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Studies on solar water pumping based micro-irrigation for sustainable vegetable cultivation

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Abstract
The growing demands of energy and water particularly in the present agricultural sector have necessitated the adoption of reliable, environment-friendly and water saving technologies so as to combat against the energy crisis and water stress in near future. It has been established that conventional sources of energy like oil, gas, coal etc. will not be able to provide the desired levels of energy security to mankind in foreseeable future. Hence, there is a global consensus for exploitation and utilization of different renewable energy resources. The search for new options should be eco-friendly as well as abundant in nature. Among the different available renewable energy resources, solar energy seems to be more promising and sustainable. Solar powered agricultural irrigation may be an attractive application for renewable energy in replacing fossil fuel powered irrigation devices to achieve energy security. The use of solar photovoltaic systems may provide good solution not only for all energy related problems of the present society but also perform excellently in terms of productivity, reliability, sustainability and environmental protection ability. Solar photovoltaic water pumping systems can provide water for irrigation without the need for any kind of fuel or the extensive maintenance as required by diesel and electric pump sets. Therefore, an attempt has been made to develop an affordable and portable solar PV water pumping system for irrigating vegetable crops in the state of Odisha. Micro-irrigation method through sprinkler system has been integrated with the solar PV device to achieve judicious utilization of water. Monthly income of Rs. 15,000/- throughout the year was possible by adopting remunerative tomato cultivation in 1 acre of land both during rabi and summer seasons in the year 2017 in coastal region of Odisha. Pay- back period of the developed set up was calculated to be only half year, due to which, it may be easily accepted by the small and marginal farmers of the state in spite of its high initial cost. The popularization of this technology would not only achieve assured water availability to the crops with improved water use efficiency measures by micro-sprinkler irrigation system compared to traditional flooded method of irrigation but also protect the environment against release of green house gases and noise pollution by the use of rising diesel and electric pump sets in the state.

Keywords: Solar photovoltaic system, Micro-irrigation, Water use efficiency, Tomato cultivation, Greenhouse gases mitigation

Introduction
Energy demand is at present growing exponentially in each segment of the national developments due to the continuous growth and expansion in different sectors like industry, agriculture, irrigation, transportation, communication, housing, health, education, city modernization, entertainment etc. To meet the increasing demands of energy, the share of coal based power plants for power generation in India is also rising day by day causing severe environmental hazards and thus global warming by releasing a considerable amount of greenhouse gases to the atmosphere. The only alternative in this context is to supplement to the existing power sector with non-conventional energy sources. Among the non-conventional energy sources, the solar energy appears to be an attractive and viable proposition because of the abundant and free availability of sun shine in the tropical areas. Moreover, electricity from solar photovoltaic system is now gaining more importance because of the rapid decline in the cost of solar PV modules through advances in research and development in this area. The attention of planners, policy makers and researchers is also now diverted to the applications of solar photovoltaic system for water pumping in irrigation sector due to recent increased water demands in agricultural sector and availability of water has become more crucial than ever before. In India, electrical and diesel powered water pumping systems are most widely used

for irrigation applications. A source of energy to pump water is also a big problem in developing countries like India. Developing a grid system is often too expensive because rural villages are frequently located too far away from existing grid lines. Even if fuel is available within the country, transporting that fuel to remote and rural villages can be difficult. There are no roads or supporting infrastructure in many remote villages. The use of renewable energy is therefore of utmost importance for water pumping applications in remote areas of many developing countries. Transportation of renewable energy systems, such as photovoltaic (PV) pumps, is much easier than the other types because they can be transported in pieces and reassembled on site (Khatib, 2010) [9]. Photovoltaic (PV) energy production is recognized as an important part of the future energy generation. Because it is non-polluting, free in its availability, and is of high reliability. These facts make the PV energy resource more attractive for many applications, especially in rural and remote areas of the developing countries like India. Solar photovoltaic (PV) water pumping has been recognized as suitable for grid-isolated rural locations in places where there are high levels of solar radiation. The state Odisha also receives a good amount of solar radiation for about 4-5 hours in a day over a period of nearly 300 days in a year (Solar Policy 2013, Govt. of Odisha). Solar photovoltaic water pumping systems can provide water for irrigation without the need for any kind of fuel or the extensive maintenance as required by diesel and electric pump sets. They are easy to install and operate, highly reliable, durable and modular, which enable future expansion. They can be installed at the site of use, avoiding the spread of long pipelines and infrastructures (Andrada and Castro, 2008) [5].

Odisha is blessed with highly fertile soil due to flowing of many rivers through it namely the Mahanadi, the Baitarani, the Bramhani, the Subarnarekha, the Budhabalanga, the Bansadhara etc. (Economic Survey of Odisha, 2013) [3]. As Odisha receives an average annual rainfall of 1500 mm, there is no dearth of water resources. Farmers of the state grow different vegetable crops round the year using hand pump, electric and diesel pumps for lifting of irrigation water. Lifting of water by hand pump is a most tedious and labour consuming operation. Similarly, non availability and erratic supply of grid connected electric supply in the remote areas and rising cost of diesel day by day necessitate the search of a sustainable source of power for assured irrigation particularly for vegetable cultivation which is now-a-days more remunerative and profitable. Cost of lifting water in the above pumping systems is many folds compared to lifting water by solar photo voltaic water pumping system (Leah C. Kelley *et al.*, 2010) [10]. Development of an affordable, durable and with a very little repair and maintenance would be preferred by the small and marginal farmers of Odisha and India in particular. Installation of electric pump sets is not at all possible at most of the locations as the agricultural fields are far away from the electric grid station. In addition, the electric tariff is increasing in every year and thus increasing the cost of water pumping operation. Further, the repair and maintenance cost of electric motor operated pump sets is generally more than that of solar photo voltaic water pumping system (Sako *et al.* 2011) [13]. When not much research work was conducted on solar photo voltaic water pumping system, then, diesel pumping system was very popular among the farming community due to its low cost and portability. During this time, the diesel cost was also cheaper. But it caused a lot of environmental pollution and global warming by the emission of substantial quantity of CO_2 into the atmosphere. The repair and maintenance cost of diesel pump set is also more than that of solar photo voltaic water pumping system.

Hence, solar photo voltaic water pumping system is today a viable option left for the farming community as its pumping cost is cheaper compared to electric and diesel pump sets. Moreover, the risk of environmental pollution is less and its repair and maintenance cost is very low. It can be installed at any location as per the desire of the farmers as solar energy is available profusely and free of cost. Portable model of solar photo voltaic water pumping system would be an added advantage for the farmers looking into the space requirement for permanent installation and fear of theft. Similarly, the need for the optimum utilization of water and energy resources has become a vital issue during the last decade and will become more essential in the future. Hence, the use of solar powered micro-irrigation system is also the need of the hour looking into the present day's concerns of energy crisis and water scarcity particularly in agricultural sector. Therefore, an attempt has been made to develop an affordable and portable solar water pumping system along with micro-irrigation device for irrigating vegetable crops in the coastal regions of Odisha and to study its feasibility among the farmers of the state for growing vegetable crops in their fields for strengthening their livelihoods and socio-economic status. The specific objectives for the present study are thus as follows;

(a) Developing a portable and affordable solar photo voltaic powered water pumping device integrated with sprinkler system for irrigating vegetable crops
(b) Feasibility and performance study of solar photo voltaic powered sprinkler irrigation system in off-grid remote areas of Odisha
(c) Techno-economic analysis of the device developed

Review of some developments in solar photovoltaic water pumping system

The approaches for energy security through solar photovoltaic power system and improved water use efficiency measures through micro-sprinkler irrigation system compared to traditional flooded method of irrigation, have thus been thought up now-a-days among the researchers, scientists and agriculturists not only for achieving assured water availability to the crops but also protecting the environment against release of green house gases and noise pollution by the use of rising diesel pump sets in the state. Attempts have already been made by some researchers in assessing the viability of solar PV water pumping system for domestic drinking water and irrigation purposes. Some developments in this area have been discussed in this section.

Hamidat *et al.* 2003 [4] studied on small-scale irrigation with photovoltaic water pumping system in Sahara regions. The authors have developed a mathematical program to test the performance of photovoltaic arrays under Saharan climatic condition. Their work showed that it is possible to use a photovoltaic water pumping system for low heads for small scale-irrigation of crops in Algerian Sahara regions. Thus, the photovoltaic (PV) water pumping system could easily cover the daily water need rates for small- scale irrigation with an area smaller than 2 ha. They also concluded that the PVPS (photovoltaic pumping system) could improve the living condition of the farmer with the development of local farming and thus the migration rural work force would be brought to an end.

Kala Meah *et al.* 2008 [7] studied on solar photo voltaic water pumping for remote locations in rural western US. They realized that solar photo voltaic water pumping system (SPVWPS) is a cost effective and environmental friendly way to pump water in remote locations where 24 hours electrical service is not necessary and maintenance is an issue. From their survey, it was indicated that a total of 88 number of solar photo voltaic water pumping systems are being installed in all 23 countries of the United States, of which 75 systems are in operation till 2005. They have observed that drought affected areas like Wyoming, Montana, Idaho, Washington, Oregon and part of Texas could use solar photo voltaic water pumping systems to improve the water supply to livestock in remote locations. They have been convinced that successful demonstration of these systems is encouraging other ranchers to try this relatively new technology as another viable water supply option. They concluded that SPVWPS had excellent performance in terms of productivity, reliability and cost effectiveness and the system could reduce the CO_2 emission considerably over its 25-year life span.

Kala Meah *et al.* 2008 [8] studied on solar photovoltaic water pumping opportunities and challenges in United States. According to their views, they stated that some improvements could be done to lower the capital investment cost and to reduce the cost of operation and maintenance services using local level operation and maintenance. The authors have demonstrated that by using local resources such as skills, materials and finances, the solar photovoltaic water pumping system (SPVWPS) could be economically viable in developing countries and competitive with the conventional diesel generator water pumping systems. They concluded that the SPVWPS should be compatible with the local culture and practices to satisfy local wishes and needs, which also could be achieved by using local resources.

Leah C. Kelley *et al.* 2010 [10] studied on the feasibility of solar powered irrigation in the United States. They developed a method for determining the technical and economic feasibility of photovoltaic power irrigation systems applicable to any geographic location and crop type in USA and applied it to several example cases. According to the opinion of authors, the results of technical feasibility analysis agreed with the results obtained from past studies and also showed that there is no technological barrier to implementation of PVP irrigation if land is available for installation of solar panels. The results of economic feasibility study suggested that the price of diesel has increased sufficiently within the last ten years to make PVP irrigation economically feasible, despite the high capital costs of photovoltaic systems. The authors concluded that as the price of the solar panels is decreasing, the capital costs would decrease making PVP systems even more economically attractive.

Gopal, C. *et al.* 2013 [6] reviewed the research developments on renewable energy source water pumping systems referring 168 research papers across the globe. They concluded that renewable energy solar water pumping systems are identified as an alternative source for replacing conventional pumping methods. The integration of renewable energy sources with water pumping systems plays a major role in reducing the consumption of conventional energy sources and their environmental impacts, particularly for irrigation applications. The solar photo voltaic water pumping systems are the most widely used renewable energy solar water pumping systems for irrigation and domestic applications, followed by wind energy water pumping systems. The solar thermal and biomass water pumping systems are less popular due to their low thermal energy conversion efficiencies.

Narela *et al.* 2013 studied the feasibility of solar photovoltaic water pumping system for irrigating banana plants. They presented the design and economic analysis of efficient solar PV water pumping system for irrigation of banana. The system was designed and installed in solar farm of Jain Irrigation System Limited (JISL), at Jalgaon (Maharashtra). The study area falls at 21° 05' N – latitude, 75° 40'E–longitude and at an altitude of 209 m above mean sea level. The PV system sizing was made in such a way that it was capable of irrigating 0.165 ha of banana plot with a daily water requirement of 9.72m^3/day and total head of 26m. Also, the life cycle cost (LCC) analysis was conducted to assess the economic viability of the system. The results of the study encouraged the use of the PV systems for water pumping application to irrigate orchards. The installed system of solar PV water pumping system was capable of irrigating 0.165 ha area of banana crop within 6.02 hrs with a daily water requirement of 9.72m^3/day.

Materials and Methods

Design and development of solar photovoltaic (SPV) micro-sprinkler irrigation system has been made for cultivating tomato in 1 acre (0.4 ha) of land to achieve secured irrigation and to improve water use efficiency mostly in vegetable cultivation. The details of the design and developments are mentioned below. The experiments were carried out during the year 2013 in the Central Farm of Orissa University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha which lies at the latitude of 20 ^{0} 15' N and longitude of 85 ^{0} 52' E and coming under warm and humid climatic condition. Tomato was cultivated both in rabi and summer season.

Design of solar photovoltaic powered sprinkler irrigation system

(A) Water requirement for vegetable crop

W_r = (Crop area x PE x P_c x K_c x w_a)/E_u

W_r = Peak water requirement (m^3/day); crop area (m^2); PE = Pan Evaporation rate (mm/day) converted to m/day; P_c = Pan Coefficient (0.7 to 0.9); K_c = Crop Coefficient (0.8 to 1); w_a = wetted area (%) (90 % for sprinkler irrigation); E_u = Emission uniformity of sprinkler irrigation (Approx. 0.8)

Putting the values of crop area = 4000 m^2; PE = 8 mm/day; P_c = 0.85; K_c = 0.9; w_a = 0.9 and E_u = 0.8

W_r = 27.54 m^3/day (27540 lit/day)

Taking irrigation interval to be 2 days, W_r = 27540/2 = 13770 lit/day = 13.77 m^3/day ≈ 14 m^3/day

(B) Sizing of PV module for above water requirement

$E = (\rho\, g\, H\, V)/3.6 \times 10^6$

E = Hydraulic energy required (kWh/day); ρ = density of water (1000 kg/m^3); g = Gravitational acceleration (9.81 m/s^2); H = Total hydraulic head (m) (15 m in this case); V = volume of water required (14 m^3/day in this case)

Putting all values, E = 0.572 kWh/day = 572 Wh/day

Assuming actual sun shine hours in a day = 6 hours' total wattage of PV module = 572/6 = 95.33 watt

Assumptions:

i) Operating factor = 0.75-0.85 (PV panel mostly does not operate at peak rated power)
ii) Pump efficiency = 70-80 % (can be taken 75 %)
iii) Motor efficiency = 75-85 % (can be taken 80 %)

iv) Mismatch factor = 0.75-0.85 (PV panel does not operate at maximum power point)

Considering system losses, wattage requirement = (Total PV panel wattage) / (pump efficiency x mismatch factor) = (95.33)/ (0.75 x 0.8) = 158,88 watt
Considering operating factor for PV panel = (Total PV panel wattage after losses) / (operating factor x motor efficiency) = (158.88)/(0.8 x 0.8) = 248.25 watt
Number of 75 w_p solar PV panel required = 248.25/75 = 3.31 ≈ 4 modules
Power rating of motor = 248.25/746 = 0.33 hp
For sprinkler irrigation system, the minimum rating of pump needs to 1.5 hp. Hence, accordingly, the size of PV system needs to be decided.

(C) Sizing of PV system for 1.5 hp rating motor
(I) Battery sizing
1.5 hp = 1119 watt
Daily water requirement for 1-acre land = 14 m^3/day
Hour of operation of motor per day for discharge of 14 m^3 water is around 1 hour
Daily energy that needs to be supplied by battery is 1119 x 1 = 1119 watt-hr
System voltage be 24 volt
In solar PV system, depth of discharge of battery may be from 70-80 % (80 % may be taken)
Hence, required charge capacity of batteries = 1119/24 = 46.6 Ah
Total Ah capacity of battery = (Energy input to motor x No. of days of autonomy)/(depth of discharge x system voltage) = (1119 x 3)/(0.8 x 24) = 174.89 Ah
We need to find out how many batteries of 12 V, 100 Ah should be used for supply required energy to the motor.
Total number of batteries = (Total Ah capacity required)/ (Ah capacity of one battery) = 174.89/100 = 1.74 ≈ 2 batteries
From two batteries, 80 Ah + 80 Ah = 160 Ah is available instead of 140 Ah (1119 x 3/24)
These two batteries need to be connected parallel to get 160 Ah.
We have battery of 100 Ah with 12 V. Hence to get 24 V system voltage, two batteries need to be connected in series. Hence, in total 4 batteries of 100 Ah 12 V are required, two of them connected in series and two such series connected batteries to be connected in parallel.

(II) PV Sizing to meet the required daily energy requirement
Normally battery efficiency varies from 80 - 90 % (85 % may be taken)
Charge controller efficiency may be taken 90 %
The energy to be supplied by the PV system to the input of battery terminal be (1119)/ (0.85 x 0.9) = 1462 wh
Taking system voltage to be 24 V, Ah requirement = 1462/24 = 60.94 Ah
Taking daily sun shine hours to be 6 hours, current requirement = 60.94/6= 10.15 ampere
Normally a 75 w_p module generate 5 ampere current, hence number of module requirement = 10.15/5 = 2.03 ≈ 2 number of modules
To get 10 ampere current and 24 V system voltage, we require 4 modules of 75 w_p
Two of them connected in series and two such series connected batteries to be connected in parallel.
Components required for PV system
i) Four batteries of 100 Ah 12 V
ii) Four modules of 75 w_p
iii) One charge controller

Cost of experimental solar photovoltaic powered sprinkler irrigation system
i) Solar PV Module (4 x 75 w_p) = 300 watt @ Rs. 60 per w_p = Rs. 18,000
ii) Batteries (4 x 100 Ah, 12 V) @ Rs. 5000 per battery = Rs. 20,000
iii) Charge controller = Rs. 3000
iv) 1.5 hp DC motor with pump set = Rs. 12,000
v) Sprinkler set up for 1-acre land = Rs. 22,000
vi) Trolley Rickshaw = Rs. 13,000
vii) Pipes, fittings, wiring etc. = Rs. 2000

Total = Rs. 90,000

The figure for the experimental set-up is shown below.

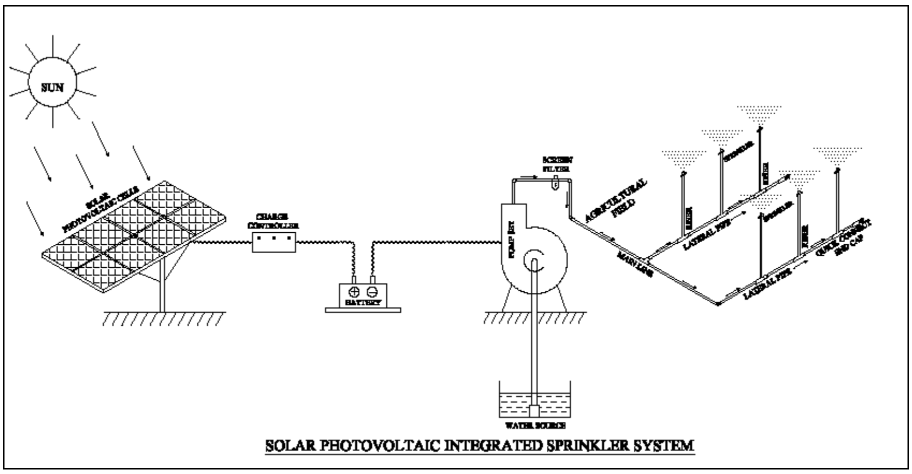

Fig 1: Solar photovoltaic integrated sprinkler system

Hourly cost of operation of various water pumping devices
Information for cost analysis
i) Cost of 1.5 hp electric pump set = Rs. 10,000
ii) Cost of 1.5 hp diesel pump set = Rs. 13,000
iii) Cost of 1.5 hp PV powered pump set = Rs. 90,000
iv) Prevailing interest rate may be taken as 10 %
v) Efficiencies of motor varies from 70-80 % (70 % taken)
vi) Efficiencies of pump varies from 70-80 % (70 % taken)
vii) Efficiencies of diesel engine varies from 30-40 % (40 % taken)

viii) Useful life of PV panel varies from 20-25 years (can be taken 22 years)
ix) Useful life of diesel engine pump set = 8 years
x) Useful life of electric pump set = 8 years
xi) Maintenance cost of PV system with sprinkler as 0.5 per cent of total capital cost per year
xii) Maintenance cost of diesel engine pump set as 10 per cent of total capital cost per year
xiii) Maintenance cost of electric pump set as 10 per cent of total capital cost per year
xiv) Annual working hours of diesel, electric pump sets and PV system be 500 hours
xv) One hp engine consumes about 250ml. diesel per hour (present cost of diesel Rs. 60/lit)
xvi) One unit of electric energy (1 kWh) = Rs. 5.00
xvii) Salvage value of diesel pump set be taken as 20 % of capital cost
xviii) Salvage value of electric pump set be taken as 20 % of capital cost
xix) Salvage value of PV powered pump set be taken as 5 % of capital cost
xx) Operator's time spent in the proposed system be 1 hr/day (labour charge Rs. 250/day)
xxi) Energy consumption (kWh) of electric pump set = (BHP) / (motor efficiency x pump efficiency) x 0.746 x 1 hour
xxii) Cost per hour of operation of diesel pump set = (BHP) / (motor efficiency x pump efficiency) x fuel consumed in litres/hour/BHP x cost of fuel/lit

(A) Hourly operating cost of PV powered water pumping device with sprinkler system

Fixed Cost
(a) Depreciation
D = (C-S)/ (L x H) where C= capital cost; S = Salvage Value; L = Useful life of device; H= Annual working hour
Putting the values of all necessary data, D= Rs. 7.77/hour
(ii) Interest (I) = (C + S)/(2) x (Interest rate/100) x (1/H) = Rs. 9.45/hour
Insurance and taxes and housing are not applicable
Total fixed cost = 7.77 + 9.45 = Rs. 17.22/hour
Variable Cost
(b) Fuel cost = Nil
(ii) Lubricants = Nil
(iii) Repair and maintenance = (C) x (0.5/100) x (1/H) = Rs. 0.9/hour
(iv) Operator's wages Rs. 250/8 = Rs. 31.25/hour
Total variable cost = 0.9 + 31.25 = Rs. 32.15/hour
Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = Rs. 49/hour

(B) Hourly operating cost of diesel pump set

Fixed Cost
(i) Depreciation
D = (C-S)/ (L x H) where C= capital cost; S = Salvage Value; L = Useful life of device; H= Annual working hour
Putting the values of all necessary data, D= Rs. 2.6/hour
(ii) Interest (I) = (C + S)/(2) x (Interest rate/100) x (1/H) = Rs. 1.56/hour
Insurance and taxes and housing are not applicable
Total fixed cost = 2.6 + 1.56 = Rs. 4.16/hour
Variable Cost
(i) Fuel cost = (1.5)/(0.4 x 0.7) x 0.25 x 60 = Rs. 80/hour
(ii) Lubricants = 20 % of cost of fuel = Rs. 16/hour
(iii) Repair and maintenance = (C) x (10/100) x (1/H) = Rs. 2.6/hour
(iv) Operator's wages Rs. 250/8 = Rs. 31.25/hour
Total variable cost = 80 + 16 + 2.6 + 31.25 = Rs. 129.85/hour
Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = Rs. 134/hour

(C) Hourly operating cost of electric pump set

Fixed Cost
(i) Depreciation
D = (C-S)/ (L x H) where C= capital cost; S = Salvage Value; L = Useful life of device; H= Annual working hour
Putting the values of all necessary data, D= Rs. 2/hour
(ii) Interest (I) = (C + S)/(2) x (Interest rate/100) x (1/H) = Rs. 1.2/hour
Insurance and taxes and housing are not applicable
Total fixed cost = 2.0 + 1.2 = Rs. 3.2/hour
Variable Cost
(i) Energy consumption (kWh) = (1.5)/(0.7 x 0.7) x 0.746 = 2.28 kWh
(i) Electric energy cost = 2.28 x 5 = Rs. 11.40/hour
(ii) Lubricants = 20 % of cost of fuel = Rs. 2.28/hour
(iii) Repair and maintenance = (C) x (10/100) x (1/H) = Rs. 2/hour
(iv) Operator's wages Rs. 250/8 = Rs. 31.25/hour
Total variable cost = 11.40 + 2.28 + 2 + 31.25 = Rs. 46.93/hour
Total operation cost per hour = Total fixed cost/hour + Total variable cost/hour = Rs. 50/hour

Results and Discussion

The results of the experiment conducted during the course of the study are presented in this section. Tomato is one of the most important and remunerative crops in Odisha and is grown in an area of 97,018 ha (Agricultural Statistics, 2012, Govt. of Odisha) [1] covering 11.02 % area of the total tomato cultivation in all India level. It ranks second in the state in vegetable production. Odisha also ranks fourth among the tomato producing states in India. It is considered as one of the most important supplementary sources of minerals and vitamins in human diet. However, targeted production and productivity is not achieved so far at par with the national level due to lack of assured irrigation facilitates both in rabi and summer season. The most prevailing variety of tomato i.e. Utkal Kumari (BT-10) has been cultivated for the present study in order to evaluate the effectiveness of the developed solar PV sprinkler irrigation device with respect to production and productivity, without depending upon conventional source of energy and flooded system of watering practice. The cost of cultivating tomato in 1 acre of land has been calculated in order to know the annual profits out of it and its expected pay-back period. Similarly, the mitigation of greenhouse gases with the use of the developed set-up has been estimated compared with traditional diesel and electric pump sets for its contribution in combating global warming and climate change and thus achieving sustainable agriculture.

Cost-Benefit Calculation of Tomato Cultivation in 1Acre (0.4 ha) Land

(A) Cost of Cultivation of Tomato in 1.0 Acre Land

Table 1: Cost of Cultivation of Tomato in 1.0 Acre Land

Sl. No.	Name of operation	Implements used	No. of operation	Man-hr/Ac	Operation cost (Rs.)	Input (kg)	Cost of input (Rs.)	Total cost (Rs.)
1	Tillage	Tractor drawn rotavator	1 1	2 1	1200 600	-	-	1800
2	Planking	Wooden planker (manual)	1	2	31.25/hour	-	-	62.50
3	Seed (Hybrid)							500
4	Planting (manual)		1	16	31.25/hour			500
5	Fertilizer	FYM Gromer Potash	Once Twice Twice			1 tractor load 100 kg 100 kg	4000 2500 2500	4000 2500 2500
6	Interculture	Manual	Thrice	40	31.25/hour			3750
7	Plant protection	Knapsack sprayer	Thrice	2	31.25/hour	Pesticides	4000	4187
8	Irrigation	Solar PV powered sprinkler system	45 (2 days interval)	1	Rs. 49/hour			2205
9	Harvesting	manual	Twice/week	120/month				3750
10	Miscellaneous							4000
Total Cost								**29,754 ≈ 30,000**

(B) Benefit

Without assured irrigation, production of tomatoes = 40 quintals/acre @ Rs. 20/kg = Rs. 80,000

With assured irrigation, production of tomatoes with 15 % increase in yield = 46 quintals/acre @ Rs. 25/kg = Rs. 1, 15, 000

Net gain = Rs. 1, 15,000 –Rs. 30,000 = Rs. 85,000 (in Rabi season)

Net gain = Rs. 1, 15,000 –Rs. 30,000 = Rs. 85,000 (in Summer season)

Considering tomato cultivation in both the seasons in a year with assured irrigation, total gain = Rs. 1, 70,000/annum

Monthly income from tomato cultivation with assured irrigation = Rs. 14,167 ≈ Rs. 15,000 per month

Simple payback period = (Initial investment cost) / (Net annual gain) = 90,000/1, 70,000 = 0.5 years or 6 months

Mitigation of CO_2 emission by use of solar photovoltaic powered water pumping system

Diesel and electricity are the two mostly used fuels to operate diesel and electric pump sets for water pumping in irrigating cultivable lands in our state of Odisha. Burning of diesel in the internal combustion engines and generation of electricity in power plants contribute a lot in the emissions of greenhouse gases to the atmosphere causing more to the present concerns of global warming and climate change. This may be due to the strong initiatives being taken by the Government to achieve more areas under assured irrigation. The replacement of diesel and electric pump sets with a reliable solar photovoltaic powered water pumping system particularly in the irrigation sector would definitely reduce to a greater extent in the emissions of greenhouse gases to the atmosphere. The existing diesel and electric pump sets in our state is 2.47 lakhs and 1.38 lakhs respectively in the power rating range of 1-5 hp. Taking the average power rating of both diesel and electric pump sets as 3 hp, the amount of emissions of CO_2 are as follows;

1. One hp engine consumes about 250 ml of diesel per hour
2. Burning of 1 litre of diesel releases 3 kg of CO_2 to the atmosphere (Manfredi et al. 2009)
3. The average carbon dioxide emission for electricity generation from coal based thermal power plant is approximately 1.58 kg of CO_2 per kWh at the source.
4. Annual working hours of diesel and electric pump sets can be taken 500 hours
5. Annual CO_2 emissions from 2.47 lakhs diesel pump sets to be 30 crore kg in our state
6. Annual CO_2 emissions from 1.38 lakhs electric pump sets to be 25 crore kg in our state
7. Total annual CO_2 emissions can be mitigated by 55 crore kg with the replacement of existing diesel and electric pump sets in our state by the adoption of solar photo voltaic powered system in irrigation sector.
8. Total annual electrical energy consumption from 1.38 lakhs electric pump sets can be saved in the tune of 15 x 10^7 kWh (saving around 15 crore units of electricity costing about Rs. 75 crores/annum)
9. Total annual diesel consumption from 2.47 lakhs diesel pump sets can be saved in the tune of 10 x 10^7 litres of diesel (saving around Rs. 600 crores/annum)

Conclusions

Sustainable energy source along with adoption of possible water management practices may be achieved with the help of solar photovoltaic micro-irrigation system in order to solve the problem of inadequate availability of two critical inputs such as energy and water for assured irrigation in agricultural sector. Micro-irrigation method through sprinkler system may also be an added advantage if integrated with the solar PV device to achieve judicious utilization of water. Hence, use of solar PV system may be a sustainable proposition of energy source for water pumping to achieve assured irrigation in the state. The findings of the present study would definitely give an insight to the farming community of the state to go for adopting the technology to strengthen their agricultural production system with secured availability of energy and water. The conclusions of the present study are as follows;

1. Wide popularization of solar photo voltaic powered water pumping system for achieving assured irrigation through sustainable energy source.
2. Monthly income of Rs. 15,000/- throughout the year may be possible by adopting remunerative vegetable cultivation in 1 acre of land during rabi and summer seasons only.
3. The small and marginal farmers of the state may be attracted to adopt solar photo voltaic powered water pumping system as the hourly operating cost is lowest i.e. Rs. 49/hour followed by Rs. 50/hour for electric pump set and Rs. 134/hour for diesel pump set.
4. The existing area under vegetable cultivation in the state may be enhanced by adopting vegetable cultivation in the unutilized land mostly during summer season due to the assured irrigation facility through solar photo voltaic system.

5. The developed set up may also be utilized for irrigating land in rainy season in case of irregular rainfall
6. Pay- back period of the developed set up is only ½ year, due to which, it may be easily accepted by the small and marginal farmers of the state in spite of its high initial cost.
7. Total annual CO_2 emissions can be mitigated by 55 crore kg with the replacement of existing diesel and electric pump sets in our state by the adoption of a reliable solar photo voltaic powered system in irrigation sector.
8. Total annual electrical energy consumption from 1.38 lakhs electric pump sets can be saved in the tune of 15 x 10^7 kWh (saving around 15 crore units of electricity costing about Rs. 75 crores/annum)
9. Total annual diesel consumption from 2.47 lakhs diesel pump sets can be saved in the tune of 10 x 10^7 litres of diesel (saving around Rs. 600 crores/annum)

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