Kathmandu University Journal of Science, Engineering and Technology, Vol. 14, No. 2, December 2020

Kathmandu University
Journal of Science, Engineering and Technology

Techno-economic analysis of solar water pumping system for irrigation in Nepal

Amrit Karki* and Sunil Prasad Lohani

Department of Mechanical Engineering, School of Engineering, Kathmandu University, Nepal

Abstract

Solar water pumping system is a process, where electricity is used to drive water pump produced from solar PV. It makes solar PV, a flexible device to be used in remote Terai- plane area in the southern region and hilly region of the country where grid connection is inaccessible. The geographical belt of Nepal is in a very good solar region having about 4 to 5 peak sun hours and more than 300 sunny days in a year. Over 22 percent of agricultural land in Nepal does not have access to irrigation round the year. However, the immediate challenges for mass dissemination of solar water pumping system is the capital cost of the system which is beyond the affordable range for small farmers and rural people. Moreover, perceived benefit analysis of investment on solar water pumping system for irrigation along with possible extension of grid seems essential for investment decision. This paper presents the techno-economic analysis of solar water pumping system based on the design, investment and yearly return from the crops per hectare of land that could be applied in remote Terai areas of Nepal. Result shows the discounted payback period of nine years, which is within the lifetime of the system. Other economic parameters for instance, benefit cost ratio of 1.6 and internal rate of return of 18.15 % mark favorable to invest for the system. In addition, the solar water pumping system is compared with grid-electric pumping system. The cost of a pumping system operated by grid electricity includes the cost of feasible grid extension. The grid extension length is calculated in view of permissible voltage constraint which was performed with software DIgSILENT PowerFactory. The results indicated that, up to four hectare of land, investment on solar water pumping system seems more economical than grid-electric water pumping system with grid extension for a kilometer.

Keywords: Irrigation; Solar water pumping system; Grid electricity; Agricultural yield; Investment decision

1. Introduction

Solar energy is one of the abundant sources of energy in Nepal. Solar Photo-Voltaic (PV) technology generates electricity from solar energy that can be used for various purposes without any harmful emission. This technology is reasonably favorable in many parts of the country due to availability of high intensity of solar energy and could be a reliable source of energy at places where the national grid has not been available yet. In addition, the time required to set up a solar PV system is very short. It seems to be an attractive and acceptable form of energy source especially in rural parts of the country as off-grid energy systems. The only challenge is upfront cost is relatively high, however once the installation is done, there is negligible cost for operation and maintenance of such system.

Solar water pumping system is one of the emerging sectors of solar PV applications in Nepal which can be a realistic solution for irrigation in rural Terai and hilly parts of the country. Terai regions are known to be an agricultural hub of the country with insufficient irrigation systems. Having huge potential of surface and underground water availability, a solar water pumping system for irrigation would be a quick and practical way out. However, if a grid line is available in the nearby region, extension of grid line may be economical than solar power system for larger land irrigation coverage [1]. The aim of this study is to find the technical and economical evaluation of solar water pumping system for irrigation in the Bara district, a rural Terai region of Nepal. The design of the system is based on the water demand of major crops cultivated and the average head of underground water available. The study estimates the cost of system per hectare land to supply the required amount of water for paddy production. Paddy is considered for designing the system as it is the major crop cultivated in Terai. For the purpose of analysis, the investigation considers a solar water pumping system supplying 3.56 hectare of land located in the rural part of Bara district. The yearly return of the investment in the irrigation system is the net revenue collected from the sale of agricultural products. The payback period, benefit cost ratio and internal rate of return (IRR) are evaluated in order to determine the financial feasibility of such systems. The study also estimates the economic length of grid extension for irrigation systems within the same investment of solar systems.

1.1. Agriculture, water and irrigation scenario in Nepal

Nearly half of the world's population depends on groundwater sources for drinking, irrigation, sanitation, industrial processes and thermal power plants [2]. Among the total global water uses, estimated water for irrigation consumes about 80 to 85 percent [3]. The surface water available in Nepal is estimated to be about 225 billion m^3 (BCM) per annum or equivalent to an average flow of 7,125 m^3/s, out of which only 15 BCM per annum is in use and in addition to surface water, a large volume of water is available in the shallow and deep aquifers which are estimated to be 8.8 BCM annually [4]. Around 95.9 percent of 15 BCM has been used for agriculture, 3.8 percent for domestic purpose and about 0.3 percent for industrial purposes [4].

Nepal has been an agricultural country from ancient times. Nepal was self-sufficient in food supply and grain production until

*Corresponding author. Email: amreetkarki@gmail.com

Table 1: Agricultural and irrigable land in Nepal [6].

Topographical regions	Agricultural land (ha)	Irrigable land (ha)
Mountain	227000	60000
Hilly	1054000	369000
Terai	1360000	1338000
Total	2641000	1766000

1990AD [4]. Nepal's economy is largely based on agriculture contributing about 30% to GDP [4]. More than 60% of the population is involved in agriculture and related activities, in which 68% is rural population [5]. The total agricultural land and proportion of irrigable land as per the topographic regions in hectare is shown in Table 1. The irrigable land is a land that is feasible for irrigation through gravity canal from nearby available surface water resources. Still a huge part of agricultural land remains unirrigated but there is the chance of getting water facility through energy sources.

Irrigation is the basic requirement for agricultural activity which increases the productivity of the land. An estimate shows that less than 8% of the country's water potential is used for irrigation [4]. The government of Nepal has started the development of an irrigation facility since 1922 AD which is nearly a century ago but there is yet to cover about 22 % of total irrigable land [7]. Among the total irrigated area 780,415 ha is served by surface water, 409,463 ha is served by ground water and 202,299 ha is served by traditional farmer made canal which is a gravity flow earthen canal made to reach to the river or pond [6].

Nepalese agriculture is mainly rain fed in core Terai regions. Agriculture production in both rain fed as well as irrigated areas are being badly affected due to droughts, flooding, erratic rainfall, and other extreme weather events. Such calamities affect the normal water volume in the source of the existing irrigation system causing overflow or lack of water in the canal. For small scale irrigation with financial support, application of solar powered water pumps can improve the living standard of underprivileged groups in rural areas. Recently, Government of Nepal and India jointly financed to provide irrigation facilities to the major Terai districts by 1350 shallow and 22 deep tube well water pumps [6]. Also, NEA regulates the electricity tariff for irrigation at lowest rate amongst all other consumers [8].

1.2. Significance of solar water pumping system for irrigation

Majority of the population is 60% of total involved in agriculture in Nepal [5]. Despite having rich potential of surface and ground water with agricultural land, lack of irrigation and available energy sources, make us lose the food production. Traditional and old structured irrigation systems operated at local level have less efficiency despites the efforts made on laborious methods [9]. The large volume of water needed for irrigation can only be provided by electro-mechanical means which pump the water from underground or nearby surface water sources, and the similar condition was seen in the field survey as shown in Fig. 1.

Fig. 1 shows the irrigation canal in Bara-Telkuwa in the month of August, a peak rainy season which clearly indicates that the situation of water supply in the dry season is worse for agricultural activity. Hence, the water requirement is significantly high. Moreover, in rural areas water pumps driven by fuel-burning generators seem to be unaffordable by most of the farmers and not a suitable maintenance and repairs facility is available.

Figure 1: Irrigation canal in Bara.

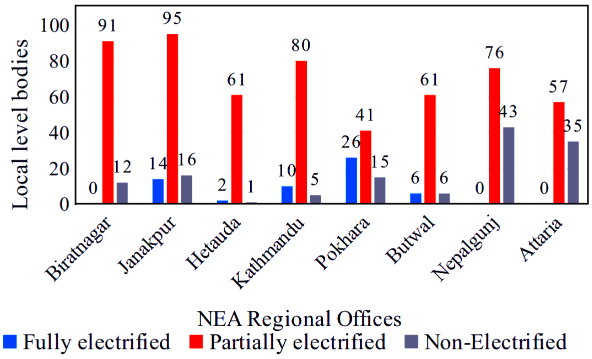

Figure 2: Electrification status of Nepal [8].

Fig. 2 shows that among 753 local level bodies of Nepal including metropolitans, sub-metropolitans, Municipalities and Rural-Municipalities, 7.70% are fully electrified, 74.63% are partially electrified (the electrification status below 50 percent) and 17.66% are non-electrified, which means there is a huge potential of solar water pumping system for irrigation [8]. In addition it has a potential to replace the imported fossil fuel source too. Introduction of efficient pumping technology and methods will help to build agricultural capacity in the rural areas and in the district at large [10]. A case study of Saptari district shows that, by the application of solar water pump, the net irrigated area is increased by 30% than the irrigation that was done using diesel and electric pumps [5].With the current subsidy scheme on solar system for irrigation supported by the government through AEPC, maximum amount up to 60% of the total cost, not exceeding NRs. 2, 000,000 per system will be provided [11]. Thus, considering these scenario, solar powered pumps seem economical, reliable and sustainable [12].

2. Method

2.1. System components description

Solar water pumping system is based on Photovoltaic (PV) technology that converts sunlight into electricity to pump water. Fig. 3 shows the schematics of a solar water pumping system. The key factors for solar water pumping system design depends on water source, daily water requirement, pumping head and the solar irradiance in the area.

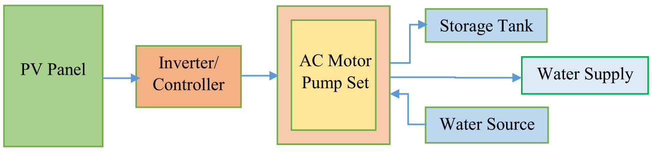

Figure 3: General schematic of solar water pump system.

2.2. Photo voltaic module

PV panels absorb and convert shortwave solar irradiance into Direct Current (DC) electricity to charge batteries or can be used directly. The power generated by a PV panel is influenced by several factors, such as the DC rating, tilt angle and the geographic location of the panel or solar irradiation profile of the site. A PV panel typically has a lifetime of 25 years [13]. The available PV module technology in the market are mono-crystalline, polycrystalline and amorphous, silicon., The PV cell performance declines as cell temperature and shading rises, that is, it has negative temperature coefficient of 0.5% per degree Celsius for crystalline silicon [13, 14].

2.3. Inverter, controller and battery set

An inverter changes DC voltage into usable AC voltage for AC appliances. Inverters are classified based on installation type, output power, and output wave format. For a safe and longer life of battery, a charge controller is an essential tool. A charge controller or battery regulator limits the rate at which the electric current is added to or drawn from electric batteries, which in turn helps prevent overcharging and potentially protects against overvoltage. Maximum Power point Tracker (MPPT) - charge controller is an electronic tracking charge controller which has higher efficiency in conversion. The MPPT- charge controller tracks the voltage and current point at which the PV panels develop maximum power, thus maximizing the overall output of the solar system [15]. For the system like water pumping where there is no emergency for back up supply MPPT- charge controller and storage tank can be used as an alternative to battery backup.

2.4. Surface mounted pump set

Surface mounted DC/AC motor pump sets are located near the water surface and are used primarily for moving water through a pipeline. Some surface mounted pumps can develop high heads and are suitable for moving water to long distances or to higher elevations. The typical suction abilities for surface solar water pumps are between 10 to 20ft used for household and community **[16].** Surface pumps also have greater exposure to the extreme climate, making them more vulnerable to freezing and harsh weather. These pumps have a higher rate of mechanical problems and failure because of the dynamics of pulling up water from well. The loss of priming fluid (water) in surface pumps can cause the burning of motor, requiring replacement. The lower efficiency due to power losses in the shaft bearings and the high cost of installation are the major disadvantages. The versatility of the surface floating unit sets makes it ideal for irrigation pumping from canals and open wells.

2.5. Deep well (submerged) pump set

The deep well submersibles pump does not work unless it is completely submerged in liquid. A typical deep well pump is 2–4 ft long and 3–5 inch in diameter which consists of an air-tight sealed motor that is closed-coupled to the body of the water pump [16]. The motor drive impeller is mounted on a single shaft. The rest of the unit consists of a cable connected to the motor and a pipe that transports the water to the surface. This is the most common type of motor pump set used in solar water pumping systems for water supply. The advantages of this equipment are easy installation, often with flexible pipe work and is submerged deep in the water thus preventing potential damage. Those submersible pumps, specifically designed for solar power have an overall efficiency of 40–70% [16].

2.6. Motor selection

Both AC and DC motors can be used along with the irrigation pump set. DC motors in general consume one-third to one-half the energy than that of AC motors but are costlier and suitable up to 3 kW system because of its common disadvantage associated with the brush contacts and commutator which require frequent maintenance [14, 17]. For submersible application the pump needs to be removed from the well for maintenance and replacing brushes thus increases running cost and decreases reliability. Since the PV panel generates DC electricity, in such a pumping system, a suitable inverter is required to convert DC to AC electrical power. The induction motor is popular for submersible pumps because of its robustness, demanding much less maintenance and is available at lower cost than DC system [18]. The advantage of the AC motor is that it can run even on grid power in case of unavailability of sufficient PV power during night hours or during cloudy days. Single phase and three phase induction motors are used, either as per the self-starting, high starting torque, high power factor, and high efficiency of three phase motor or easy maintenance and low cost of single phase motors.

2.7. Pump selection

A pump selection is based on the nature of fluid, head and discharge required by the work. Based on design and operating principle, pumps are divided into two major groups as positive displacement and non-positive displacement or dynamic pump [19]. Positive displacement pump works by forcing a fixed volume of fluid from inlet to outlet of pump and is further classified into rotary and reciprocating type. The rotary pump moves fluid by rotating mechanism and reciprocating pump moves the fluid using one or more oscillating pistons or plungers with valves. Also, a non-positive displacement pump works when an increase in fluid pressure from inlet to outlet is created, then this pressure difference drives the fluid. It is further classified as a centrifugal pump and special effect pump. Centrifugal pumps are the most common type which uses a rotating impeller to increase the pressure and flow of the fluid. By the nature of flow, centrifugal pumps are classified under radial, mixed and axial-flow pump. Positive displacement pump (reciprocating) has lower flow rates and work on high heads, which is less affected by head and low variation in irradiation whereas due to presence of high speed impellers centrifugal pumps are suitable for large flow rates and low head applications and on increasing on head and decreasing in irradiance reduce the flow rate [19].

2.8. Design of the system

For the sizing of the solar water pumping system, the following equations have been used.

2.8.1. Motor-pump capacity

Motor-pump capacity (P_{mp}) in kW is calculated as shown in equation 1 [19].

$$P_{mp} = \frac{9.81x\ TDH(\text{m}) \times Q(\text{m}^3/\text{s})}{\eta_{mp}} \quad (1)$$

where, η_{mp} is motor-pump system efficiency as given in equation 2.

$$\eta_{mp} = \frac{\text{hydraulic energy output}}{\text{electrical energy input}} \quad (2)$$

2.8.2. Solar photo voltaic array capacity

Solar photo voltaic array power (P_{pv}) in kWp is as given in equation 3 [14].

$P_{pv} = E_h / (I_T \times F_m \times F_t)$ (3)

Where, I_T is the average daily solar irradiation (kWh/m^{2}day) incident on the plane of array, F_m is the array mismatch factor; generally used 0.8, F_t is temperature derating factor for array power loss due to heat; generally 0.8 for warm climate and 0.9 for cool climate [19,14], and E_h is hydraulic energy in kWh is as shown in equation 4 [14].

$E_h = \rho \times g \times V \times \text{TDH} / (\eta_{mp} \times \eta_i \times 3.6 \times 10^6)$ (4)

Where, ρ is the water density, g is the acceleration due to gravity (9.81 m/s^2), TDH is the total dynamic head (m), V (m^3/day) is the volume of water required per day and η_i is the inverter efficiency; generally set to 0.9 to 0.95[20].

2.8.3. Inverter capacity

Inverter size in kVA is given by equation 5 [14].

Inverter capacity = $\frac{\text{Load in kW}}{\text{Load p.f.} \times \eta_i}$ (5)

Where, p.f. is the power factor of the induction motor generally lies between 0.7 to 0.9 and the actual rating of inverter is always needed to be overrated by 20- 25 % considering the safety factor for starting(inrush) current [21].

2.9. Selection of conductor length

DIgSILENT PowerFactory is an assimilated power system analysis tool that comprises reliable and flexible system modelling capabilities with advanced solution algorithms and unique object-oriented database management [22]. Extension of a distribution line is the distance up to which a certain load is supplied without violating the conductor loading and voltage drop limits [23]. Among a variety of power analysis features of the Power Factory package, load-flow is used for the analysis.

2.10. Methods for economic analysis

The following methods are applied to calculate the economic evaluation of the system.

2.10.1. Net Present worth (NPW)

This method gives the definite decision rule. If the NPW is a positive value, then the project is suitable to invest. It is calculated as:

NPW = Equivalent PW of future cash flow – Initial investment [24]

For current value of a future sum with a specified return rate and for uniform series is calculated as:

PW= $\frac{(1+i)^n - 1}{i\ (1+i)^n}$ [25]

Where, i is rate of return and n is return period of the project.

2.10.2. Benefit Cost (B/C) ratio

This method gives the rate of gain from the investment within the lifetime of the project at present value and is calculated as given in equation 6 [24, 25]:

B/C ratio= $\frac{\text{PW of benefit}}{\text{Initial Investment}}$ (6)

The B/C ratio must be equal or greater than 1 to accept the project. Higher the value of B/C ratio it will be better to invest.

Table 2: Water demand and base period of major crops [7].

Major crops	Average water requirement (cm)	Average base period (day)
Paddy	90	120
Wheat	45	130
Maize	50	130
Potato	50	150
Pulses	50	120
Mustard	35	125
Sunflower	90	100
Radish	30	60
Cabbage	30	120

2.10.3. Discounted payback period

This method gives the time of return on investment. Discounted payback method accounts for the time value of money and will give a more accurate estimate on return than simple payback method. To evaluate discounted payback period, discounted cash inflow for each period is calculated as shown in equation 7[24]:

Discounted cash flow= $\frac{\text{Actual Cash inflow}}{(1+i)^n}$ (7)

Where, i is the discount rate and n is the period to which cash inflow occurs.

2.10.4. Internal Rate of Return (IRR)

This method gives the interest rate at which the cost of investment leads to the benefits of the investment. This means that all gains from the investment are inherent to the time value of money and that the investment has a zero net present value at this interest rate. By using trial and error methods IRR is evaluated [25].

2.11. Irrigation water requirement

Irrigation water requirement depends on types of crop cultivated. In Terai area, paddy is the basic crop used to cultivate in the monsoon season of a year whereas other crops are cultivated in a random pattern. Upon availability of water, farmers generally grow vegetables rather than wheat in the dry winter season. Table 2 shows the major crops cultivated in the Terai area.

The total volume of water requirement per hectare for paddy production is equivalent to 90 cm times a hectare within the base period of 120 days [7].

3. Results and discussion

3.1. Daily water requirement of crops

The total volume of water required by the paddy for the base period in its lifetime is 9000 m^3/hec. As per the number of days in the base period of paddy, per day water volume required is 75 m^3/day. For designing the solar system for irrigation, peak sun hour is taken as 6 hours a day, in consideration of improvising the average solar insolation of 4.7 kWh/m^2/day with one axis tracking throughout the year. As it supplies yearly additional energy up to 33.6 % from the same PV configuration [28]. Taking effective operation of the solar pump for equivalent 6 peak sun hour a day, it pumps 12.5 m^3/hr to supply 75 m^3 volume of water in a day. Fig. 4 shows the per hour water requirement of major crops in a hectare.

3.2. Capacity of pump, panel and inverter

There is variation in the availability of underground water, as per the field survey in Bara District the head was taken in the range of 10 meter to 50 meter for irrigation purposes [26]. Fig. 5 shows

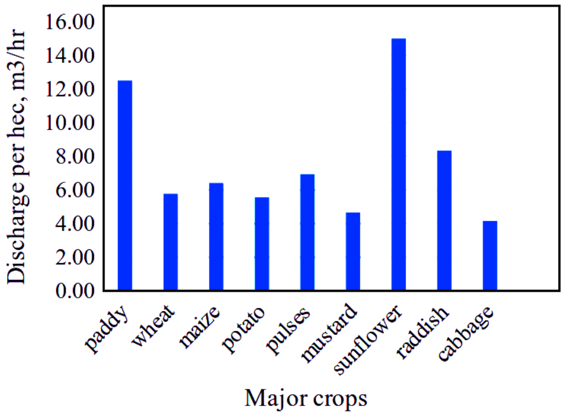

Figure 4: Major crops water requirement.

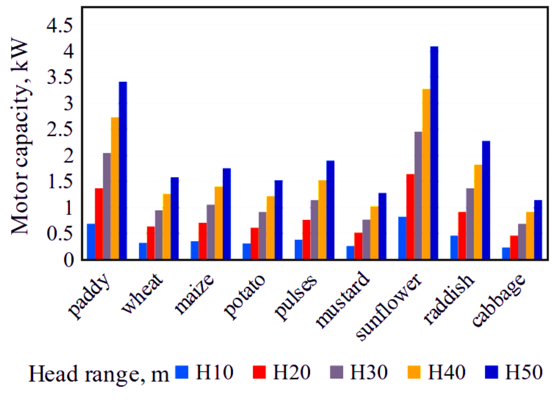

Figure 5: Motor capacity in kW.

the power rating of motor capacity for pumps in kW for major crops water requirement and range of head chosen.

For paddy, with water requirement of 12.5 m^3/hr/hec and head of 10 m depth from ground level, the system requires the pump capacity of 0.68 kW.

Similarly, for paddy, with water requirement of 12.5 m^3/hr/hec and head of 10 m depth from ground level, PV panel capacity of 1.27 kWp and inverter capacity of 1.28 kVA were obtained as shown in Fig. 6 and Fig. 7, respectively.

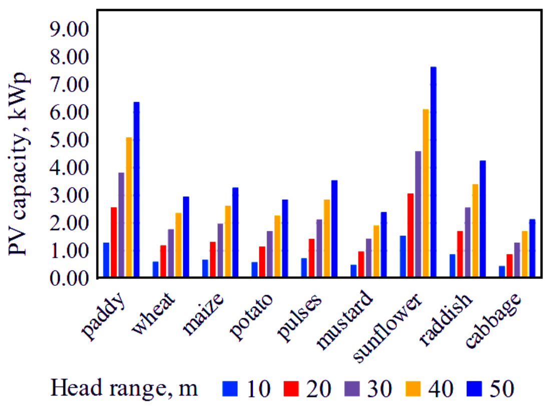

Figure 6: PV capacity in kWp.

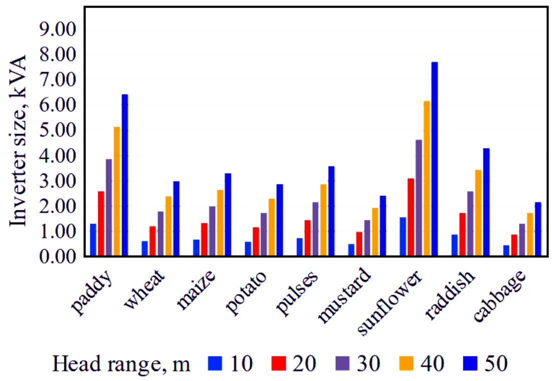

Figure 7: Inverter size in kVA.

3.3. Complete size and cost of system

Paddy is the major crop produced and consumed in all over the country. So, considering paddy as a major cultivated crop, solar water pumping system is designed as per the water requirement of paddy. Hence, to determine the size and cost of the system the daily water requirement of 12.5 (m^3/hr/hec) of paddy and general head range of 30 meter was chosen considering the field study in Bara district to have sustainable water supply throughout the year. The calculation of system cost is estimated for three phase systems of power supply. Total investment cost of the system comprises the cost of each component with installation, maintenance and repair cost for its useful lifetime as shown in Table 3.

The total cost is also inclusive of land cost required by the PV panel. For a land of 1 hectare, the required capacity of three phase induction motor is 2.04 kW, PV panel is 3.81 kW and three phase inverter is 3.84 kVA. In Bara district the average cost of land in rural parts is 75,000 NRs. per dhur (16.95 m^2) area. The general panel area will cover 19.07 square meter for 1 hectare system and the total system cost is calculated to be NRs. 6, 83,693. Increasing size of irrigable land demands a larger system and consequently requires larger land area for PV panels. For land size of 18 hectare and above, PV panel covers land area more than a kattha (339m^2).

3.4. Revenue from crops

Table 4 shows the revenue generated before and after the irrigation system for a hectare of land obtained from the community farm of Telkuwa village in Bara district of Nepal.

In terms of return, wheat was excluded because vegetables were a better alternative as per the recent year cultivation pattern after the availability of irrigation water. Whatever the condition of rain, paddy is an inevitable crop cultivated in the monsoon season in Bara. Beside monsoon season, either wheat or vegetable was cultivated in a year. Although the net return from wheat also increased from NRs. 20671 to NRs. 35436 after the availability of irrigation facilities, vegetable production showed comparatively higher profit and also water was more efficiently utilized.

3.5. Investment decision

After the facility of irrigation, wheat was replaced by vegetable farming. So, revenue from paddy and vegetables for a year are accounted for economic evaluation. In the following Table 5, economic analysis of solar water pumping system for 1 hectare land taking a useful life of 25 years and taking the minimum attractive rate of return (MARR) at 10 percent is evaluated.

The result shows the net present worth(NPW) of the cash flow is positive, benefit cost (B/C) ratio is greater than 1, IRR is greater than MARR and discounted payback period lies within 9th year

Table 3: Size and cost of solar water pumping system.

Field area (hec)	Pump (kW)	Panel size (kWp)	Area of panel (m^2)	Inverter (kVA)	Total system cost (NRs.)
1	2.04	3.81	19.07	3.84	683,693
2	4.08	7.62	38.10	7.68	1,365,884
3	6.12	11.43	57.15	11.52	2,048,826
4	8.16	15.24	76.20	15.36	2,731,768
5	10.20	19.05	95.25	19.20	3,414,710
6	12.24	22.86	114.30	23.04	4,097,652
7	14.28	26.67	133.35	26.88	4,780,594
8	16.32	30.48	152.40	30.72	5,463,536
9	18.36	34.29	171.45	34.56	6,146,479
10	20.40	38.10	190.50	38.40	6,829,421
11	22.44	41.91	209.55	42.24	7,512,363
12	24.48	45.72	228.60	46.08	8,195,305
13	26.52	49.53	247.65	49.92	8,878,247
14	28.56	53.34	266.70	53.76	9,561,189
15	30.60	57.15	285.75	57.60	10,244,131

Table 4: Revenue from crops before and after irrigation.

Crops	Before irrigation (NRs.)	After Irrigation (NRs.)	Increased %
Rice	35436	64966	83.33
Wheat	20671	35436	71.43
Vegetables	-	59146	-
Yearly return	64966	124112 (Excluding wheat)	91.04

Table 5: Investment decision.

Cases for 1 hectare system	Results
Useful life (years)	25
Initial investment (NRs.)	683693
MARR %	10
Annual revenue saved (NRs.)	124112.0
Present worth of benefit (NRs.)	1126569.6
Net Present Worth (NPW) of cash flow (NRs.)	442876.6
Benefit cost ratio (B/C ratio)	1.6
Internal Rate of Return (IRR) %	18.15
Payback period (years)	9
Investment Decision	YES

from the day of investment taking the inflation rate of 10 percent. Hence, investment can be done.

3.6. Selection of equivalent length of conductor

The technically feasible grid extension distance to the farmland from the nearest 3 phase, 400V distribution line is simulated in DIgSILENT Power Factory. Under technical consideration, the voltage profile is maintained for 5% deviation from rated voltage level of 400 V [21, 27].

Assuming the same useful life of solar water pump and electric pump system, Table 6 shows the possible extension of conductor length such that both systems will have the same cost. For a hectare of land requiring pump capacity of 2.04 kW, mole conductor is selected. As per the cost of the selected conductor, 0.61 km length of conductor is possible within the cost of solar pump system. But only, considering the voltage drop limit for 5 percent, the grid can be extended up to 1.5 km.

Table 6: Selection of conductor and length.

Land (hec)	Pump (kW)	Economical equivalent length (km)	ACSR conductor	Technical feasible length (km)
1	2.04	0.61	Mole	1.50
2	4.08	0.83	Mole	0.75
3	6.12	0.93	Squirrel	0.90
4	8.16	0.99	Weasel	1.10
5	10.2	1.04	Weasel	0.85
6	12.24	1.07	Fox	0.85
7	14.28	1.09	Rabbit	1.00
8	16.32	1.11	Rabbit	0.90
9	18.36	1.12	Horse	1.10
10	20.4	1.13	Horse	1.00
11	22.44	1.14	Otter	1.10
12	24.48	1.15	Otter	0.95
13	26.52	1.15	Dog	1.15
14	28.56	1.16	Dog	1.05
15	30.6	1.17	Dog	1.00

The breakeven point lies at 4 hectare as shown in Fig. 8, up to which the investment on solar system seems economical than grid extension for a distance of 1 kilometer. However, the grid system looks more economical above 4 hectare for irrigation system. Likewise from the analysis, the breakeven point is 7 hectare if grid should be extended up to 1.5 km and 11 hectare if grid should be extended up to 2 km.

4. Conclusion

Solar water pumping system is an appropriate system for irrigation purposes for all region of Nepal where grid electricity is not available. Up to 4 hectare of land, solar system is more economical than a grid-electric pump system with an extension of 1 km grid length. The difference between the cost of solar and grid electric pumping system increases gradually as the size of land increases, that means we can have longer grid length from the cost of larger

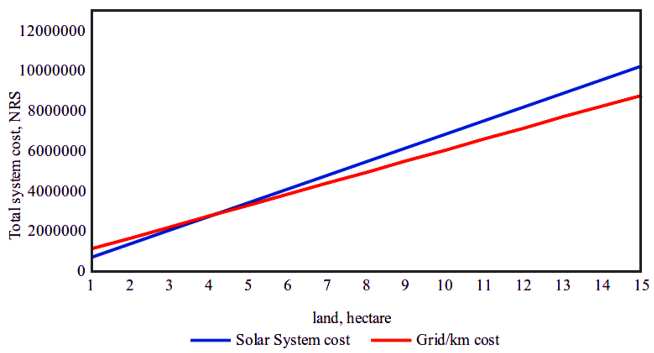

Figure 8: Breakeven point for solar and grid system for irrigation.

solar system.

On the basis of water requirement of paddy, the total system of solar water pump for irrigation was designed and cost of system was calculated for various sizes. The cost of PV panel covers more than 60 percent of total system cost and is major driving factor for the overall cost of solar water pumping system. On increasing size of PV panel, it demands the extra land area to install which also accounts for considerable cost. In the case of Bara district, taking rural parts, the land area required to mount the panels cost for around 25 percent of the cost of PV panel.
It is seen that after the intervention of irrigation system there is 83.33 percent increase in income from paddy and 71.43 percent from wheat in a year from a hectare of land but also, rate of return from vegetable is higher than that of wheat. Economic evaluation performed by using these return values from irrigation in a year provides the payback period of 9 years for 1 hectare system. Likewise, the obtained result of Net Present Value is positive, IRR is 18.15% and Benefit Cost ratio is 1.6, showing positive results to invest on solar water pumping system for irrigation.

References

[1] Meah K, Fletcher S, & Ula S, Solar photovoltaic water pumping for remote locations, *Renewable and Sustainable Energy Reviews*, 12(2) (2008) 472-487.

[2] Oki T, & Kanae S, Global hydrological cycles and world water resources. *Science*, 313(5790) (2006) 1068-1072.

[3] Berndes G, Bioenergy and water—the implications of large-scale bioenergy production for water use and supply. *Global environmental change*, 12(4) (2002) 253-271.

[4] Water and Energy Commission Secretariat Government of Nepal, "Government of Nepal Water and Energy Commission Secretariat, *Water resources of Nepal in the c context of climate change* (2011).

[5] International Centre for Integrated Mountain Development (ICIMOD), *Sustainable Financial Solutions for the Adoption of Solar Powered Irrigation Pumps in Nepal's Terai*, `www.icimod.org`, February 2017.

[6] Department of Irrigation, *Annual book DOI 2073*, `http://doi.gov.np/annual-book/`, January 2018.

[7] Department of Irrigation. *Irrigation Hand book DOI 2075*, (2018).

[8] Nepal Electricity Authority (NEA), *A year in review-Fiscal Year 2017/18*, http://www.nea.org.np/annual_report; August 2018.

[9] Glieck, P H, The Changing Water Paradigm, A Look at Twenty-First Century Water Resource Development. *Water International*, *25*(1) (2000) 127-138.

[10] Planning, Design, and Monitoring & Evaluation Division-Department of Irrigation, *Development of Database for Irrigation Development in Nepal*, `http://doi.gov.np/wp-content/uploads/2015/10/IrrigationDatabaseFinalReport.pdf`.

[11] Ministry of Population and Environment- Alternative Energy Promotion Centre, *Renewable Energy Subsidy Policy*, no. May, p. 17, 2016.

[12] Dhital R P, Parajuli B, Bajracharya T R & Shrestha R, Sustainability Assessment of Rural Solar PV Water Pumping System in Nepal, In: *Proceedings of IOE Graduate Conference*, 2014.

[13] Verma D, Nema, S, Shandilya, A M & Dash, S K, Maximum power point tracking (MPPT) techniques: Recapitulation in solar photovoltaic systems. *Renewable and Sustainable Energy Reviews*, *54* (2016) 1018-1034.

[14] Eker B, Solar powered water pumping systems, *Trakia Journal of Sciences*, 3(7) (2005) 7-11.

[15] Raza K, *Experimental Assessment of Photovoltaic Irrigation System*, Masters Thesis, Wright State University, 2014.

[16] Sontake V C & Kalamkar V R, Solar photovoltaic water pumping system-A comprehensive review. *Renewable and Sustainable Energy Reviews*, 59 (2016)1038-1067.

[17] UNDP, *Solar-powered pumping in Lebanon: A Comprehensive Guide on Solar Water Pumping Solutions*, 69 (2015).

[18] Ould-Amrouche S, Rekioua D & Hamidat A, Modelling photovoltaic water pumping systems and evaluation of their CO2 emissions mitigation potential. *Applied energy*, 87(11) (2010) 3451-3459.

[19] Masters G M, *Renewable and efficient electric power systems*, John Wiley & Sons (2013).

[20] Campana P E, Li H, Zhang J, Zhang R, Liu J & Yan J, Economic optimization of photovoltaic water pumping systems for irrigation. *Energy Conversion and Management*, 95 (2015) 32-41.

[21] Gupta J B, *A course in Electrical Power*, S.K. Kataria and Sons, New A.S. Offset Printers, Delhi- 110092 (2011).

[22] Burke J J, *Power distribution engineering: fundamentals and applications*. CRC Press (2017).

[23] Mandal S & Pahwa A, Optimal selection of conductors for distribution feeders. *IEEE Transactions on Power systems*, 17(1) (2002) 192-197.

[24] Campana P E, Olsson A, Li H & Yan J, An economic analysis of photovoltaic water pumping irrigation systems. *International Journal of Green Energy*, 13(8) (2016) 831-839.

[25] Adhikari I & Shrestha S K, *Engineering Economics*, S.K. Publication (2009).

[26] Ground Water Resources Development Board, *Underground water Datasheet 2074* (2018).

[27] Farr H H, *Transmission Line Design Manual: A Guide for the Investigation, Development, and Design of Power Transmission Lines*. US Department of the Interior, Water and Power Resources Service (1980).

[28] Singh R & Banerjee R, Impact of solar panel orientation on large scale rooftop solar photovoltaic scenario for Mumbai. *Energy Procedia*, 90 (2016) 401-411.