pump controller and specification of solar pump set (Table 3) using for lifting water are given at the end of this section.

4.2.1 Site 1: Kothi Khola Solar Pumping System, Hariwan, Sarlahi

The system includes fifteen (15) number of solar panels of JinKO Solar, Chinese company, each has electrical rating of 545-watt, 49.52 volt and 13.94 A current, producing system voltage of 612 volt of 6.95 kW of DC output power. The systems (Water flow, voltage, current, frequency etc.) are controlling with controller of maximum DC input and DC output capacity of system device is of LATTEYS Industries Ltd, Indian company. The submersible water pump-set of 7.5 kW (10 HP) of 2.7 LPS flow with 85 m of rated head of same company has installed in well near the bank of Kothi khola. The technical specification is shown in fig 4.6.

Fig 4.6 System Description of Kothi Khola Solar Pumping Site

4.2.2 Site 2: Chandranagar, Ga. Pa., 1, Sarlahi, Jagat Narayan Tharu

The system includes nine (9) number of solar panels of ALPEX SOLAR, Indian company, each has electrical rating of 320-watt, 46.55 volt and 9.15 A current, producing system voltage of 335 volt of 2.45 kW of DC output power. The systems (Water flow, voltage, current, frequency etc.) are controlling with Solar Pump MPPT Controller of Intelenergi Global Pvt Ltd, Indian company to operate and control maximum DC input and DC output power of the system. The centrifugal mono-block pump-set of 1.5 kW (2 HP) of 2.5” x 2.5” having 600 LPM flow with 10 meters of rated head of same Intelenergi Global Pvt Ltd, Indian company. The details of the solar irrigation system are given in fig. 4.7.

Fig 4.7 System Description of Solar Lift Irrigation at Chandranagar Ga. Pa, 1 Site

4.2.3 Site 3: Ishworpur Municipality -10, Babarganj, Sarlahi, Jagat Narayan Tharu

The system includes seven number of solar panels of Lubi Electronics, Indian company, each has electrical rating of 330-watt, 45.98 volt and 9.10 A current, producing system voltage of 266.77 volt of 1.96 kW of DC output power. The systems (Water flow, voltage, current, frequency etc.) are controlling with Solar Pump MPPT Controller of ETHOS POWER PVT LTD, Indian company to operate and control maximum DC input and DC output power of the system. The centrifugal mono-block pump-set of 1.5 kW (2 HP) of 2.5” x 2.5” having 2.9 LPS flow with 10 meters of rated head of same Ethos Power Pvt Ltd, Indian company. The details of the solar system are given in fig. 4.8.

Fig 4.8 System Description of Solar Lift Irrigation at Ishworpur Municipality -10, Site

4.2.4 Site 4: Mithila Solar PV Power Project, Janakpur, Dhanusha

The company don't want to share technical specification of the project only minimal information has provided which is explained in the section 3.1.4.

4.2.5 Site 5: Karjanaha, Magarwasha, Siraha (Mr. Keshab Prasad Koirala)

The system includes nine number of solar panels of SENZA SOLAR, Indian company, each has electrical rating of 315-watt, 45.07 volt and 8.8 A current, producing system voltage of 337.32 volt of 2.41 kW of DC output power. The systems (Water flow, voltage, current, frequency etc.) are controlling with Solar DC Pumpset Controller of LATTEYS Industries Limited, Indian company to operate and control maximum DC input and DC output power of the system. The centrifugal mono-block pump of 1.5 kW (2 HP) of 2.5" x 2.5" having 2.3 LPS flow with 10 meters of rated head of same LATTEYS, Indian company. The details of the solar system are given in fig. 4.9.

Fig 4.9 System Description of Solar Lift Irrigation at Karjanaha, Magarwasha, Siraha site

(***Note: The other technical specification of Solar panel, Controller/ Inverter, Water Pump set etc. of existing Solar Lift Irrigation System has been summarized in the Table 2 and Table 3 respectively***)

Table 2 Power Source Design Parameter: Technical specification of installed solar panel in the farmers farm

Input Power Source:		1 = Solar (DC) only	2 = Both DC & Electricity (AC)		3 = Have system 2 but 1 in Use			
Sunshine Level:		1 = High	2 = Medium	3 = Low/foggy	4 = Rainy	5 = Snow		
Water Used for:		1 = Irrigation	2 = Drinking	3 = Fishing	4 = Livestock farming	5 =1&2	6 = 1&3	7 = 1, 3, 4
Operator		1 = Male	2 = Female					
Solar Company:	Type:	1 = India	2 = China	3 = Japan	4 = Others			

Site	Input Power Source	DC Input			DC Output			AC Output			Sunshine Level	Operator	Solar Company	
		V(max)	I(Amp)	P (Watt)	V (max)	I (Amp)	P (Watt)	V (max)	I (Amp)	P (Watt)			Type	Name
1	1	742.8	13.94	8175	612.0	13.36	6948.8	-	-	-	2555	1	2	Jinko
2	1	419.0	9.15	2880	335.3	8.60	2448.0	-	-	-		1	1	Alpex
3	1	321.9	9.10	2310	266.8	8.66	1963.5	-	-	-		1	1	Lubi Elec.
4	2			12352954			10500011			10000000		1	1	Unknown
5	1	405.6	9.80	2835	337.3	8.41	2409.8	-	-	-		1	1	Senza solar
6	1	405.6	10.80	2835	337.3	8.41	2409.8	-	-	-		2	1	Senza solar
7	1	415.8	9.13	2925	340.2	8.61	2486.3	-	-	-		1	1	vikramsolar
8	1	415.8	9.13	2925	340.2	8.61	2486.3	-	-	-		1	1	vikramsolar
9	3	2068.2	9.08	14850	1706.4	8.71	12622.5	-	-	-		1	2	Seraphim Solar Sy.
10	3	368.0	9.25	2600	296.8	8.77	2210.0	-	-	-		1	1	HHV Solar Swelect
11	1	268.0	7.24	1500	215.8	7.24	1275.0	-	-	-		1	1	Alpex
12	1	455.2	9.25	3350	374.0	8.96	2847.5	-	-	-		1	1	Sunbond Energy
13	1	275.4	7.00	1500	227.4	6.60	1275.0	-	-	-		1	4	EverExceed U.K.
14	2			6800000				-	-	6800000		1	1	Unknown
15	1	250.8	1.29	240	201.6	1.20	204.0	-	-	-		1	1	Unknown
16	2	319.2	9.00	2205	259.7	8.51	1874.3	220	12	1686.83		1	2	TrinaSolar
17	1	320.6	8.92	2205	262.5	8.4	1874.3	-	-	-		1	1	ROHS
18	1	316.89	9.09	2240	260.33	8.72	1904.0	-	-	-		1	1	RITIKA Sy. P.L.
19	1	319.2	9	2205	259.7	8.51	1874.3	-	-	-		1	2	TrinaSolar
20	1	316.89	9.09	2240	260.33	8.72	1904.0	-	-	-		1	1	RITIKA Sy. P.L.
21	1	320.6	8.92	2205	262.5	8.4	1874.3	-	-	-		1	1	ROHS
22	1	320.6	8.92	2205	262.5	8.4	1874.3	-	-	-		1	1	ROHS
23	1	320.6	9.13	2275	263.2	8.65	1933.8	-	-	-	2	1	1	Shakti Eco
24	1	330.4	8.71	2205	272.3	8.65	1874.3	-	-	-	2	1	1	FDS
25	1	137.4	9.13	975	112.8	8.65	828.8	-	-	-	1	1	1	Shakti Eco
26	1	412.2	9.13	2925	338.4	8.65	2486.3	-	-	-	1	1	1	Shakti Eco
27	1	410.4	9.45	2970	334.8	8.88	2524.5	-	-	-	1	2	1	CS6U330P
28	1	274.8	9.13	1950	225.6	8.65	1657.5	-	-	-	1	1	1	Shakti Eco
29	3	412.2	9.13	2925	338.4	8.65	2486.3	-	-	-	1	1	1	Shakti Eco
30	1	274.8	9.13	1950	225.6	8.65	1657.5	-	-	-	1	1	1	Shakti Eco

Table 3: Design Specification of Solar Water Pumps and Operating System

Power Used for Operation of;	1 = Water lifting (Pump)	2 = Others than water lifting (Eg. Lighting, Thermal etc)	3 = 1 & 2
Pump Categories	1 = Centrifugal	2 = Submersable	3 = Others than 1 or 2
Company Type	1 = Indian	2 = Chinese	3 = Others than 1 or 2
Do lift system have storage tank?	1 = Yes	2 = No	

Site	Solar Power Used for	Capacity of Pump (kW)	Energy Req./Hrs (kJ)	Pump Categories	Pump			Water Lift (Head, m)	Discharge of Pump (LPS)	Storage Tank?	
					Model No.	Comp.	Company Name			Y/N	Cap. (L)
1	1	7.5	27000	2	TPSDCB	1	Latteys Inds. Ltd.	85	2.78	1	20000
2	1	1.5	5400	1	ETG2HP10M2520WP	1	Intelenergi Global	10 - 14	10	2	NA
3	1	1.5	5400	1	EPPL-1800-2-DC(A)	1	Ethospower	10	2.9	1	NA
4	2										
5	1	1.5	5400	1	LCMDC10-1801	1	Latteys Inds. Ltd.	10	2.3	2	NA
6	1	1.5	5400	2	LCMDC10-1801	2	Latteys Inds. Ltd.	10	2.3	2	NA
7	1	0.75	2700	1	EPPL-900-1-DC(A)	1	Ethospower	10	1.2	2	NA
8	1	0.75	2700	1	EPPL-900-1-DC(A)	1	Ethospower	10	1.2	2	NA
9	1	-	-	2		1	C&S Electric	-	-	1	125400
10	1	-	-	2	AC/DC Hybrid 350v	1	-	-	-	1	24000
11	1	1.5	5400	2	-	1	-	-	0.69	2	NA
12	1	1.5	5400	2	-	1	-	120	0.69	1	20000
13	1	0.75	2700	2	-	1	-	70	0.46	1	5000
14	2										
15	3										
16	1	1.5	5400	1		1	PEDROLLO	14.5	18.33	2	NA
17	1	1.5	5400	2		1	PEDROLLO	14.5	18.33	2	NA
18	1	1.5	5400	2		1	PEDROLLO	14.5	18.33	2	NA
19	1	1.5	5400	2		1	PEDROLLO	14.5	18.33	2	NA
20	1	1.5	5400	2		1	PEDROLLO	14.5	18.33	2	NA
21	1	1.5	5400	2		1	PEDROLLO	14.5	18.33	2	NA
22	1	1.5	5400	2		1	PEDROLLO	14.5	18.33	2	NA
23	1	1.5	5400	2	LCMDC10-1801	1	Latteys Inds. Ltd.	10	1.2	2	NA
24	1	1.5	5400	1	LCMDC10-1801	1	Latteys Inds. Ltd.	10	2.3	2	NA
25	1	0.75	2700	1					1.2	2	NA
26	1	1.5	5400	2	LCMDC10-1801	2	Latteys Inds. Ltd.	10	2.3	2	NA
27	1	2.25	8100	1	LCMDC10-1801	2	Latteys Inds. Ltd.	10	3.5	1	64000
28	1	1.5	5400	1		2			2.3	2	NA
29	1	1.5	5400	2	LCMDC10-1801	2	Latteys Inds. Ltd.	70	2.3	1	30000
30	1	1.5	5400	1	LCMDC10-1801	2	Latteys Inds. Ltd.	10	2.3	2	NA

4.3 General Feedback of Farmers

This section summarized the farmers perceptions on the installed solar system. Here the users view has written in the voice of his own reported during the field observation in the interview with solar irrigation users and in FGD discussion.

4.3.1 Site 1: Kothi Khola Solar Pumping System, Hariwan, Sarlahi

They are very satisfied with the drinking water supply project installed by the donor agencies where, drinking water problem of the community of Kothi Khola Solar Pumping System group has been solved. They are happy for the support of donor agencies because the community do not need to bear any cost during the installation but are unknown about the total investment. They said that 20000 liters of water tank (reservoir) has been constructed by the Hariwan, Municipality, Sarlahi with the investment of 4 lakhs. The system is well functioning till date.

4.3.2 Site 2: Chandranagar, Ga. Pa., 1, Sarlahi, at Jagat Narayan Tharu farm

The users, Mr. Jagat Narayan Tharu found quite happy with this solar lift irrigation. According to him, with the facilities of irrigation he had able to increase the annual intensity of irrigation and do not need any investment during the installment. He is able to irrigate his field without any investment and without operating cost. He further said that he had changed the cropping pattern, where he had increased the area of sugarcane and started seasonal vegetable production like cauliflower, onion potato, tomato etc. in some of his land. He has realized that the production of crop has been increased significantly because of timely irrigation. The remaining cropping pattern was kept as before.

4.3.3 Site 3: Ishworpur Municipality -10, Babarganj, Sarlahi, at Upendra Mahato farm

Mr. Upendra Mahato, the solar lift irrigation users, found very happy with this kind of solar irrigation. According to him, with the facilities of irrigation he had able to increase the annual intensity of irrigation and do invested very minimal amounts of NRs 60,000 out of total investment NRs 3,00,000 during system installation. He said this cost is nothing in terms of increasing productivity, because even for a shallow tube-well installation in the area they need to invest more. He is now able to irrigate his field without any operating cost at any time whenever he needed. He further said that he had changed the cropping pattern, where he had increased the area of seasonal vegetable production like cauliflower, onion potato, tomato etc. in some of his land and the remaining cropping pattern was kept as before. He has realized that the production of crop has been increased significantly because of timely irrigation. Both he and his wife keep busy in vegetable production and has increased their income significantly. They added that they do not need to go abroad for income generation, they getting good income and staying with their family too.

4.3.4 Site 4: Mithila Solar PV Power Project, Janakpur, Dhanusha

During the meeting with the Mithila Solar PV Power Project, manager we discussed about the possibilities of converting the existing solar system in to the multiple use of it in agriculture sector. According to them, it is possible to use the same controller to operate the DC motor operated agriculture machinery but till date they had not conducted any experiment practiced and had advice to work together for making the concept successful.

4.3.5 Site 5: Karjanaha, Magarwasha, Siraha (Mr. Keshab Prasad Koirala)

Mr. Keshab Prasad Koirala, the solar lift irrigation users, was migrated from mid hill to Karjanaha Magarwasha, Siraha district with a vision to make himself sustainable through agriculture production and found quite happy with his farming system where this kind of solar irrigation added him as a motivation factor, encouraging him to stay working in his farm. According to him, with the facilities of irrigation he had able to increase the annual intensity of irrigation and do invested very minimal amounts of NRs 65,000 out of total investment NRs 3,25,000 during installation. He is now able to irrigate his field without any operating cost at any time whenever he needed. He has focused seasonal and off-season vegetable production after this assured irrigation. He has realized that the production of crop has been increased significantly because of timely assured irrigation. He added that he wants youngster encouraging by making himself success in vegetable production. He generates income initially from seedling celling but he lost his protected structure by catching fire during the fire in community houses and had stopped producing seedling at the time of visit.

(***Note: The General feedback of farmers using existing Solar Lift Irrigation System has been summarized in the Table 4 and 5 respectively, paced in result and discussion section***)

4.4 Evaluation Remarks of Studied Solar System

Our team visited the existing solar pumping system in the farmers field, studied physically and take an interview as well as conduct FGD at different site. From the discussion and physical observations, we do evaluation of existing solar lift irrigation system and had explained the specific site evaluation as below:

4.4.1 Site 1: Kothi Khola Solar Pumping System, Hariwan, Sarlahi

The Kothi Khola Solar Pumping System is well functioning during the field visit, and the system is lifting water from the well dug near the bank of Kothi Khola for the purpose of Drinking Water for the community of Kothi Khola Drinking Water Group. The user groups are not aware about the capacity of the system and the capacity they are utilizing. It has found that the solar system has output capacity of 6.9 kW based on the solar panel installed at the site whereas the system has designed for the input capacity of 9 kW (Fig. 1.2). Even the installed capacity of the system i.e. 6.9 kW has not been using efficiently. It has found that the pump capacity designed for lifting drinking water is 7.5 kW (10 HP) which is greater than the available output of system, whereas the specification of the submersible pumpset are unknown because it was found poured in well. But the main thing the users says that the water tank reservoir filled in 2 hours, this means the flow of the pumpset is only 2.78 LPS which may be getting from low capacity pumpset if so it can be utilized for operating 2 nos. of same size of irrigation pump from the running river or groundwater source near by the pumping system.

The drinking water is collecting in the reservoir tank having capacity of 20000 liters which can be filled in 2 hours as mentioned by the user groups. The site is located in the sunny region of Sarlahi, so daily peak sunshine of 8 hours (8 AM to 4 PM) can be utilized efficiently with maximum voltage output. Since the system has high capacity, it is possible to operate 6 kW of any other kind of DC motor for the operation of agriculture operations like threshing of rice and wheat crop or shelling if corn. The site has rural road sufficient for the 4-wheel vehicle and NEA grid runs side by side of the road, thus there has an option for the user groups to run small size of agri-industry.

4.4.2 Site 2: Chandranagar, Ga. Pa., 1, Sarlahi, Jagat Narayan Tharu

The solar pumping system at Chandranagar Ga. Pa. 1, at Mr Jagat Narayan Tharu's farm has found well-functioning during the field visit, and the system is lifting water from the shallow tube well. It has strange to know that the users of solar lift irrigation system in the locality are afraid to put the solar control panel, water pump etc., in the field because of thieves, so they had constructed the farm house in the field to keep their solar system safe. The users, Mr Tharu is unknown about the further use of its solar power. While, describing him about its further application of solar energy, he get excited to make use of solar energy in the off season and during the time when the system is not using for irrigating his farm. It has found that the solar system has output capacity of 2.45 kW (Table 3), which is equivalent to 3.27 HP. Thus, if the farmers are provided with the 3 HP (2.25 kW)

DC motor operated agricultural farm machinery like, sugarcane expeller he could able to start celling sugarcane juice because he has already facilities of farm house near the solar system installed. Likewise, other farm machinery like, corn sheller, rice thresher etc. of small size upto 3 HP DC motor capacity may be fruitful to farmer.

4.4.3 Site 3: Ishworpur Municipality -10, Babarganj, Sarlahi, Jagat Narayan Tharu

Two number of solar pumping system has found at Ishworpur Municipality- 10, Babarganj, at Mr Upendra Mahato's farm land one of these two has found well-functioning from which the system is lifting water from the shallow tube well. Whereas, the another was not in use during the field visit, because of control system stolen by thieves. It has strange to know that the users of solar lift irrigation system in the locality are afraid to put the solar control panel, water pump etc., in the field because of thieves, so they had constructed the farm house in the field to keep their solar system safe. The users, Mr Mahato is unknown about the further use of its solar power. While, describing him about its further application of solar energy, he get excited to make use of solar energy in the off season and during the time when the system is not using for irrigating his farm. It has found that the solar system has output capacity of about 1.96 kW (Table 3), which is equivalent to 2.61 HP. Thus, if the farmers are provided with the 2 HP (1.5 kW) DC motor operated agricultural farm machinery like, carrot cleaner, corn sheller, winnowing machine, chaff cutter etc. of small size upto 2.5 HP DC motor capacity may be fruitful to this farmer.

4.4.4 Site 4: Mithila Solar PV Power Project, Janakpur, Dhanusha

Our team seat with the technical team of Mithila Solar PV Power Project, Janakpur, Dhanusha and concluded that till date in Nepal the multiple use of solar lift irrigation system has not been practiced. All the donor organization has just focus to support rural farmers in solving the lift irrigation problem. The technical team of this project said that since the existing solar water pump controller working to operate the DC solar pump it is possible to operate any machine connected to DC motor. But they are not familiar about the load of agriculture machineries which may be different than that of solar water pump set motor which may work on low voltage compromising with low discharge. The technicians of the projects agreed to support working together in making the solar lift irrigation system multifunction. The meeting further concluded that there is lots of opportunity to use solar energy of existing solar lift irrigation system.

4.4.5 Site 5: Karjanaha, Magarwasha, Siraha (Mr. Keshab Prasad Koirala)

The solar pumping system at Karjanaha Magarwasha, Siraha, site of Mr Keshab Prasad Koirala's farm has found well-established and the system is lifting water from the shallow tube well but because of controller switch damaged, the system is not functioning well during the field visit. He had also constructed the farm house in the field to keep their solar system safe. The users, Mr Koirala. This solar irrigation users are found motivated towards agriculture and have skill in nursery establishment and vegetable production. He also agreed that the solar system is being used only in the days when he need irrigation water and hence found not utilizing every day. It has found that the solar system has output capacity of 2.41 kW (Table 3), which is equivalent to 3.21 HP. Thus, if the farmers are provided with the 3 HP (2.25 kW) DC motor operated agricultural farm machinery like, chaff cutter, zinger washer machine, vegetable grading machine, etc., could be proven fruitful to his farm produce. Since he has already facilities of protected structure so he can operate some machines required to control the environment inside the structure like, exhaust fan, similarly he is interested in hydroponic cultivation so water circulation system can be operating by this solar system. For this farmer, there is lots of opportunity to make utilization of wastage solar energy of his solar system where, there is possible to operate small size upto 2.25 HP DC motor capacity.

(***Note: Evaluation remarks of study team member on existing Solar Lift Irrigation System has been summarized in the Table 2 and 5 respectively, paced in different section of this report***)

5 FINDINGS AND DISCUSSION

5.1 Characteristics, Status and Uses of Solar Lift Irrigation System

Nepal having good solar energy potential with an average of more than 300 sunny days per year and average solar radiation of 4.4 kWh/m^2/day to 5.5 kWh/m^2/day [Solargis, 2017]. Subsidy policy, 2009 introduced subsidy in solar pumping for drinking and micro-irrigation and enriched by recent renewable energy subsidy policy 2016 with provision of solar pumping system for irrigation [MOPE, 2016]. Alternate Energy Promotion Center (AEPC), GoN, has already supported huge numbers of solar lift irrigation system (SLIS). In addition to government programs, non-government organizations are also promoting solar pumping technology by mobilizing grant and credits. However, subsidy or grant are provided mainly for purchasing the capital equipment to improve access to water for irrigation purpose in study area.

5.1.1 Ownership and Current Status of Existing Solar Lift Irrigation System

Access to irrigation technology underpins easy and reliable water access. However, land ownership is a prerequisite to access water sources and finance to secure irrigation technologies. Yet, exploitative and unequal gender and caste relations determine access to and benefit from productive resources such as land and water.

In our field study, among the 30 samples data it has found that 50% of the installed solar lift irrigation system has been owned by individual farmers, that means the 50% SLIS has been installed in the individual farmers field and that particular farmers are responsibilities to take care about it and get benefited from it by irrigating their land only (Table 4, Fig. 5.1 a). Whereas, 37% has group ownership where all kind of management and benefit from the installed SLIS has been shared by this group and any decision regarding this SLIS has been taken in group and only 13% of installed solar system has industrialized and the energy is being commercialized.

Solar irrigation pumps (SIPs) are proven women-friendly technology but in our study, it has found that more than 90% users are male who are engaged in operating the SLIS and only 10% female are operating this kind of technology. This shows, there is lack of motivation among the women that they are unable to operate those kinds of technologies and may have dependency on men.

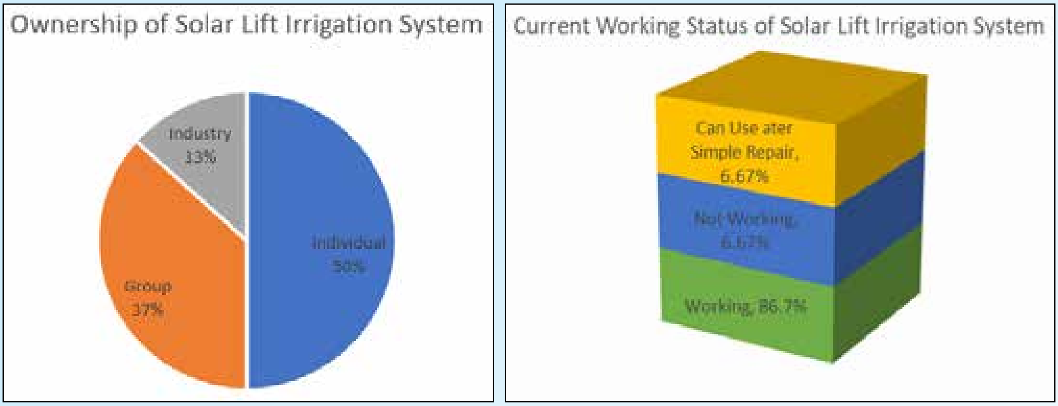


Fig. 5.1 (a) Ownership of Existing SLIS and (b) Its Working Condition during Field Study

Solar lift irrigation has been found installed throughout the country. In the field visit, we ask all most all farmers to operate the solar pumps which are in operating conditions and it has found that 86.7% of the existing installed solar pumps are in good working condition and they are still using for the purpose they had installed (Fig 5.1 b). Whereas, about 6.7% of them are not working because of greater investment required for its repair and maintenance which they are not interested to do so but 6.7% of them can be bring underutilization after simple repair and maintenance of either pump, or control switch or some connections etc.

5.1.2 Cost Shearing (12) in Installation and Operation of the System

Most farmers in Nepal find it challenging to manage the non-subsidised cost of SIP that they need to pay upfront. Hence the role of financial institutions to improve access to finance for these farmers is crucial. Several government institutions that work in the water, irrigation and agriculture sectors play a vital role in overall solar irrigation project (SIP) and ground water development and management.

In the study area we ask the solar power users about the installation cost of the solar system they had installed in their farm. Among them only, 4% of the solar irrigation users had invested their own cost during the installation and in its maintenance whereas, 71% (Fig. 5.2 and Table 4) of those users had share minimal cost, 10 - 20% of the total installation cost whereas, 80 – 90% of its installation cost were shared by different government organizations like AEPC, Department of Irrigation, PMAMP etc., NGO's & INGO's as shown in Table 4 and as discussed below in next paragraph. Also, 25% of the solar irrigation users agreed that all (100%) of the installation cost had beared by those support organization and are unknown about the total installation cost. The farmers who do not share the installation cost looks very happy because free irrigation facilities are now available to their farms where no operation cost is required. Also, who had paid the minimal amount during the installation agreed that because our investment in installation made them motivated to take better care and maintenance of the solar system. The farmers who had got free of all cost had lost some of the control panel and pumping set stolen by thieves.

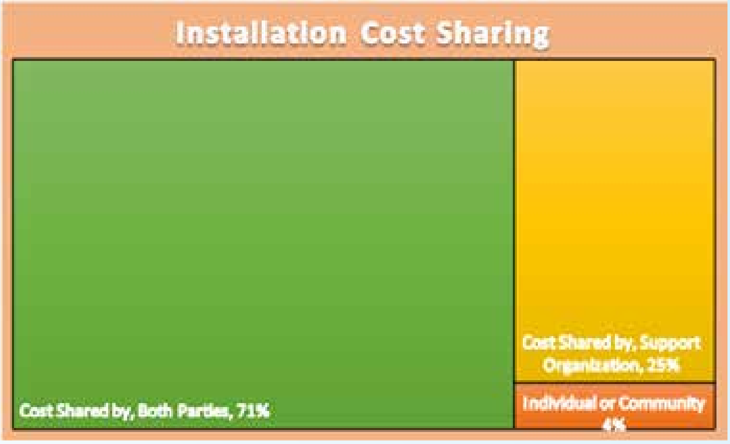


Fig 5.2 Investment During Installation by Individuals/Groups and/or Support Organization

Since 2015, APEC has been heavily involved in the promotion of SIPs with subsidies. DWRI, under MoEWRI, is a government organisation with a mandate to plan, develop, maintain, operate, manage, and monitor different modes of environmentally sustainable and socially acceptable Irrigation Projects. Nepal's private sector is heavily involved in the solar energy sector. AEPC worked closely with the private sector to promote SIPs and disseminate SIP subsidies to the farmers. A study conducted by IWMI on the GoN's subsidy delivery mechanism indicates that more than 80% of applications for SIPs are received through private SIP service providers (Pandey et al., 2020).

Table 4: Characteristics, Status and Uses of Solar Lift Irrigation System

Ownership:		1 = Individual	2 = Group	3 = Industry		
Infrastructure Near By:	Grid:	1 = NEA	2 = Micro-hydro	3 = Solar	4 = No Grid	
	Road:	1 = Highway	2 = Rural	3 = Narrow Path	4 = Field Bunds	
Source of Water:		1 = GW-Tubewell	2 = Running River	3 = Well in 2	4 = Well	5 = Pond/Lake
Current Status:		1 = On Use	2 = Not in Use	3 = Will be used after simple repair		
Lifted Water Used for: Purpose		1 = Irrigation	2 = Drinking	3 = Livestock, 4 = Fishing	5 = Others	6 = Combine
Cost Shared By:		1 = Individual or Community		2 = Support Organization	3 = Both 1 & 2	

Site ID	Ownership	Infrastructue		Source of Water	Current Status	Water Use For				Installation Cost (Rs)	Cost Shared		Cost Shared % in NRs	
		Grid	Road			Purpose	Irri. (Ha)	Drink (HH)	Others		By	Support Organization	By (2)	Organization
1	2	1	2	3	1	2		55	NA	Unknown	2	Japan, AEPC, UNDP & DWSSM	0	100%
2	1	1	2	1	1	1	1.5	NA	NA	375000	2	NGO, unkonw	0	375000
3	1	4	1	1	2	1	1.5	NA	NA	300000	3	Gangamai Sinchi Yajona	60000	240000
4	3	1	1		1	5	0	0	AC Grid		1	NA	100%	0
5	1	1	2	1	3	1	1	NA	NA	325000	3	AEPC, Provincial Gov.	65000	260000
6	1	1	2	5	2	1	2	NA	NA	190000	3	AEPC	38000	152000
7	1	1	2	1	1	1	1	NA	NA	Unknown	2	Unknown	0	100%
8	1	1	2	1	1	1	1	NA	NA	Unknown	3	Unknown	10000	Remaining
9	2	1	1	3	1	6	2.5	39	NA	16900000	3	Depart of Irrigation	1859000	15041000
10	2	1	2	3	1	2	NA	50	NA	600000	3	PMAMP	90000	510000
11	3	4	3	5	1	1	4	NA	NA	500000	3	PMAMP	75000	425000
12	2	1	2	2	1	1	0.4	NA	NA	1200000	3	PMAMP	180000	1020000
13	1	1	3	3	1	6	0.05	1	Livestock	580000	3	PMAMP	80000	500000
14	3	1	1		1	5	NA	NA	AC grid	640000000	1		640000000	0
15	1	1	1	1	1	6	0.5	1	NA		1			
16	2	1	2	1	3	1	3	NA	NA	500000	3	PMAMP	85000	415000
17	3	1	2	1	1	1	2	NA	NA	545000	3	Unknown	45000	500000
18	2	1	2	1	1	1	0.75	NA	NA	540000	3	PMAMP	80000	460000
19	2	1	3	1	1	1	1.25	NA	NA	540000	3	PMAMP	80000	460000
20	2	1	1	1	1	1	0.15	NA	NA	Unknown	3	PMAMP	20%	80%
21	2	1	3	1	1	1	1.66	NA	NA	540000	3	PMAMP	80000	460000
22	2	1	3	1	1	1	1.66	NA	NA	540000	3	PMAMP	80000	460000
23	1	4	4	1	1	1	1.67	NA	NA		2		0	100%
24	1	4	4	1	1	1	1.00	NA	NA	960000	2	AEPC, Palika (40%)	0	960000
25	1	1	2	1	1	1	0.33	NA	NA	400000	2	Unknown	0	400000
26	2	1	2	3	1	1	6	NA	NA		2	Bagmati Irri. Project	100%	
27	1	1	2	3	1	6	2	NA	NA		3			
28	1	1	4	1	1	1	2.3	NA	NA	900000	3	Pradesh Nirdeshnalaya	20%	80%
29	1	1	2	1	1	6	1	NA	NA	900000	3	Ogranization	180000	720000
30	1	1	2	1	1	1	2	NA	NA		3	DOA	20%	80%

5.1.3 Infrastructure Nearby the Existing Solar Lift Irrigation System

Infrastructure development in the area like, road, electricity and availability of irrigation water plays crucial role in selecting such kind of solar lift irrigation project by different donor agencies or government organization in canalizing their subsidy for distribution of solar power irrigation system. In this survey, we find that 86.7% of study site had NEA grid facilities available nearby the farm having solar lift irrigation and only 13.3% of the site had no grid connected (Fig. 5.3 and Table 4). This, can be described in two ways, first, the farmers who do not have NEA grid had not given the importance and thus do not have any of the two option for irrigating their farm. In another way we can say that the site which are near by the NEA grid had an option to sell their wastage solar power by connecting their solar system in the NEA grid during the off season or when they are not using solar power for irrigation. In return they could have an option to get subsidise electric bill they may use in their farm.

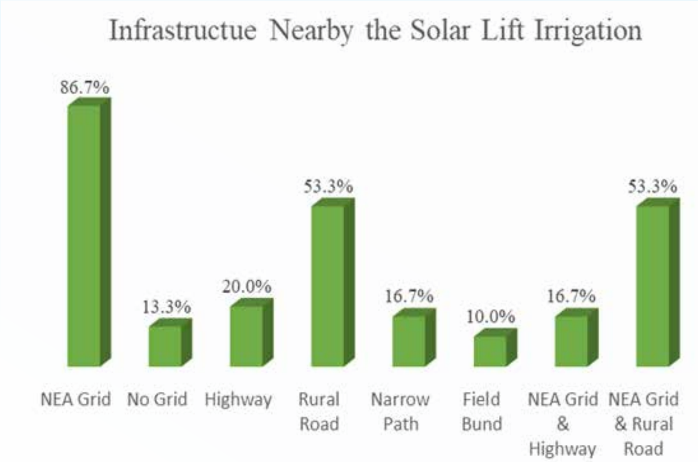


Fig. 5.3 Infrastructure (Road and NEA grid) Facilities Near the Study Site

Similarly, the analysis of data as shown in Fig 5.3 shows that the most of the solar irrigation has found installed in farm connected with rural road and 20% of the total visited site were highway connected likewise, 16.7% of site has narrow path facilities and 10% site has only field bund to reach the solar irrigation system for its operation and maintenance. This data also provides two concepts; the first vision may look like that the farmers field which are in remote area are given priority which makes justice to rural farmers but and the main purpose of those solar pawer was limited for lifting water only where the unutilized solar power are remains wastage. The interesting facts come from this study is that 53.3% of the total site has both NEA grid and rural road connectivity, i.e. all the site which had installed near by the rural road had also facilities of NEA grid. This, has an opportunity for the rural farmers to utilized their westing solar power in operating agriculture machineries like winnowing machine, chaff cutter, corn sheller etc. when they are not using these solar powers for irrigation. The analysis data in fig. 5.3 shows that 16.7% of the solar irrigation users has facilities of both NEA grid and highway near by the site which may have an opportunity for them to starting with small agro-industries.

5.1.4 Types of Solar System and Pumps Available in the Nepalese Market (28, 16)

The significant component of solar lift irrigation (SLI) system is the pump, solar panels, and inverter. Most of these components are imported from India or China, which takes approximately four to eight weeks. In the study, about 60% SLI users were found using submersible solar pump lifting water from tube-well, well-constructed at the bank of running river, ponds and tube well whereas, about 40% have centrifugal pump lifting water from the shallow tube well (Table 3).

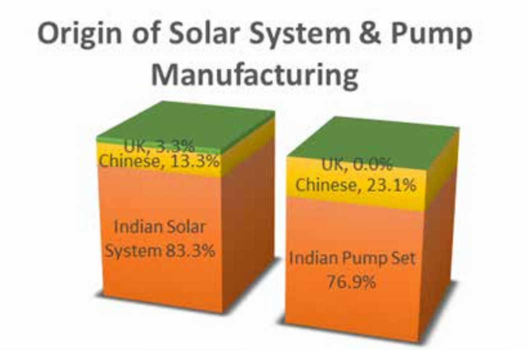


Fig.5.4 Different Type of Solar System and Pump Installed in Farmers Field

As said above, survey data reviled that 83.3% of Nepalese solar companies were supplying Indian solar panel, Inverter and controller in the existing solar lift irrigation installed in Nepalese farmers field whereas, 13.3% are supplying Chinese solar system and few about 3 – 4% are importing from UK respectively. Similar, scenario was observed in the installation of pump set where, about 77% of solar pump are Indian originated and 23% are of Chinese company. This concluded that the Indian market has highly dominated the Nepalese market installing the solar lift irrigation system in Nepalese farmers field.

5.1.5 Input and Output power Source in the Existing Solar Installed in Farmers Field

Solar water pumping system mainly consists of the following components: <u>*Solar Module:*</u> Solar modules are used to produce DC electricity to operate DC solar motors directly. If AC motor is used then inverter is needed to convert DC electricity received for PV module into AC electricity. Output AC electricity from inverter is then finally used to operate AC motors. If DC motor is used then DC electricity from PV module is directly used to operate DC solar motor in the presence of various controller. Thus, knowing the type of AC or DC current as a input or as an output power is an important factor to understand the operation of different type of pump or to make the system multi-functions.

In this study, 80 % of the installed solar irrigation system had only the DC input facilities whereas 20% inverter connected to the solar panel has found both DC and AC input facilities but only 10% of them are using both AC and DC input (Table 2) also, called the Hybrid Model Inverter. Thus, to make the existing solar lift irrigation multi-function, there may be the need of changing the inverter will be one of the possible to obtain continuous AC output or DC output using selective inverter. Whereas, the solar system having connected with AC and DC input with AC output can be used to operate different kind of agricultural machine having AC motor.

5.2 Effectiveness of Solar Lift Irrigation System at different Agro-ecological Zone of Nepal

The correlation between water demand and solar energy potential is hound high in Nepal. Solar lift irrigation (SLI) could provide water during the dry months when demand is at its peak, building climate resilience and increase food production into the dry season. Solar-Powered Irrigation System (SPIS) is a solution to many problems of the agricultural system. Several projects with innovative business models have been piloted in Nepal and has proven that for SLI to be financially feasible, the Capacity Utilization Factor (CUF) of SLI needs to be increased. For example, using grid integration of SIP to improve the CUF and integrating technologies such as drip irrigation to decrease the per-unit cost of the irrigation water from SIP could help achieve greater agricultural productivity. Here are some of the parameters we studied during the study to evaluate the effectiveness of existing SLI in different agro-ecological zone of Nepal.

5.2.1 Solar Power Application

As renewable energy trickles into our lives more with each passing day, we must understand the industrial applications of solar energy. We will continue to see new applications of solar technologies to improve our environmental impact, reduce daily energy costs, and make our lives better overall. There are many perks to living a solar lifestyle. Using the solar energy applications for solar pumping, lighting, operating agricultural machineries as well as establishing agro-industries could create an efficient solar energy system right at farmstead.

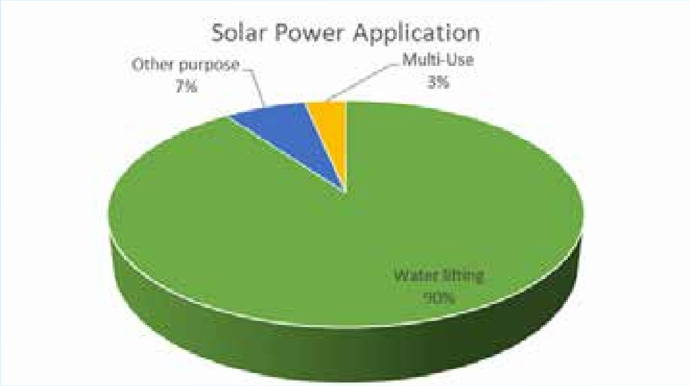
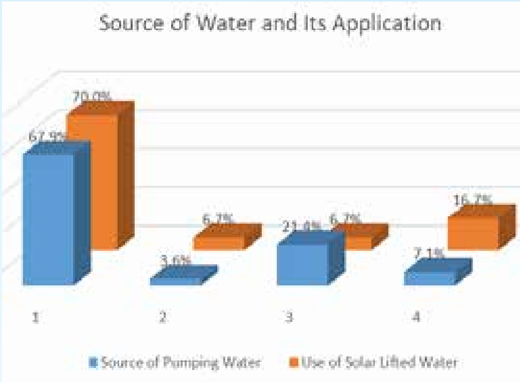


Fig. 5.5 Application of Solar Power Installed for SLI

It has found that the solar system installed at Nepalese farmers field are not using their available solar energy efficiently, those solar system are limited in lifting water only. The survey data (Table 3, Fig 5.5) shows, that 90% of solar installed in the farm are using for lifting water, 7% are using for lighting purpose and had connected to the NEA grid line whereas only 3% farmers are using those energy in different agriculture activities like pumping water, lighting, and drying the agriculture produce of their farm. This, indicate that the Nepalese farmers and donor agencies working in the field of SLI projects were limiting the application of solar power they have installed. The possible application of these solar energy is needed to be explore and required to upgrade the solar system so that the farmers could get multiple benefit from the same system.

5.2.2 Source of Water Pumping and It's Uses

Sources of irrigation water can be Groundwater extracted from springs or by using borings or wells, flood water spreading, surface water withdrawn from the flow of a stream, lakes or reservoirs or non-conventional sources like treated wastewater, desalinated water or drainage water. Agriculture in the Terai is wholly dependent on seasonal surface water, while groundwater is underutilized. Groundwater potential decreases with increasing elevation. The Siwalik's springs, and Himalayan glaciers contribute to year-round flow in major river basins.



Indicator	Source of Pumping Water	Use of Solar Lifted Water
1	GW Tubewell	Irrigation
2	Running River	Drinking
3	Well in River	Others
5	Pond Lake	Combine

Fig. 5.6 Source of Irrigation water available at the site of existing SLI and Its use after pumping

The source of water lifted from individual existing solar lift irrigation system studied at farmers field are given in table 4. The analysis chat in fig. 5.6 illustrate that about 70% of the existing solar irrigation system installed in the farmers field have ground water source pumping from either sallow tube-well or deep tube well specially in Terai region whereas, 21.4% of the ground water source is available in mid-hill pumping from the well-constructed near the bank of river. Similarly, 3.6% of water source were found receiving from the running river and about 7% source of pumping water are getting from the pond or lake which farmers were found harvesting in rainy season.

The survey data shown in fig 5.6, illustrate that 70% of solar users are pumping the water for the irrigation purpose only and 6.7% farmers are lifting water for drinking purpose whereas, 16.7% farmers are using lifted water for different agriculture activities like irrigation, livestock and fish farming and 6.7% solar power installed are found utilizing for other purpose rather than agriculture like lighting or connected to NEA electric grid.

5.2.3 Repair and Maintenance Requirement

Regularly scheduled maintenance should encompass various tasks to ensure the power functioning of the solar system. One of the primary maintenance tasks for solar irrigation systems is regular cleaning and inspection. Solar panels are exposed to the elements, accumulating dust, dirt, and debris over time. This buildup can significantly reduce the system's efficiency by blocking sunlight absorption.

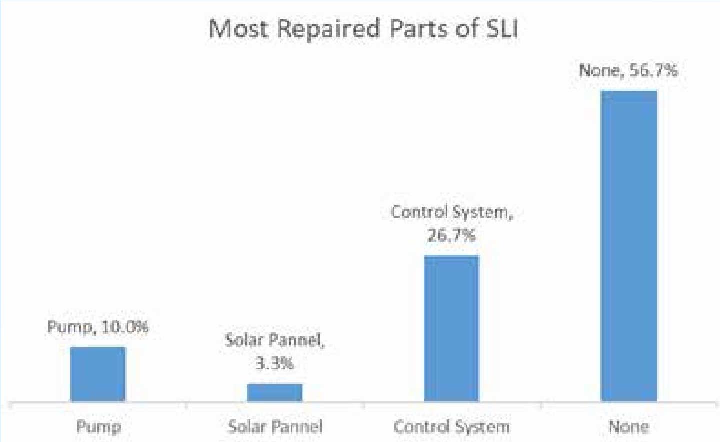


Fig. 5.7 Major Parts of Solar Lift Irrigation Repaired by Farmers

The performance of the existing solar lift irrigation was evaluated in the farmers field by asking them about number of times the SLI system need to be repair and what major parts of the system required regular or casual repair and maintenance for its smooth operations. The survey data shows, that 60% of the existing SLI users had not faced any trouble till date and had not repaired any component but they regularly clean the solar panel before they use it. Among the users who says the system has repaired some times are facing problem with controller i.e. inverter, water pump/motor, and solar panel. About 26.7% users said that the major damaging part are the controller which are specially found in Terai region with the particular companies' model and 10% of the farmers had problem with the water pump whereas, about 3% farmers had damaged solar panel in the previous years. This shows the overall performance of the solar lift irrigation are found good from repair and maintenance perspective. The farmers who had repaired some of the components as illustrated also do not had paid much more expensive. But, the components which the farmers indicated need to be upgraded for its durability and quality performance of solar lift irrigation system development.

5.3 Impact of Solar System Installed at Farmer's Field

The market for solar pumps is rapidly increasing due to rapidly declining costs and technology improvements that are replacing traditional manual (hand) pumps, mechanical windmills, and diesel engines around the globe. They are also reducing the demands on local and national power grids. Solar pumping has become a significant and growing niche for the solar energy industry. Solar pumps are an important way for smallholder farmers to increase crop yields through irrigation; fish farmers can increase fish yields through reliable water and improved aeration; and livestock herders can increase income through a reliable water supply for their animal's welfare. Following are some of the reviewed points based on which the impact of existing solar irrigation systems has evaluated in this report.

5.3.1 Impact of Solar Lift Irrigation on Yield, Cropping Pattern, and Annual Income of Farmers

One of the main reasons being low agricultural productivity with traditional farming practices and unavailability of irrigation facilities and inadequate irrigation water. Solar lift irrigation technologies bring an opportunity for the small farmers, lifting the available source of irrigation water on time. This, could improve the yield of the crop, farmers can change the existing cropping pattern and can move toward the cash crop cultivation which finally improve the economic condition of the farmers.

In this study we collect the information on the impact of solar lift irrigation technologies on the crop yield, cropping pattern, and their annual income and the information are summarized in the table 5. In the study, 92.3% farmers agreed that after the installation of this SLI system the crop yield has improved significantly were disagreed with this statement (Fig. 5.8). Similarly, about 77% SLI system users had changed the cropping pattern in their farm shifting from cereal crops to cash crop cultivation like vegetable, sugarcane etc., and almost all the farmers who agreed with their crop yield improvement and who had improved the cropping pattern had increased the annual income from their farm produce. They evoke that since they have assured irrigation with after installation of SLI system they had opportunity to increase the cropping intensity and improved annual and seasonal irrigation intensity.

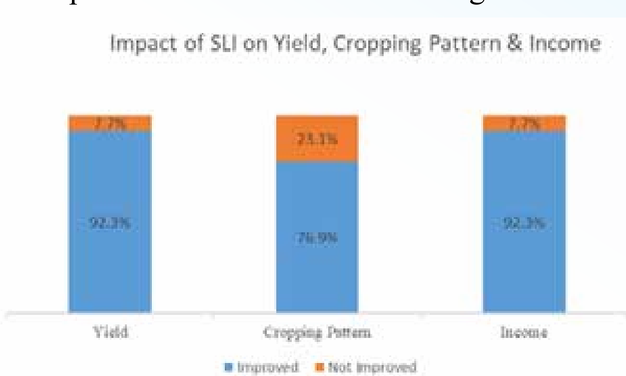


Fig. 5.8 Impact of Solar Lift Irrigation on Yield, Cropping Pattern and Income

5.3.2 Farmers Impression on Solar Lift Irrigation Technologies

Any technology could not be sustained without satisfaction of its users. The solar lift irrigation (SLI) technologies which required high installation cost relates directly with the poor Nepalese farmers who have very low purchasing and repair maintenance capacity. Even the technologies have been subsidized with more than 80% installation cost the farmers must satisfy with the performance of SLI and its repair maintenance cost. Although SLI technologies is a mature and proven technology, its sustainability depends on farmers impression with the optimum utilization of the technology.

Our team in the field visit tried to perceive the farmers impression, on the effective application of the SLI, their ability to take proper care maintenance and its sustainability. The farmers feedback received through the key informant interviews and the focal group discussion (FGD), has been summarized in the Table 5 and the FGD minutes are attached in Annex III. The result shows that, 40.7% farmers (Fig. 5.9) are found satisfied on using the SLI technology in their farm among them about 25.9% farmer are satisfied who are expecting to optimum the use of available solar energy through making it multiple use in operating the other agriculture machineries. Likewise, the 22.2% farmers whose has repaired their SLI system are expecting to enhance their own skill through training or expecting to have repair maintenance services. Some of the SLI users (about 3.7%) said, the system has very low discharge capacity which make engage through out the day time for a single irrigation whereas, 7.4% farmers give the combine reactions on the existing SLI technologies.

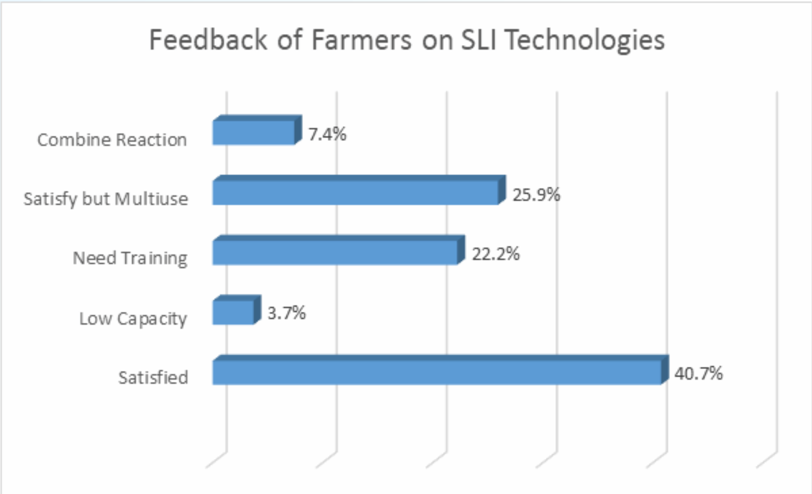


Fig. 5.9 Farmers Satisfaction Level after Installation of SLI System

5.3.3 Team Evaluation of Studied Solar Lift Irritation System

Solar Lift Irrigation (SLI) technologies holds lots of promise to reduce energy and water scarcity and provide year-round irrigation. However, securing high initial capital investment and establishing financial mechanisms remain key challenges. Most parts of the Terai region of Nepal lack irrigation facilities and depend upon the monsoon and winter rains for crop production. Farmers who are able to pay are using motors operated by petrol or diesel to pump ground water for irrigation because of unreliable supply of electricity. This not only increases the investment for agriculture, but also is contributing to increase greenhouse gases in atmosphere. Use of solar-based irrigation system can be a good solution to overcome water scarcity without increasing carbon foot print. This, study keep field visit, key informant interview and expert group meeting to collect the existing status of existing SLI system and to understand the effectiveness of the SLI system, which are explained in the earlier section with farmers perceptions. The second main objective of the study was to find out the possible solution for optimizing the application of existing SLI system. For this, we conduct expert group discussion at PMAMP, Khumaltar office (Fig. 5.10) and the output of the discussion has been explained below;

Expert Group Meeting

In this study, an expert group meeting was conducted including experts from Institute of Engineering, Alternative Energy Promotion Centre, ICIMOD Renewable Energy Specialist, Nepal Electricity Authority and officials from Ministry of Agriculture and Livestock Development. The Expert Group Meeting discussed opportunities for use and application of solar energy on agricultural ecosystems, sustainability and rights-based approaches to irrigation water management in the context of climate change. Particularly, how the multiple use of energy collected in solar panels could be made possible from same motor in different unit operations of agriculture was the main agenda of expert group meeting. The renewable energy specialist from ICIMOD suggested three models for multiple use of solar energy from same device includes;

i. Use of hybrid model,

ii. Conduct extensive research to understand what type of agricultural machineries can be operate from the existing SLI system and

iii. Upgrade the existing system for grid-connected SLI system.

Among these three alternatives, he suggested grid connection to NEA mains is most viable, sustainable and cost-effective to farmers because it works on the principle of Energy Bank which, not only uses produced solar energy but also sells the excess one. The academic expert from Institute of Engineering recommended to increase use of renewable energy in agriculture sector.

In the context of changing climate, the experts urged to discourage using diesel and petrol as a fuel in agriculture production and post-processing, replacing those by clean energy including solar. Agriculture is the prime sector causing greenhouse gas emission throughout the world, which can only be minimized by replacing fossils fuels via renewable energy. In addition, senior engineer of Nepal Electricity Authority told that there might be troubles starting AC motors with solar power. It is because the motor needs a big jolt of electricity at first, more than what solar panels can provide. For instance, a 2 HP motor capacitor or starter needs as much power as a 5-6 HP one to start. So, the solar energy might not be just enough which however, could be managed after detailed research.

In summary, the expert group meeting recommended to do more systematic research about multiple use of solar energy in agriculture. As it is crystal clear proven fact that agriculture is one of the most energy-intensive profession, priority of clean energy in that sector could be the mild-stone in climate change management. The meeting also concluded that in stationary unit operations like drying, threshing, winnowing and etc., solar energy collected on the same panel could be utilized in easier. To reduce input production cost in agriculture and make it a sustained profitable business, use of alternative energy certainly contribute to an extent.

The expert's discussion meeting conclusion justify, the statements of several international researchers where, Mérida García et al. (2019) suggested establishing a grid connection to an isolated solar lift irrigation (SLI) increases the possibility of using 80% of the plant's energy. Grid-connected SLI has lower Levelized Energy Costs (LEC) than off-grid SLI, and addresses over-abstraction of groundwater issues by feeding excess energy into the grid (Mantri et al. 2020). The AEPC-subsidized SLIs in Nepal are off-grid systems and are installed at least 300 m from the nearest grid. As the grid expansion of the Nepal Electricity Authority (NEA) occurs, the gap between grid-connected and off-grid areas will diminish rapidly. This presents an opportunity for grid-connected solar irrigation.

Fig. 5.10 Expert Group Discussion Meeting held at PMAMP, Khumaltar

Table: 5 Impact of Solar Lift Irrigation System on Crop Yield, Cropping Pattern and Economic Condition of Farmers

Most repair parts of system		1 = Pump	2 = Solar pannel	3 = Control system	4 = Others than 1, 2 or 3	
Impact of lift system:	Yield:	1 = Improved	2 = Not Improved			
	Crop Pattern:	1 = Changed	2 = Not Changed			
	Income:	1 = Improved	2 = Not Improved			
	Major Crop:	1 = Cereal (R/W/M)	2 = Vegetable (P/O)	3 =others (Oil seed, Sugarcane)	4 = 1 & 2; 5 = 1 & 3; 6 = 2 & 3	7 = 1, 2 & 3
Impact Level of Solar System:		1 = Low discharge	2 = Need more labor	3 = Need frequent repair	4 = 1 & 2; 5 = 1 & 3	6 = 2 & 3
		7 = Not used in income generating activities (Like used in drinking only or Lighting etc.), 8 = Useful				9 = 1 & 8
General Feedback of Farmers:		1 = Satisfied	2 = More capacity	3 =multiuse; 4 = training	5 = 1 & 2; 6 = 1 & 3 7 = Combine reaction	
Evaluation Remarks:		1 = Low utilization	2 = Possible to make multi-use	3 = 1 & 2	4 = Un-utilized in off season	5 = 4 & 2

Site ID	No. of Time Repaired/ Yr	Repair Cost (NRs/Yr)	Most Repaired Parts	Impact of Lift System					Impact level- solar system	Max. Operation Hrs/Days	General Feedback of Farmer	Evaluation Remarks
				Yield	Crop Pattern	Income	Major Crop	Income/Yr				
1	0	0	NA	2	2	2	4	NA	7	4	6	3
2	0	0	NA	1	1	1	7	NA	8	7	7	5
3	0	0	NA	1	1	1	4	700000	9	7	7	1
4												
5	1	0	Control switch	1	1	1	2	360000	9	7hr*10 M	6	3
6	0	0	NA	1	1	1	2	300000	4	7hr*10 M	2	2
7	0	0	NA	1	1	1	2		8	7hr*10 M	1	3
8	0	0	NA	1	1	1	2		8	7hr*10 M	1	3
9	0	0	NA	1	1	1	4	double	8		6	5
10	0	0	NA						7	6 hrs/day	6	2
11	0	0	NA	1	2	1	3	1300000	9	6 hrs/day	6	2
12	1	-	Solar panel add	1	1	1	2		9	6 hrs/day	1	4
13	1	27000	pump	1	1	1	2	35% increase	8	6 hrs/day	6	1
14												
15												
16	1	2000	Control switch	1	1	1	1		5	7 hr/day	6	1
17	3	8000	Switch, motor	1	1	1	1	40% inc.	5	7 hr/day	4	1
18	0	0	NA	1	1	1	1	10% inc.	8	7 hr/day	4	1
19	2	8000	Motor	1	1	1	1	20% inc	5	7 hr/day	4	1
20	1	20000	Controller	1	1	1	1	15% inc	5	7 hr/day	4	1
21	2	4000	Controller	1	1	1	1	25% inc	5	7 hr/day	4	1
22	2	15000	Controller	1	1	1	1	25% inc.	5	7 hr/day	4	1
23	0	0	NA	1	1	1	1		1	7hr*10 M	1	1
24	1	Warranty	Controller	1	1	1	1		5	7hr*10 M	1	3
25	0	0	NA	1	2	2	2		1		1	4
26	1	Nominal	Switch	1	1	1	5		3		1	5
27	0	0	NA	2	2	1	7	8 to 9 lakh	1		1	2
28	0	0	NA	1	2	1	1		1		1	2
29	1	0	Controller	1	2	1	5		1		1	2
30	0	0	NA	1	1	1	4		1		1	2

6 Conclusion and Recommendations

Irrigation is the artificial application of water to soil, in accordance with the crop requirements and is supplied to supplement the water available from rainfall. A reliable & suitable irrigation water supply can result in vast improvements in agricultural production & assure the economic vitality of the region. Many civilizations have been dependent on irrigated agriculture to provide the basis of their society & enhance the security of their people. In many areas of the world including Nepal, the amount & timing of rainfall are not adequate to meet the crop-water requirements & hence irrigation is essential. Similarly, in a tropical country like Nepal, where the natural rainfall occurs mainly during the monsoon season from June to September, irrigation is essential for the proper growth of plants throughout the year. The goal & overall objective of irrigation sector is to develop controlled & year-round irrigation in a sustainable way through proper utilization of available water resources for increasing the agricultural productivity thereby raising livelihood of rural community. Water, being a limited resource, its efficient use is basic for the survival of the ever increasing population of the world. It means, every effort must be made to make the best use of water, so as to make water possible a high level of continuous production. Our aim today is to increase agricultural production per unit volume of water, per unit area of cropped land, per unit time.

After introduction of diesel and petrol engine with irrigation pump, it's become crucial for Nepalese farmers. Such pumps rapidly adopted for pumping either ground water, especially from shallow tube wells (STWs) and/ or surface water like running river, ponds, channels waters to irrigate their field and feel very relief as compared to the traditional irrigation system where, traditional hand pump, Dhanki Pump, Don or Swing buckets etc. were used for the purpose. Such farmers, either using surface water or groundwater for irrigation, rely on diesel pumps because grid electricity is not available everywhere and have no any alternative source of energy. Irrigation using diesel & petrol pumps is both expensive and harmful to the environment. The agriculture sector (including irrigation) alone accounts for around 10.5% of the total diesel consumption in the country. In this regards Solar-powered Irrigation Pumps (SIPs) have emerged as a viable alternative to diesel pumps. The SIP technology makes it suitable for rural farms which are far away from the NEA electric grid. Such, SIP technology sustainably manages the water-energy and climate inter-linkages. The GoN agencies like AEPC, DOI, Krishi Gyan Kendra, PMAMP etc. with different INGOs, and NGOs, are found supporting the individual farmers or farmer's groups for the installation of such solar lift irrigation (SLI) technologies in their farms. Many projects have lunched and had found updating the time wise scenario of SIP through case study of particular areas only and never had thought about its sustainability, its optimum uses and its impacts on agriculture as well as user's status.

This study aimed to document the existing status of solar lift irrigation technology installed at farmer's field. The main objective of this study is to understand the need of agricultural machineries and possibilities to make the existing solar powered lift irrigation multifunctional to operate the agricultural machines for the SPI users' farmer. With this aim, the study team visited the selected site of different agro-ecological zone of Nepal and developed observation checklist to perceive the quantitative data. Alongside quantitative data, a qualitative data was retrieved through Key Informant Interview (KII), Focal Group Discussion (FGD), local suppliers' information, and finally conducted the technical working group meeting with the experts of this field.

This report presents a brief analysis of the current status of SLI technologies in Nepal in terms of its functioning, current application in agriculture, impact on production and economic status of farmers, social benefits and future possible ways to make it sustainability through multiple uses of existing solar energy. The study data showed that 63% of SLI has been owned by individual farmers and 37% has group ownership where 86.7% SLI was found in working conditions. Though globally panel costs have declined rapidly, standalone off-grid SIPs still remain expensive from small and marginal farmers in Nepal. The GoN has been gradually increasing the budget allocated for subsidizing SIP. In 71% of total installed SLI, different government organizations like AEPC, Department of Irrigation, PMAMP etc., as well as NGOs & INGOs had shared 80-90% of the installation cost whereas, 100% installation cost has been supported by those organization in 25% of existing SLI users farm. Even, the GoN and support organization are investing huge cost for farmers, 70% of them are using it only for irrigating field and 16.7% are lifting water for livestock, fishing along with irrigation. This concluded that the farmers are not utilizing SLI technology efficiently, on the other hand farmers need huge energy for other farm operation like threshing, chaff cutting, winnowing, drying etc. which can be achieved from existing solar panel installed for SLI system. The study and expert group discussion concluded that since, about 87% of existing SLI had NEA grid nearby its site, it is possible to connect all those SLI system to NEA grid line to make the existing SLI system multifunction benefiting those farmers both in electric bill for supplying unused energy to NEA and can make the system applicable for broad areas of using agriculture machinery or any other farm operations.

In addition, this study explored opportunities for use and application of solar energy on agricultural ecosystems, sustainability and rights-based approaches to irrigation water management in the context of climate change. Particularly, how the multiple use of energy collected in solar panels could be made possible from same motor in different unit operations of agriculture was the main agenda. Three alternatives discovered includes;

i. Use of hybrid model,

ii. Conduct extensive research to understand what type of agricultural machineries can be operate from the existing SLI system and

iii. Upgrade the existing system for grid-connected SLI system.

Among these three alternatives, grid connection to NEA mains is found to be the most viable, sustainable and cost-effective to farmers because it works on the principle of Energy Bank which, not only uses produced solar energy but also sells the excess one. As it is a crystal clear proven fact that agriculture is one of the most energy-intensive profession, priority of clean energy in that sector could be the mild-stone in climate change management. The study also concluded that in stationary unit operations like drying, threshing, winnowing and etc., solar energy collected on the same panel could be utilized relatively easier compared to other operations.

The current strategy of solar energy application in lift irrigation could not be successful if favorable plan and policy will not be developed to bring the investment for its optimal output. This study thus, would like to recommend that the existing policy need to be improved in such a way that the users will be motivated to connect the SIP into the NEA grid line and subsidies the SIP based on the possible application by them so that the investment will be justified based on the productive uses of solar panel and also contribute national energy supply system. Grid-connected solar system could be the best option. However, a more systematic research about multiple use of solar power in different activities of agriculture from land preparation to post-processing has urgent need for sustainability of water and energy.

Acknowledgement

This formal acknowledgement may not express depth of feelings and emotion towards the persons and institutions who contributed this study. At first, we would like to express our profound gratitude & sincere appreciation to former project director, PMAMP- Binod Bhattrai and current officiating project director Hikmat Kumar Shrestha, who have been very kind and supportive throughout this study period. Next, a heartfelt appreciation goes to Mrs Ina Devkota for continuous cooperation and constructive advice to formulate specific objectives and Literature Review chapter of this book in the present shape. Expert group's valuable suggestions and free exchange of ideas facilitated us to deepen the selected subject matter of the study. Presence and assistance of all these valued people made the journey of this study important, exciting, and novel in the history of Nepal's agriculture sector, particularly linking multifaceted use of solar energy and agriculture.

Similarly, we would like to use this opportunity to express our heartiest respect and acknowledgement to PMAMP Madhesh province team: Er Uday, Mr Jha, Chandan, Er Ravi Chaudhary, Er Sunil Mandal; PMAMP Koshi province team: Er Jayes Koirala and Amrit Karki; PMAMP Gandaki province team: Roshan Adhikari, Er Arjun Gautam; PMAMP Karnali province team: Puspa Paudel, Er Pashupati Gareri, Kabita Shahi and Mina Thapa whose constant selfless support helped us from very beginning to end of this study. We are also thankful to all the staffs at PMAMP for supporting activities and finance. Last but not the least, we are also indebted to the printing press for quality publication on time.

References

Asian Development Bank 2016. Water Resources Project Preparatory Facility Package 6- Pre-Feasibility Study Report of Mid-Hill Lift Irrigation Project, available online at: 45206-001-tacr-en_1.pdf.

Allamine, H.M., Buyuktas, D., and Karaca, C. 2023. Effect of regulated deficit irrigation on productivity, evapotranspiration and quality of grain sorghum. *Irrigation Science* 41: 277–293.

Biswas, AK &Tortajada, C 2009, 'Changing global water management landscape', in AK Biswas, C Tortajada& R Izquierdo (eds), *Water resources development and management*, Springer, Berlin, pp. 1-34.

Chand, J., Akhter, F. and Jha, S. 2023. A Review on Challenges, Opportunities and Outlook of Water Sector Privatization for Sustainability and Water Scarcity Management. *American Journal of Water Science & Engineering* 9: 41-49.

Chand, J., Hewa, G., Hassanli, A. and Myers, B. 2021. Deficit Irrigation on Tomato Production in a Greenhouse Environment: A Review. *Journal of Irrigation & Drainage Engineering* 147: 1–10.

Chand, JB., Hewa, G., Hassanli, A. & Myers, B. (2023). Basic economics on deficit irrigation and water quality dynamics for horticulture production in a greenhouse environment. Australian Journal of Crop Science 17 (1), 52-60.

Corcoles, JI, de Juan, JA, Ortega, JF, Tarjuelo, JM & Moreno, MA 2012, 'Evaluation of irrigation system by using benchmarking techniques', *Journal of Irrigation and Drainage Engineering*, vol. 138, no. 3, pp. 225-234.

Costa, JM &Heuvelink, EP 2016, 'The global tomato industry', in E.P. Heuvelink (eds.), *Tomato production,* CABI Publishing, USA.

Dantas, F.D.G., Santos, M.V.F. and Lima, G.F.d. 2023. Drip irrigation with saline water combined with mulch cover as strategies for forage cactus production in semi-arid zones. *Irrigation Science* 41: 295–308.

Das, TK., Saharawat, YS., Bhattacharyya, R., Sudhissri, S., Bandyopadhyay, KK., Sharma, AR. and Jat, ML. 2018. Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize-wheat cropping system in the North-western Indo-Gangetic Plains. *Field Crops Research* 215, 222-231.

Davies, W, Wilkinson, S & Loveys, B 2002, 'Stomatal control by chemical signaling and the exploitation of this mechanism to increase water use efficiency in agriculture', *New Phytologist*, vol.153, pp.449-460.

Devkota, GP 2007. Renewable Energy Technology in Nepal. Universal Consultancy Services Pvt Ltd, Kathmandu, Nepal.

Dhungel, R., Anderson, R.G. and French, A.N. 2023. Remote sensing-based energy balance for lettuce in an arid environment: influence of management scenarios on irrigation and evapotranspiration modeling. *Irrigation Science* 41: 197–214.

Djurovi´c, N, Cosi´c, M, Striˇcevi´c, R, Savi´c, S &Domazetc, M 2016, 'Effect of irrigation regime and application of kaolin on yield, quality and water use efficiency of tomato', *Scientia Horticulturae*, vol. 201, pp. 271-278.

Du, T, Kang, S, Zhang, J, Davies & WJ 2015, 'Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security', *Journal of Experimental Botany*, vol. 66, pp.

2253-2269.

Duque-Acevedo, M, Belmonte-Ureña, LJ, Plaza-Úbeda, JA & Camacho-Ferre, F 2020, 'The Management of Agricultural Waste Biomass in the Framework of Circular Economy and Bioeconomy: An Opportunity for Greenhouse Agriculture in Southeast Spain', *Agronomy*, vol. 10, pp. 1-22.

Francaviglia, R & Bene, CD 2019, 'Deficit Drip Irrigation in Processing Tomato Production in the Mediterranean Basin. A Data Analysis for Italy', *Agriculture*, vol. 9, pp. 1-14.

Gao, H., Fu, T. and Tang, S. 2023. Effects of saline water irrigation on winter wheat and its safe utilization under a subsurface drainage system in coastal saline-alkali land of Hebei Province, China. *Irrigation Science* 41: 251–260.

Garcia-Caparros, P, Contreras, JI, Baeza, R, Segura, ML & Lao, MT 2017, 'Integral Management of Irrigation Water in Intensive Horticultural Systems of Almería', *Sustainability*, vol. 9, pp. 1-21.

Gautam, U. 2012. Nepal: Food security, a localized institutional irrigation perspective on public irrigation systems. *Hydro Nepal: Journal of Water, Energy and Environment* 11: 95-99.

Gautam, K.R., Pande, P.R., Paudel, R. and Pradhan, A. B. 2016. Pre-Feasibility Study Report of Mid-Hill Lift Irrigation Project. Retrieved from ADB: https://www.adb.org/sites/default/files/project-documents/45206/45206-001-tacr-en_1.pdf.

Giuliani, MM, Carucci, F, Nardella, E, Francavilla, M, Ricciardi, L, Lotti, C &Gatta, G 2018, 'Combined effects of deficit irrigation and strobilurin application on gas exchange, yield and water use efficiency in tomato (Solanum lycopersicum L.), *Scientia Horticulturae*, vol. 233, pp. 149-158.

Godfrey, S, Labhasetwar, P &Wate, S 2009, 'Grey water reuse in residential schools in Madhya Pradesh, India- a case study of cost-benefit analysis', *Resources, Conservation and Analysis,* vol. 53, no. 5, pp. 287-293.

Hashem, MS, El-Abedin, TZ & Al-Ghobari, HM 2018, 'Assessing effects of deficitirrigation techniques on water productivity of tomato for subsurface dripirrigation system', *International Journal of Agricultural and Biological Engineering*, vol. 11, pp. 156-167.

Hassanli, A M &Pezzaniti, D 2013, 'Crop irrigation scheduling in South Australia: a case study', *Water*, vol. 40, pp. 92-97.

ICID. 2023. Which on-farm techniques can increase water productivity, available at: https://congress.icidevents.org/About.aspx.

International Water Management Institute 2024, Available at: https://solar.iwmi.org/country-updates/nepal/.

Jha, SK, Gao, Y, Liu, H, Huang, Z, Wang, G, Liang, Y & Duan, A 2017, 'Root development and water uptake in winter wheat under different irrigation methods and scheduling for North China', *Agricultural Water Management*, vol. 182, pp. 139-150.

Justice, S; Biggs, S 2013. In mechanization for rural development: a review of patterns and progress from around the world. Food and Agriculture Organization of the United Nations (UNFAO). pp: 67-98.

Koumpli, A. & Kanakoudis, V. (2022). Privatization and Remunicipalization of Water Supply: A Global Research. Environmental Sciences Proceedings 21, 1-9

Lamsal, D 2024. Sustainability and Life Cycle Cost Assessment of the off-grid and on-grid lift irrigation schemes of Bagmati Province, Nepal. Master's Thesis. Thesis for the Degree of Master of Science in Interdisciplinary Water Resources Management (iWRM). Nepal Engineering College, Pokhara University, Nepal.

Lea-cox, JD, Bauerle, WL, Iersel, MWV, Kantor, GF, Bauerle, TL, Lichtenberg, E, Kind, DM & Crawford, L 2013, 'Advancing wireless sensor networks for irrigation management of ornamental crops: an overview', *HortTechnology*, vol. 23, pp. 717-724.

Liu, J, Hu, T, Feng, P, Wang, L & Yang, S 2019, 'Tomato yield and water use efficiency change with various soil moisture and potassium levels during different growth stages', *PLOS One*, vol. 14, pp. 1-14.

Lovelli, S, Potenza, G, Castronuovo, D, Perniola, M & Candido, V 2017, 'Yield, quality and water use efficiency of processing tomatoes produced under different irrigation regimes in Mediterranean environment', *Italian Journal of Agronomy*, vol. 12, pp. 17-24.

Lu, J, Shao, G, Cui, J, Wang, X &Keabetswe, L 2019, 'Yield, fruit quality and water use efficiency of tomato for processing under regulated deficit irrigation: A meta-analysis', *Agricultural WaterManagement*, vol. 222, pp. 301-312.

Mantri, S.R.; Kasibhatla, R.S.; Chennapragada, V.K.B. 2020*. Grid-connected vs. off-grid solar water pumping systems for agriculture in India: A comparative study. Energy Sources, Part A: Recovery, Utilization and Environmental Effects.*https://doi.org/10.1080/15567036.2020.1745957

Mérida García, A.; Gallagher, J.; McNabola, A.; Camacho Poyato, E.; Montesinos Barrios, P.; Rodríguez Díaz, J.A. 2019. *Comparing the environmental and economic impacts of on- or off-grid solar photovoltaics with traditional energy sources for rural irrigation systems.* Renewable Energy 140: 895–904. https://doi.org/10.1016/J.RENENE.2019.03.122

Meron, M 2007, 'Irrigation scheduling', in FR Lamm, JE Ayars& FS Nakayama (eds), '*Micro irrigation for crop production',* Elsevier, Amsterdam, The Netherlands.

Michael, AM; Ojha, TP 2014. Principles of Agricultural Engineering Volume 1. Jain Brothers, New Delhi, India.

Mishra, AK 2014, 'Climate change and challenges of water and food security'*, International Journal of Sustainable Built Environment*, vol. 3, pp. 153-165.

Montazar, A 2019, *Agricultural Irrigation*, MDPI, Basel, Switzerland.

Montenegro, SG, Montenegro A & Ragab, R 2010, 'Improving agricultural water management in the semi-arid region of Brazil: experimental and modelling study', *Irrigation Science*, vol. 28, pp. 301–316.

Montesano, FF, Serio, F, Mininni, C, Signore, A, Parente, A&Santamaria, P2015, 'Tensiometer-based irrigation management of sub irrigated soilless tomato: Effects of substrate matric potential control on crop performance', Frontiers *in Plant Science*, vol. 6, pp. 1-11.

NASA (2023). Freshwater Availability Toolkit. https://www.earthdata.nasa.gov/learn/toolkits/freshwater- availability-toolkit (accessed 1 March 2023).

PMAMP 2023. Agricultural Mechanization: Inventory, Expenditure and Outcome. Available at: https://www.pmamp.gov.np/sites/default/files/2023-07/PMAMP%20INVENTORY%20BOOK%20 2080.pdf.

Pradhan, P. and Belbase, M. 2018. Institutional reforms in irrigation sector for sustainable agricultural water management including water user associations in Nepal. *Hydro Nepal: Journal of Water, Energy, and Environment* 23: 58-70.

Prasad, N. (2014). PRIVATISATION OF WATER: A HISTORICAL PERSPECTIVE. Law, Environment and Development Journal 3, 1-21.

Practical Action 2023. Available at: https://practicalaction.org/news-media/2021/09/03/10-barriers-stopping-solar-powered-irrigation-at-scale-in-nepal/.

Prazeres, AR, Rivas, J, Almeida, MA, Patanita, M, Dores, J & Carvalho, F 2016, 'Agricultural reuse of cheese whey wastewater treated by NaOH precipitation for tomato production under several saline conditions and sludge management', *Agricultural Water Management*, vol. 167, pp. 62-74.

Pulido-Bosch, A, Rigol-Sanchez, JP, Vallejos, A, Andreu, JM, Ceron, JC, Molina-Sanchez, L & Sola, F 2018, 'Impacts of agricultural irrigation on groundwater salinity', *Environmental Earth Sciences*, vol. 77, no. 197, pp. 1-14.

Riazi, F., Fidelis, T., Matos, M. V., Sousa, M. C., Teles, F. & Roebeling, P. (2023). Institutional arrangements for water reuse: assessing challenges for the transition to water circularity. Water Policy, 1-20.

Scheer, C, Grace, PR, Rowlings, DW &Payero, J 2013, 'Soil N2O and CO2 emissions from cotton in Australia under varying irrigation management', *Nutrient Cycling in Agroecosystems*, vol. 95, pp. 43-56.

Scherer, TF, Franzen, D &Cihacek, L 2017, 'Soil, water and plant characteristics important to irrigation', North Dakota State University, North Dakota, USA.

Shrestha, S; Neupane, N. 2023. Can Solar or electric-based irrigation pumps be alternatives to diesel pumps for sustainable groundwater irrigation in Nepal's Terai. Proceedings of the National Groundwater Symposium 2023.

Shrestha, S.; Uprety, L. 2021. Solar irrigation in Nepal: a situation analysis report. Colombo, Sri

Lanka: International Water Management Institute (IWMI). 43p. doi: https://doi.org/10.5337/2021.218.

Stikic, R, Popovic, S, Srdic, M, Savic, D, Jovanovic, Z, Prokic LJ &Zdravkovic, J 2009, 'Partial root drying: A new technique for growing plants that saves water improves the quality of fruit', *Bulgarian Journal of Plant Physiology*, vol. 2, pp. 164-171.

Valipour, M 2015, 'Future of agricultural water management in Africa', *Archives of Agronomy and Soil Science*, vol. 61, pp. 907-927.

Zhang, D, Du, Q, Zhang, Z, Jiao, X, Song, X & Li, J 2017, 'Vapour pressure deficit control in relation to water transport and water productivity in greenhouse tomato production during summer', *Scientific Reports*, vol. 7, pp. 1-11.

Solargis, 2017, "Solar Resource and Photovoltaic Potential of Nepal," World Bank Group (ESMAP), 2017.

MOPE, 2016. Ministry of Population and Environment, "Renewable Energy Subsidy Policy, 2073 BS," Ministry of Population and Environment, GoN, Kathmandu.

Pandey, V. P., Kafle, K., Upreti, L., Mukherji, A., Shrestha, G., & Khadka, M. (2020). A Rapid Assessment of AEPC's Subsidy Delivery Mechanism for Solar Irrigation Pumps (SIPs) in Nepal. Kathmandu: International Water Management Institute.

ANNEX

Annex I: Sample Format of Questionnaire for KII and FGD

Objective of field study were explained to the Solar Lift Irrigation users to perceive their vision in adaptation of such technologies and their experience in utilizing it through following Questionnaire?

1. Location of Lift Irrigation System:

   Altitude: ………m Coordinate: …………………………………….........
   Date: ………

2. Lift irrigation system owned by: **Individual** *(go to 2.1)*/ **Group** *(go to 2.2)*

   2.1. Name of pump owner (if individual): ……………………………….....

   2.2. Group Name (if owned by group): ……………………………...............

   and name of group leader: ………………………………………....................

3. Address of owner/group: ……………………………………………………....

   ……………………………………… Mobile No.: ……….............................

4. Local suppliers contact: …………………………………………….............

5. Infrastructure nearby the lift irrigation:

   5.1. Electricity grid line: Yes / No if Yes: NEA/ Micro-hydro/ Solar

   5.2. Road: Yes / No if Yes: Highway/ Rural road/Narrow path/ Field Bunds

Lift Irrigation System Information:

6. Water lifted from: Ground water/ Running river/ Well/ Pond/ ....

7. Current status: On Use/ Not in Use/ Will be used after (**Simple/ Major)** repair

   7.1. What are major reasons (if not in use): ....
   …...

8. Major uses of water lift system: **Irrigation** (goto 8.1)/ **Drinking water** (goto 8.2)/ ………..

8.1. Irrigation area covered: ………. Ha/ Kattha/ Bigha/ Ropani/ ……………….

8.2. Drinking household covered: ……………… household

9. Installation year (YYYY/ MM/ DD): ………………………….

10. Installation cost (Complete set of lift irrigation system): NRS ………………….

11. Supporting Organization (if any): ………………………………………..............

12. Cost of installation shared by:

Individual or Community: All Cost /…………. % / NRS ………………...
Support organization: All Cost / ……………. % / NRS …

Lift Irrigation Design Parameters:

13. Source of power: Electrical/solar/ diesel engine/petrol engine/Traditional (manual)/ Zero energy/ power tiller/ ……

13.1. If Solar lift system:

i. Output: System Voltage (V_{max}) = …….. V

Current (Imp) = …….. A Power (P_{max}) = …….. Watt

ii. Average sunshine hour/day in a particular month:

Month	बै.	जे.	अ.	सा.	भा.	आ.	का.	म.	पु	मा.	फा.	चै.
Hr/day												
Climate												

Climate: **H** for high (Sunny), **M** = medium, **L** = low (Foggy), **R** = rainy, **S** = snow

iii. DC input: DC voltage = …… V DC current = ……… A

iv. AC output: output voltage = … V Rated current =...... A (1-ϕ); ....A (3-ϕ)

v. **Do solar power of solar irrigation system used for other than irrigation: Yes/ No**

If yes, what purpose? ……………………………………………………..

13.2. If other source of power used for operation of pump please specify its capacity:

………………………………………………………………………………

14. Energy/Fuel required to operate pump for 1 hour: ………………………

15. Pump categories: Centrifugal/Reciprocating piston pump/paddle pump/…………………

16. Pump Model No: …………………… Company: ………………………….

17. Operator: Male / Female Age: ………… Years

18. Lifting Head: Rated Head: ………... Measured actual head: V/H ………

19. Discharge: Rated ……………. LPS Measured ….……... LPS

20. Rent cost for lifting irrigation water for 1 hour: NRS …………

21. Do lift irrigation system have storage tank? Yes/ No

21.1. If yes, Capacity of tank: ……………….…………… M^3 / Liters

22. Basic Requirement for Operation: ………………………………………

………………………………………………………………………….

23. Number of times the pump repaired annually: ……….

24. Average cost required per repaired: NRS ………….. or Repaired Cost/ Year: NRS …..

25. Most repaired parts: ……………………………………………………...

26. Do the yield improved after installation of lift irrigation system: Yes/ No

26.1. If yes, how much? …………………………….

26.2. If No, what are major reason/ drawback: ………………………………

27. Lift Irrigation Operation Schedule:

Crop Type: Name			
Crop Schedule (month: from ~ To)			
Crop Area			
No of operation day			
Operation Hour /Day			

28. Are the farmers/Operator satisfied with this lift irrigation set? Yes / No

    If No what is the expectation: ……………..……

29. General feedback of farmers: ………………………………………………
    ………………………………………………………………………………
    ………………………………………………………………………………
    ……………………………………………………………

30. Evaluator Remarks: …........……………………………………………………
    …………………..........................……………………………………………
    ………………………………………………………………………………
    ………………………………………………………………………………
    ………………………………………………………………………………
    ………………..

Evaluator Name/Signature:

Annex II: Location Information of Study Area

Site ID	Altitude (m)	Lat.	Long.	Ownership (*)	Ownership Name	Owner Mobile	Group Name (if own by Group)	Pump Location Information	Local Suppliers	Install Year
1	142.95	27°03'58"	85°33'57"	2	Ram B. Banjam	9862570533	Kothi Khola Khane Pani	Hariyon-1, Koti Khola, Sarlahi	NYS Eng. & Construction	2080/02
2	117.65	26°55'23"	85°37'04"	1	Jagat Narayan Tharu	9746690581	NA	Chandranagar Ga.Pa., 1 Sarlahi		2079/02
3	146.30	26°59'58"	85°38'25"	1	Upendra Mahato	9809631313	NA	Ishworpur-10, Muni., Babarganj	Gangamai Sinchie Yajona	2080/02
4	195.07	26°56'16"	85°56'42"	3	Kushal Project Nepal	9844059197	Mithila Solar PV Power	Mahendranagar, Janakpur, Dhanusa	ECO Power Dev.Comp.P.	2078
5	145.69	26°51'33"	86°12'39"	1	Keshab P. Koirala	9811788455	NA	Karjanha, Magarwasha, Siraha		2079
6	123.14	26°49'30"	86°14'12"	1	Usha davi Mahaseth	9842828340	NA	Mirchaiya, Jiba-1, Siraha		2079
7	146.00	26°37'52"	86°45'58"	1	Jogilal Chaudhari	9807725160	NA	Jandaul, Aganisair, Saptari		2078
8	144.17	26°37'51"	86°46'01"	1	Puspa Devi (Tharuni)	9807765875	NA	Jandaul, Aganisair, Saptari		2078
9	519.07	27°25'15"	85°52'04"	2	Manil K. Shrestha	9810234327	आमा समुह, बेलधारी	Gumari chaour, Khadadevi, Ramachhap	C & S Electric	2078
10	428.55	28°06'38"	84°13'24"	2	Shiva Prasad Ojha	9846442067	पोल्याङ्गटार टाकुन्जा कृषक समुह	Polayangtaar Rupa Ga. Pa. 3, Kaski	Mukti Energy	2079/01
11	665.38	28°09'28"	84°06'40"	3	Purna Bahadur Gurunj	9810021892	गुरुङ्ग एग्रो फारम	Simaldanda, Pachabiya, Kaski	Mukti Energy	2078/01
12	1043.94	28°16'51"	83°56'34"	2	Budhi Prasad Bhandari	9820632178	Belchautara Krishak samuha	Pokhara-25,Hemja, Kaski	SK Machineries, Pokhara	2080/01
13	734.57	28°10'33"	83°58'28"	1	Ganesh Pandey	9856013491	NA	Pokhara-17, Birauta, Kaski	Mukti Energy	2078/12
14	95.40	26°30'48"	87°16'55"	3	Purna Chaudhari	9848295199	GI Solar Pvt. Ltd.	Buddhiganga-4, Morang	Kushal Project Nepal	2079/12
15	92.66	26°29'57"	87°16'31"	1	Babu Raja Shrestha			Morang	Self Designed	Contn.
16	81.08	26°23'20"	88°00'42"	2	Laxmi Pajyar	9804932531	हरित कृषक समुह	Kachankawal Ga.Pa.-4, Jhapa		2074/75
17	73.15	26°23'22"	88°00'21"	3	Ravi Chandra Ojha	9824985990	साना किसन कृषि सहकारी स.लि.	Kachankawal Ga.Pa.-6, Jhapa		2074
18	77.72	26°23'21"	88°01'35"	2	Babita Kafle		बनियानी कृषि सहकारी	Kachankawal Ga.Pa.-6, Jhapa		2075
19	82.30	26°25'20"	88°00'55"	2	Dilli Nepal	9852677952	सवायेम्बु कृषक समुह	Kachankawal Ga.Pa.-6, Jhapa		2074
20	83.82	26°22'02"	88°00'05"	2	Tika Chhapaguai	9815003009	त्रिबेणी महिला कृषक समुह	Kachankawal Ga.Pa.-3, Jhapa		2075
21	71.63	26°23'43"	88°02'11"	2	Damber B. Limbu	9813372552	सयपत्री कृषि सहकारी	Kachankawal Ga.Pa.-3, Jhapa		2075
22	74.68	26°24'06"	88°01'33"	2	Binod Khadka	9842672502	साना किसान सहकारी	Kachankawal Ga.Pa.-3, Jhapa		2074
23	70.35	27°2'20"	84°31'31"	1	Binda Shah			Chhirpur-5, Bishwa		2076
24	70.22	27°1'51"	84°42'49"	1	Nazir Miya	9811246909		Chirpur Nagarpalika-5		2077
25	180.72	27°34'8"	84°36'23"	1	Dan P. Bhandari			Khairani		2077
26	110.36	27°34'15"	84°36'36"	2		9814883193	Group	Bagmati Nagarpalika-55		2077
27	90.51	27°27'23"	84°55'49"	1	Radha K. Tamang	9855061368		Sundi, Chitwan	Namuna Energy	2076/77
28	170.49	27°33'54"	84°35'16"	1	Suraj Mahato			Chitwan		2076/77
29	140.01	27°34'46"	84°14'27"	1	Bandhu Chaudhary	9845078516		Garuda, Mohamadpur-5		2076/77
30	140.56	27°35'43"	84°34'06"	1	Bachan Mahato	9845320578		Khairani-7, Chitwan	Pradesh Nirdeshanalaya	2076/77

* Ownership: 1 = Individual 2 = Group 3 = Company/ Industry

Annex III: Photographs of FGD Meeting and SLI Study Site Visit

Surkhet- Karnali Province

Ramechhap- Bagmati Province

Siraha, Saptari- Madhes Province

Morang- Koshi Province

Morang- Koshi Province

Jhapa- Koshi Province

Kaski- Gandaki Province