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DESIGN AND ECONOMIC ANALYSIS OF A SOLAR POWERED DRIP IRRIGATION SYSTEM

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Abstract

This study has focused on economic analysis of solar powered drip irrigation system irrigating one hectare of maize in Kajevuba marshland located in Kigali capital city of Rwanda.

Previous research has shown that the irrigation of maize in this region requires a 1.4Kw DC submersible pump whose flow rate is 117LPM and that is powered by six solar modules , of 270W each one, connected in series to supply the peak power of 1.627 kWp (Felicien,2022).

In this study, a drip irrigation system has been designed and by using 2lph capacity emitters, the irrigation time was obtained as 1.2 hours. 12mm lateral pipe whose length is 50 m was used and 126 laterals were connected to 3 manifolds of 50mm diameter and 33m of length to cover the half field. The same size (50mm) was adopted for the main pipe whose length is 150m.

An economic analysis was done and the LCC was obtained as $6889.3. The total annual benefit was obtained as $1179 and the simple payback period was found as 5.4years. The internal rate of return obtained in this study is 18.5%.

1. Introduction

Energy is essential to achieve nearly every Sustainable Development Goal and to combat the change of climate [1]. Solar energy is far the largest energy resource estimated up to approximately 50,000EJ/year [2].

Rwanda is covering an area of 26338 km^2 and its estimated population is 13.6 millions. This means a density of 515 inhabitants per km^2 in average, which makes it to have the most density in Africa [4]. It is an East Africa country located at latitudes from 1.050 to 2.840^{0}S and longitude from 28.860 to 30.90^{0}E [5].
The neighboring countries are: DRC, Tanzania, Uganda and Burundi. The country has five provinces and thirty districts.

2. Background of the Project

Solar water pumping systems are a reliable mean to provide sustainable water access for households in off-grid communities [5].

Solar resources and water scarcity have a close relationship: In the period of intense sun shines there is ability to provide much water for irrigation. On the other hand, irrigation on rainy days is not necessary [6]. The price of PV systems is now competitive with other conventional systems like diesel. However, it is still a significant challenge to make them affordable for the communities living in low-income areas [7].

Rwanda is known for its abundant water resources due to its climate but these resources are not distributed equally across the country. [8]

Using irrigation to strengthen rain fed agriculture can play a significant role in stabilizing or increasing food production and reducing poverty. [9]

The availability of water is another factor to be considered for field irrigations. The principal resources of irrigation water in Rwanda are rivers, lakes, water dams, groundwater resources and wetlands. [5]

Some researches for impact of irrigation on reduction of poverty in Rwanda have been done basing on diesel, electrical and hand pumping systems. The application of PVWPS pilot projects has started in Rwanda but till now, only a small number of solar water pumps are operating in the whole country. Approximate average of every month solar radiation changes between 4.3 and 5.2 kWh per m^2per day throughout the country, although the most part remains unused [7].

Rwanda location lies in the Great Lakes region of the continent of Africa and geographically has mountains to the west, savannas to the east and lakes across the country. Although Rwanda is located in the tropical zone, it has a warm climate because of its high altitude resulting in temperature and precipitations milder than those from neighboring equatorial regions [8].

The “A” agricultural season starts in September and ends in February, “B” is between starts in March and July, and last season “C” is specially for marshland crops and lies between August and September. [9].

The every month mean precipitation distribution in Rwanda from 1990 to 2019 shows an excess of precipitation from September to late May and a decrease from early June to late August. (World Bank 2021)

3. Problem statement

Solar water pumping systems are a reliable mean to provide sustainable water access for households in off-grid communities [10].

Solar resources and water scarcity have a close relationship: In the period of intense sun shines there is ability to provide much water for irrigation. On the other hand, irrigation on rainy days is

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not necessary [11, 12]. The price of PV systems is now competitive with other conventional systems like diesel [13, 14]. However, it is still a significant challenge to make them affordable for the communities living in low-income areas.

Rwanda is known for its abundant water resources due to its climate but these resources are not distributed equally across the country. The availability of Water aids farmers to irrigate their fields and achieve higher yields.

Some researches for impact of irrigation on reduction of poverty in Rwanda have been done basing on diesel, electrical and hand pumping systems. The application of PVWPS pilot projects has started in Rwanda but till now, only a small number of solar water pumps are operating in the whole country.

4. Objectives of the study

4.1. Main Objectives

The principal objective of this work is to design and plan a drip irrigation system in order to make a detailed economic analysis.

4.2. Specific Objectives

- Decide the appropriate layout of the drip irrigation system
- Hydraulic design of the system in terms of lateral, submain and main pipes. The successful design is a compromise between the choice of high uniformity and low installation cost
- Calculation of combined systems LCC
- Calculation of Payback period, NPV and IRR

5. Literature Review

The Surface irrigation is used with small plots, flooding the soil surface with water to penetrate the root zone and make it available for use by plants. Surface irrigation is potentially very efficient when all relevant factors are under the careful control of an experienced farmer. However, they often lack skills in water management and tend to be less efficient. For design purposes he uses a typical efficiency of 60% [15].

Drip or drip irrigation involves applying water in the form of droplets directly to the target plant near its base. Water is conveyed through a system of flexible low-pressure pipes and delivered to plants with drip nozzles [16]. Unlike other types of irrigation, where the entire soil profile is moistened, water is dropped onto the ground at a very low flow rate ranging between 1-20 l/h from emitters [17]

The sprinkler Irrigation is rainfall-like system that distributes water through a system of pumping pipes. Discharge spray heads distribute water over the ground surface. Water is distributed under pressure in the pipes and sprayed into the air for finally coming down in small droplets falling to the ground terrain like natural rain. Those systems are enormously more efficient and labor-saving than surface irrigation and are easily applicable to sandy soils [15].
For good uniformity, operate many sprinklers in close proximity so that the patterns overlap. This is because a single rotary impact sprinkler produces a circular wetting pattern with poor uniformity. A key factor in successful sprinkler operation is pressure. Operating pressures are typically in the range of 2 to 6 bar. The efficiency of these systems is about 75% [18].

Drip irrigation is the most effective method and therefore it is adopted in this project to irrigate one hectare of maize in Kajevuba marshland.

6. Research method

In this study, the trial and error method is used in Darcy-Weisbach formula to find out the appropriate diameter of the lateral, manifold and main pipe such that the head loss is within allowable limits for the adopted layout.

The economic analysis is done by using prices from different internet sources, literature review and applying the financing formulae.

6.1. Design of drip irrigation system

The drip irrigation design is extremely important to provide uniformly the needed amount of water to the plants. The major target of this design is to determine the dimensions of different parts of the system so that it can supply the desired amount of water with a uniform application while minimizing its costs.

The main component parts are: control station, main pipe, submains, hydrants, manifolds and laterals with emitters. The main supplies water to the submains and the laterals are supplied by the submains. The water for irrigation is distributed by emitters that are attached to laterals.

In this project, the design is focused on selection of drip emitters, lateral and manifolds sizes, mains sizes and selection of necessary filters.

To supply the required amount of water fairly evenly to each crop, the irrigation system should be designed so that the required water pressure is maintained in the network of the pipes and the required operating pressure is supplied by those pipes to the emitters.

The control station includes the supply line placed horizontally at a lowest height of 60 cm above the floor having air release and check valves, two hose outlets of 3/4 inches for linking with a fertilizer injector and between those outlets there is a shutoff valve. It includes also a filter and a fertilizer injector and a sand separator when it is needed [19].

Drip irrigation allows irrigating the entire field at once but this may require high drainage which may be unavailable, separate mains of large diameter, larger sub-mains and filtration units which may make it very expensive. Therefore, the entire array should be divided into an appropriate number of subunits. Every subunit is built and operated individually by placing a valve in its head and then the deliveries of the individual subunits are calculated. If the subunit discharge exceeds the available runoff from the water resource, its area is reduced proportionally to balance runoff demand and available runoff. In this project a square shape of 1ha is considered with 100m long for each side. The well is dug at left side corner and the submain is placed in the center of the field.

ISSN 2320-9186

6.1.1. Spacing between laterals

For better growth and maize development, the correct spacing should be taken into consideration. The recommended distance between rows is 75cm and the recommended plant spacing is 30cm. For hand planting, it is easier to plant two seeds per mound with rows 75 cm apart and mounds spaced by 60 cm [20].

6.1.2. Selection of Emitters

Drip emitters are accessories for drip irrigation systems that regulate even water flow. Emitters push water out much more slowly to keep plants from over-watering.

Drip emitters are mainly of two types: online emitters and inline emitters. Online emitters are attached to on top of laterals, while inline emitters are drippers that are part of the the laterals themselves. For row crops, the emitters should be spaced so as to wet the entire strip of the row. For dense row crops, in-line/integrated emitters are preferred,
and for plantations/orchards, online emitters are preferred. Single output emitter is used for row plants [21]. Discharger flow rates come in different ranges relating the type of emitter, and the best chosen emitter is the one that will not cause runoff or deep penetration of the considered soil type. The flow rates of drip emitters range from 0.6 to 15 lph.

By considering one emitter per plant, the required volume of water for each emitter is the product of the irrigated area and the irrigation depth [22].

$V=0.75*0.60*5.26*10^{-3} \quad =2.4*10^{-3}m^3$

By using 2lph capacity emitters, the irrigation time is 2.4/2 resulting in 1.2 hours.

The submain being laid at the center of the field, the lateral length becomes 50m

6.1.3. Calculation of discharge of lateral

The distance between emitters being 0.60m, the number of emitters per lateral is 84 and the total discharge rate through one lateral is 168lph.

By using a pump of 118lpm capacity, the number of lateral that can be operated at time is 118*60/168 resulting in 42 laterals.

The maximum number of laterals depends on row spacing and the breadth of the field and it is given by 100/0.75 meaning 133 laterals per field. The number of manifolds depends on the maximum number of laterals that can be operated at time and it is given by 133/42 i.e. 3 manifolds per half field having a length of about 33m. Therefore the total number of lateral adopted per half field is 126.

6.1.4. Size of lateral

The lateral is the smallest diameter tube in the system. They are mounted in a fixed position perpendicular to the manifolds, arranged along the rows of plants and installed with water drippers at regular intervals. They are usually made of LLDPE of 12, 16 and 20 millimeter sizes [23]. The relationship between velocity of water (V), discharge rate (Q) and the internal area of the pipe (A) is given by V=Q/A. In the plastic pipes, the maximum recommended flow velocity for PVC and PE manufacturers should not exceed 1.5 m/s [19]. By using a 12mm diameter pipe, the water velocity is $V=4*168/(\pi*12^2)=0.41$m/s

6.1.5. The Reynolds number

One of the problems Reynolds studied experimentally is the flow transition from an ordered type of flow called 'laminar' to a more chaotic type called 'turbulent'. He discovered that when certain parameter combinations within the flow exceed thresholds, the properties of the flow change. The combination was later called the "Reynolds number" mathematically defined as the ratio of inertia and viscous forces that is mathematically expressed as follows:

$$N_R=DV\rho/\mu \quad (1)$$

With μ and ρ are respectively the dynamic viscosity (N-s/m^2) and the density of the fluid (kg/m^3). For Reynolds numbers less than 2,300, the flow can be expected to be laminar, and for Reynolds numbers greater than about 4,000, the flow becomes turbulent. The interval between the two limits is called the "Transition flow" [24].

The dynamic viscosity of water at 25^{o}C is $891*10^{-6}$ [25]

The Reynolds number in this project is given by: $N_R = 1000*12*10^{-3}*0.41/891*10^{-6}$ =5522 (turbulent flow)

6.1.6. The effect of friction factor

The analysis of hydrodynamic state of controlled piping systems is based on calculation of flow distribution which requires the knowledge of friction factor f depending on the pipe wall surface and fluid flow modes interpreted by the corresponding Reynolds number [26].

$f=64/R_N$, for $R_N<2300$ (Poiseuille equation) (2)

$f=0.32N_R^{-0.25}$, for $4000 \leq R_N \leq 100000$ (Blasius equation) (3)

$f=0.80+2\log(N_R/f^{0.5})$ (Prandtl equation) [27]. (4)

In this project, the friction factor related to the Reynolds number is given by equation 3

$f = 0.32*5522^{-0.25} = 0.037$.

The tube wall roughness *k* depends on the pipe material and it is given by the equation 16 given in [28]:

$K=0.811*(f/g)$ (5)

$K==3.06*10^{-3}$

6.1.7. Friction and head loss calculations

A Darcy-Weisbach equation, Hazen Williams equation or Scobey equation are used to calculate the friction loss (H_f). The general form of these equations can be written as [29]:

$H_f=KCLQ^m/D^{2m+n}$ (6)

Where: K is the friction factor depending on pipe material; L is the pipe length, Q is the flow rate in lateral, D is the pipe diameter in millimeter and c, m, n are constants obtained from the table1.

Table1: Constants of friction loss equations (Source: James, 1988)

Equation for calculating Hf	c	m	n
Darcy-weisbach	277778	2.00	1.00
Hazen-williams	591722	1.85	1.17
Scobey	610042	1.90	1.10

The head loss caused by the emitter connections in the laterals can be determined by replacing every connection by an equivalent imaginary pipe length, also called “equivalent length”. (Barinas and Howell,1980). The correcting length in the equation 6 for barb losses is given by:

$L=50m+\text{number of emitters}*C_L$

C_L is the emitter equivalent length obtained from the figure 1.

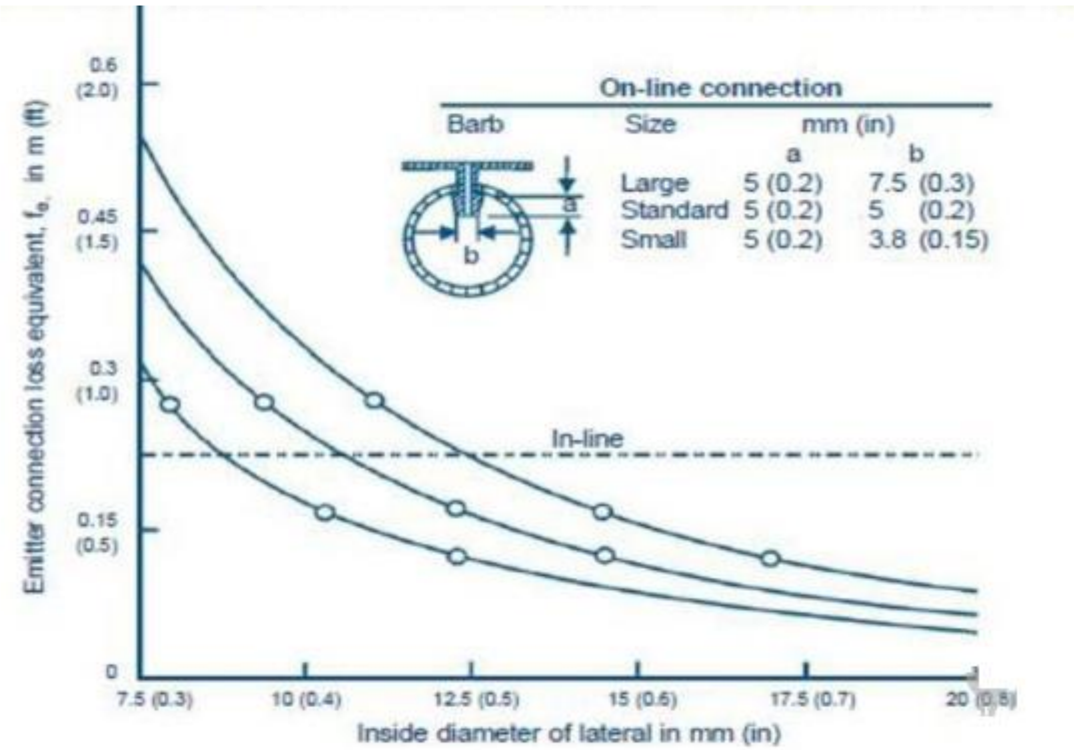

Figure 1: Values of emitter connection loss for different size of barbs and lateral diameter

(Source: Bliesner and Keller, 1990)

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For a standard barb size C_L value is 0.18 considering a 12mm diameter lateral.

L=50+ (84*0.18) =65.12

The friction loss is then:

$H_f=3.06*10^{-3}*277778*65.12*2.8^2/(12^5)=1.7m$

The head loss results in summation of friction loss due to surface resistance and minor loss due to pipeline shape change [26].

To calculate the actual losses, the friction loss is multiplied by Christiansen's reduction factor, F, in order to compensate the water supplied along the lateral line. The value of F depends on the outlet number evenly distributed along the pipeline and it is expressed as follows [29]:

$$F= (m+1)^{-1}+ (1/2N) + (m-1)^{0.5}/6N^2 \quad (7)$$

Where F, m and N are respectively Christiansen's F factor; velocity exponent in the formula used for friction-loss computation and number of outlets. The table2 provides the values of Christiansen's reduction factor for different number of outlets.

Table2: F factor for multiple outlets [30].

Number of outlets	F value (m = 2.0)	Number of outlets	F value (m = 2.0)
1	1.0	12	0.376
2	0.62	15	0.367
3	0.52	20	0.360
4	0.47	24	0.355
5	0.44	28	0.351
6	0.42	30	0.350
7	0.41	40	0.345
8	0.40	50	0.343
9	0.39	100	0.338
10	0.385	>	0.333

For our drip irrigation the Christiansen's factor is =1/3+1/168+1/ $(6*84^2)$ =0.34

Then, the head loss (h_l) equation can be expressed as follows [31]:

$$h_l=FH_f+M_l \quad (8)$$

Where H_f and M_l are respectively friction loss and minor losses

By assuming the manor losses to zero, the head loss in lateral is:

h1=0.34*1.7=0.578m

This head loss is acceptable as it less than 5% of the static head (18m*0.05=0.9m) [28], thus the lateral size is 12mm.

6.1.8. Design of manifold

Manifolds are attached to hydrants and are typically placed on the surface along the edge of the plot to supply lateral lines. They can be any type of tube accessible, usually HDPE available in 2-3 inch sizes.

The Main and all manifolds are designed so that friction losses at the beginning of the system's network do not exceed approximately 15% of the required total head [31].

By assuming a manifold diameter of 50mm, the water velocity is V=Q/A

$= (118*10^{-3}*4)/ [60*\pi*(50*10^{-3})^2] =1m/s$

The Reynold number $N_R =1000*50*10^{-3}*1/891*10^{-6}=56117$

$f=0.32N_R^{-0.25}=0.021$

$K=0.811*(0.021/9.81) =1.74*10^{-3}$

For a 33m long manifold the friction loss is given by equation 6

$Hf=1.74*10^{-3}*277778*33*118^2/50^5=0.71m$

ISSN 2320-9186

The value of F obtained from Table 2 for 42 outlets is 0.34

The head loss in manifold is hl=0.71*0.34=0.24m. This loss is accepted as it is less than 15% of the total dynamic head (20*0.15=3m), thus the manifold adopted size is 50mm.

6.1.9. Design of main pipeline

The same size is adopted for the main line pipe whose length is 150m and the corresponding values of friction loss is $H_f=1.74*10^{-3}*277778*150*118^2/50^5=3.2m$

The value of F obtained from Table 2 for 6 outlets is 0.42

The head loss in main pipe is hl=3.2*0.42=1.34m (accepted).

Knowing the size of laterals, manifolds and main pipeline, the irrigation system cost can be easily estimated.

7. Economic Analysis

In general, the design of any system and project selection depends on numerous factors. One of them is determination of the costs involved in starting the system and operating it over its lifetime.

7.1. Calculation of initial investment costs

Capital costs usually depend on the size of the components and are somewhat proportional to the power rating of the system. The size of the pipes or ducts must be determined in order to analyze the distribution system costs. The Installation cost should include labor and the cost of borehole drilling [32]. The initial investment costs includes both the initial costs of PV water pumping and drip irrigation systems

7.1.1. Costs of PVWPS

PVWPS costs mainly consist of purchasing equipment for solar pumping systems:
pumps, PV modules, control systems, wiring etc. They also include system installation and design engineering as indicated in Table3.

Table3: PV water pumping system costs

Equipment	Price	Source
SQF Pump	$1940.38	https://www.zerohomebills.com/product/submersible-pump-grundfos-sq-flex-5a-7/
Solar panel (with 25-year linear output warranty)	$84.30*6	https://www.zerohomebills.com/product-category/solar-photovoltaic-pv/solar-photovoltaic-panels/solar-polycrystalline-panels/
Control unit	$521.50	https://thesolarstore.com/grundfos-sqflex-cu200-interface-box-pump-controller-p-534.html#:~:text=Price%3A%20%24521.50&text=The%20CU200%20interface%20box%20communicates,and%20water%20level%20switch%20input.
Level switch	$69.45	https://thesolarstore.com/grundfos-sqflex-water-level-switch-use-with-cu200-only-p-535.html
Support structure	$ 305.98	[32]
MC4 Solarline Output Cable	$39.69	https://thesolarstore.com/mc4-solarline-pv-array-output-cable-30-10-awg-p-640.html
SQFlex IO50 Interface Box Pump Controller	$99.75	https://thesolarstore.com/advanced_search_result.php?keywords=io50&search_in_description=1
Miscellaneous cost	30% of the total cost($796.521)	[33]
Installation cost	25% of the total cost ($663.77)	[33]

The total cost of PV water pumping system is $4421.341

7.1.2. Costs of drip irrigation system

The drip irrigation system costs depend on the area size of the irrigation field and the kind of tubing and emitters used. Different costs of the system components are indicated in the table 4.

Table 4: drip irrigation system costs.

Item	Price	Source
50mm main line pipe	150*$0.21	alibaba.com/product-detail/16mm-20mm-25mm-32mm-40mm-50mm_1600576948062.html?spm=a2700.details.0.0.32b257c1LH2ox4
50mm manifold pipe	32*6*$0.21	alibaba.com/product-detail/16mm-20mm-25mm-32mm-40mm-50mm_1600576948062.html?spm=a2700.details.0.0.32b257c1LH2ox4
Lateral pipe	42*6*50*$0.02	https://www.alibaba.com/product-detail/hot-sale-12mm-Drip-Pipefor_62404159901.html?spm=a2700.7724857.0.0.6ae5794aFqKciM
Drip emitters	84*42*6*$0.02	https://eshiong.en.made-in-china.com/product/LdKtiaMGZVhX/China-Agricultural-Drip-Tube-PE-Pipe-Irrigation-Pressure-Compensating-Emitters-Dripper.html
valves	10*$3.67	https://dir.indiamart.com/impcat/drip-valve.html
120 mesh Screen filter	$36.00	https://www.alibaba.com/product-detail/Irrigation-Screen-Filter-2-Irrigation-Screen_62342657092.html?spm=a2700.7735675.0.0.67722738kDMHoi&s=p
Water reservoir	$ 645.33	https://www.flipkart.com/search?q=water%20tank&otracker =search&otracker=search&marketplace=FLIPKART&as-show=on&as=off
Pressure gauge	$3.15	https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_ en&CatId=&tab=all&SearchText=pressure+gauge
Air valve	$28	https://www.alibaba.com/product-detail/Male-Thread-Plastic-Irrigation-Air-Release_1600696373647.html?spm=a2700.7735675.0.0.29f23245t1VvUP&s=p
Fertilizer solution tank	$62.55	https://www.indiamart.com/proddetail/drip-irrigation-fertilizer-tank-16942783873.html
Fertilizer injector pump	$5.51	https://www.flipkart.com/cruze-venturi-fertilizer-injector-2-12-length-drip-irrigation-kit/p/itmdafdec70d5d7d
Labor cost	$75	https://www.angi.com/articles/drip-irrigation-cuts-down-yard-work-water-usage.htm

The total cost of drip irrigation system is $1639.42

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The initial capital cost is calculated by summing the cost of PV water pumping system and the cost of drip irrigation system and is obtained as $6060.761.

7.2. Recurrent cost calculations

Recurrent costs consist of maintenance, replacements and operation costs. PVWPS replacement costs take place at intervals equal to the estimated time of life of every component. The table 4.3 shows the different items that require to be replaced during the system lifetime and the correspondent costs. The longest lifetime is 25 years lived by solar modules and therefore it is considered as the analysis period. Some Brushless Direct Current Motors have a lifetime of 10,000 hours and therefore in this project the dc pump system does not need to be replaced [34]. The item that will probably need to be replaced is the control unit whose lifetime is limited to 10 years [35]. A replacement R occurring at n^{th} year has a present value given by [32] as follows:

$$P_W(R) = R / (1+d)^n \quad (9)$$

And the annual payment has a present value given by:

$$P_W(A) = A\,[(1+d)^n - 1] / [d\,(d+1)^n] \quad (10)$$

n and d are respectively the analysis lifetime and discount rate. Generally, the annual cost of operation and maintenance is assumed to be 1% of capital cost and the discount rate is about 10%. Solar pump operating costs are typically zero because no personnel are required during its daily operation. However, fewer interventions can be needed for irrigation practice and an amount of about 2$ per man can be daily spent [36].

Table 5: recurrent costs and lifetime of different components

Cost/lifetime	Estimated value
PV Panel lifetime	25 years
SQF-5A-7 pump lifetime	25 years
Annual operation and maintenance cost	$60.6
Present worth of O&M cost	$550
Control unit replacement cost at 10^{th} year	$201
Control unit replacement cost at 20^{th} year	$77.5

The total present worth of recurrent costs is obtained as $828.5

7.3. Life Cycle Cost

The life cycle cost of the project is obtained by summing the initial capital cost, the present worth of annual operation and maintenance cost and replacement cost present worth *(*Rekioua, Ould-Amrouche and Hamidat 2010*).* In this project the calculated LCC cost is $6889.3.

An uncertainty range of 1% of LCC can be assumed to overcome the negative impacts of change in pre-assumed prices.

7.4. Benefit analysis

7.4.1. Income from surplus of electricity

Since the design of PV water pump is done for the month of July which is the worst, there will always be a production of excess electricity in other months of irrigation. At the same time, the surplus in production of electricity is exceeded even in months without irrigation.

From the Figure 3.7 the irrigation is required from the second decade of June until to the second decade of September. Durind the 263 remaing days the electricity can be sold to the distribution company. By considering 7sunhours per day, the corresponding energy is estimated to be 2,577.4 kWh. The price of electricity being 0.236 U.S. Dollar per kWh [37], the total annual amount of surplus electricity is $608.

7.4.2. Impact of saved diesel fuel

The replacement of the diesel-powered pump system with a PVWPS for irrigating one hectare field can save the average quantity of 391.2l of diesel fuel per season [38].

The current price of diesel fuel in Rwanda being $1.46 per liter, the total income from the saved fuel is $571. The total annual benefit is obtained as $1179.

7.5. Discounted and Simple Payback Period

Payback period indicates the elapsed time between the time of initial investment and the time at which cumulative savings are enough to balance the initial investment.

For the simple payback period, we do not consider the time value of money

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$T_{sp} = C_o / (B - C)$ (11)

With T_{sp}, C_o and B are respectively Simple Payback Period, initial capital investment and benefits of the project

C is the Costs of the project (maintenance and operation costs).

In this project T_{sp} = 6060.761/ (1179- 60.6) =5.4years

The Discounted Payback Period takes into account the discount rate and is determined using the Equation 12

$T_{dp} = \{\ln (B - C) - \ln[(B - C) - dCo]\}/\ln(1 + d)$ (12)

T_{dp} is the discounted Payback Period and d is the discount rate

$T_{dp} = \{\ln (1179 - 60.6) - \ln[(117.9 - 60.6) - 0.1*6060.761]\}/\ln(1 + 0.1)$

In this project the discounted payback period is 8Years.

7.6. Net Present Value

NPV is the difference between the present worth of the benefits and the present worth of the costs induced by the investment.

A positive NPV means that a positive surplus indicates that the financial situation of the investor will improve by implementing the project whereas its negative value shows a financial loss during the project lifetime.

Mathematically, the net present value is expressed as shown in equation 13.

$N_{PV} = - C_o + (B - C) \times [(1+d)^n - 1] / [d(1 + d)^n]$ (13)

$= -6060.761 + 1118.4[(1+0.1)^{25} - 1] / [0.1(1 + d)^{25}]$ =\$4091

7.7. Internal rate of return

The Internal rate of Return is the discount rate which results in zero Net Present Value of the future cash flows. It is also defined as the annual return that decreases the NPV to zero.

IRR is expressed mathematically by equation 25

$$IRR= (B - C)/ C_o \quad (14)$$

The value of IRR in this project is obtained as 18.5%.

8. Findings and Discussions

Drip irrigation ensures the uniformity in water application from which, all field plants receive the same amount of water, resulting in high irrigation efficiency that causes less water wastage, fertilizers and power. The whole field is divided into six subunits by taking into account the capacity of the designed pump. The main pipeline, the manifolds and laterals are designed in order to have the frictional head loss included within the specified and accepted limits. Their corresponding dimensions are shown in Table 6.

Table 6: Drip irrigation tubing sizes

Component	Diameter	Length	Head loss	Maximum limit
Lateral	12mm	50m	0.578m	0.9m
Manifold	50mm	33m	0.24m.	3m
Main	50mm	150m	1.34m	3m

The uniformity of water application and system cost depend highly on the selection of the different components of the system. Therefore the utilization of small size pipelines has contributed to the reduction of initial investment cost resulting in good feasibility and viability of the project. The project economic analysis results have showed that the cost of the PVWPS is the most powerful parameter that affects the Initial Capital Cost, in particular the cost of pump system and the PV modules; while the saved diesel fuel and the surplus electricity produced significantly affect NPV and PBP.

The results from an economic analysis of the project shown in Table 7 have confirmed that the project is feasible due to:

- Short payback period
- Positive net present value
- Good internal rate of return

Table 7: Economic analysis parameters

Parameter	Value
Payback period	5years
Net present value	$4091
Internal rate of return	18.5%

8. Conclusion and recommendations

8.1. Conclusion

In this irrigation method, the droplets of water are moved under pressure through drippers connected to the irrigation tubing network. Both the sizing and spacing of laterals and selection of suitable drip emitters depend on crop to be irrigated. The determination of dripper discharges depends on crop water requirement. The PVWPS payback period depends on the life cycle cost and the total annual benefits: The more annual money is saved, the shorter is the PBP for a fixed LCC.

8.2. Recommendations

From the research findings and remarks, a set of recommendations is given to government of Rwanda to ensure a quick diffusion of solar irrigation pumps in all provinces of the country:

- The use of SIS should be encouraged among farmers and corresponding partners by using strengthen sensitization methods
- Creation of SIS schemes and fixation of amount of subsidies by Government for both on and off grid SISs.
- Farmers, technology suppliers and entrepreneurs willing to invest in providing solar irrigation services should be facilitated to have access to credits o pay their shares.
- Creation of environment that facilitates investing in SIS technology and enhancement of domestic capacity in the manufacturing and assembling of SISs and accessories.
- Promote sustainable agriculture applications protecting land, water resources and biodiversity
- Technician should be trained to increase their capacity in SIS installation and maintenance.

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