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Performance of subsidized solar pump and its utility for smallholders' irrigation in the Eastern region of India

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ABSTRACT

Groundwater abstraction to meet irrigation demand is becoming a costly affair due to significant energy poverty in terms of electricity deficits and substantial increase in the cost of fossil fuel. Under this scenario, solar energy could be the most viable and sustainable option given its potential over India's geographical location. The dominance of small farms, policy frameworks, and financing schemes to increase solar energy use; many Indian states are offering heavy subsidies, even up to 90%, on small-capacity solar pumps to benefit smallholders. One of the popular and subsidized systems is a 3.0 horsepower solar water pumping system among the system categories. This paper presents the status of smallholders' irrigation, photovoltaic technology, and its possible application, and performance of a 3.0 horsepower solar pumping system evaluated under the incidence solar radiation of 3.4-6.4 kWh/m^2/day and the prevailing groundwater depth regime in Eastern region of India. This could help the smallholders to plan for crops and cropping sequences under the command area of this pump for more benefits.

Keywords: Energy, irrigation, solar radiation, groundwater, small farms

INTRODUCTION

Indian landscape is dominated by smallholders who cultivate the land of an area less than 2 ha and share a major portion of the operational land of the country. Out of 138 million 84.8% are small farms and of 159.18 million ha operational land, the farms accounted for 44.3% (Agriculture Census 2010-11). But, the smallholders are highly susceptible to poverty and hunger as neither they get sufficient food production nor the income for livelihood sustenance, even though small holdings are better in efficiency with high-yielding varieties and required resource inputs (NCEUS, 2008; Sen, 1962; 1964, Mazumdar, 1965; Berry, 1972; Bardhan, 1973). Smallholders commonly grow staple crops of low commercial value due to resource crunch, though in this era of globalization, the smallholders can play a major role in food production, if they had access to key ingredients in crop production (Lipton, 2006; Lobell et.al.,2008; Held et al., 2005,). Out of various factors, the assured water supply is the most important input which provides a better opportunity to grow higher-value crops and crop diversification (WDR, 2008; Polak and Yoder, 2006)

In India number of groundwater abstraction structures is around 30 million and these structures are operated by either diesel or electricity. About 84% of pumps are diesel operated and the rest 16% are by electricity (Shah, 2009). But the smallholders' irrigation is sieged by the deteriorated farm power supply, an embargo on electricity connections, and a many-fold increase in diesel prices. This energy squeeze undermines the adoption of precision irrigation technologies and the stable and profitable production of smallholders.

India is not well endowed with reserves of fossil fuels and natural gases. Providing energy access and energy security at will to smallholders at an affordable cost is a major issue. Renewable energy, mainly solar energy, could be a key part of the solutions and is likely to play an increasingly important role in energy access. India possesses a very large solar energy potential with average solar radiation of 4.0-7.0 kWhm^{-2} day^{-1} with 250-300 clear sunny days in a year, and this can be a year-round reliable source of energy for agricultural operations (Sharma et al., 2012; Jaswal, 2009. Solar energy has the advantage of providing off-grid electricity in rural areas where billion liters of diesel are being used in groundwater pumping and irrigation as lifting 100 m^3 of water to a height of 10 m needs 4.5 kWh of energy.

The traditional method flood of irrigation has put additional stress on groundwater resources and the cost of abstraction. Therefore, water management on scientific lines has become inevitable for resource sustainability in the short and long run. As per Hillel (1989) and Keller et al. (2001) adoption of modern irrigation technologies is well suited when the farmers depend on groundwater as this would be enabling them to expand their cultivated area with crop diversification which will generate more income and employment.

Coupling pressurized irrigation systems such as drip and micro-sprinklers with solar pumping systems will reduce the over-exploitation of groundwater and environmental problems. This will also increase water use efficiency and crop yields (Qureshi, 2001; Sivanappan, 2002; Namara *et al.*, 2005; Narayanamoorthy, 1997; Dhawan, 2000). The impact of the drip method of irrigation over the flood method of irrigation on a few crops is reported in (Table 1).

Solar Photovoltaic Technology

The power of solar radiation per unit area is called *irradiance* or *insolation* (Wm^{-2}). Solar energy is converted into electrical energy by *solar cells*. Assemblies of solar cells are called a solar module and is used to capture sunlight energy. When multiple modules are assembled it is referred to as a *solar panel or array*. The efficiency and power output of a module corresponding to 1000 W/m^2 at 25 ^0C temperature is known as Standard Test Condition (STC). The rated power of a module at these conditions is referred to as *Watt-peak* (Wp). Typically, solar radiation intensity varies from morning to sunset, i.e. from a few W/m^2 to 0.9 kWm^{-2}. The integration of the solar intensity over time gives solar insolation ($Wh/m^2/day$). India receives average solar insolation between 4-7 $kWh/m^2/day$.

In SPV technology the efficiency of the module is important in array size determination to generate a given amount of electrical energy. The efficiency of the module depends on the material of the solar cells. Solar modules are categorized as *crystalline*, *polycrystalline,* and *amorphous* or *thin film*. The efficiencies of solar cells of different materials and the surface area of the array required for the generation of $1kW_p$ power are reported in Table 2.

To maximize power generation, solar modules should always be kept perpendicular to the sun rays. This requires tracking structure and tracking can be automatic or manual depending on the need of the user. To avoid the extra cost of tracking infrastructure fixed mounting is preferred. The advantages of SPV technologies over conventional

Table 1. Water saving and yield increase by DMI over FMI

Name of the crops	Water saving over FMI (%)	Yield increase over FMI (%)	Name of the crops	Water saving over FMI (%)	Yield increase over FMI (%)
Vegetables			**Fruit Crops**		
Ash gourd	12	12	Cabbage	60	2
Bottle gourd	12	47	Cauliflower	34	39
Brinjal	53	14	Papaya	68	77
Beet root	79	7	Banana	45	52
Sweet potato	61	40	Grapes	48	23
Potato	Nil	46	Lemon	81	35
Lady's finger	84	13	Watermelon	Nil	179
Onion	25	31	**Other Crops**		
Radish	77	13	Sugarcane	65	33
Tomato	79	43	Cotton	60	25
Chilly	62	44	Groundnut	40	66
Ridge gourd	5 9	17			
Cabbage	60	2			
Cauliflower	34	39			

Source: Narayanamoorthy (2004a &2004b). DMI: Drip method of irrigation FMI: Flood method of irrigation

Table 2. The efficiency of different solar cells and modules

Cell material	Max. cell efficiency (lab)	Max. cell efficiency (Mass prod.)	Typical Module efficiency	Surface area req. for $1kW_p$ power	Comment
Monocrystalline silicon	24.7%	22.0%	15.5%	$6.7m^2$	Highest price, affected by temperature
Polycrystalline silicon	20.35	17.4%	14%	$7.2m^2$	Medium price, affected by temperature
Amorphous silicon	12.1%	6.8%	6%	$16.7m^2$	Medium to low price, not affected by temperature
CIS/CIGS	20.0%	11.6%	10%	$10.0m^2$	
CdTe	16.5%	12.0%	7%	$14.3m^2$	
Concentrated cells	41.1%	36.5%	28%	$3.6m^2$	

Source: Quaschning (2010)

technologies are lying in the fact that it is reliable, convenient, durable, environmentally benign, low maintenance, and respond instantaneously to solar radiation. SPV technology is sustainable even in isolated and remote areas. Most of the commercially available solar modules are capable of producing electricity for at least 20 years (Dunlop, 2005). Based on the full life cycle, photovoltaic is an economically viable and therefore favorable solution for many small power applications, particularly in groundwater pumping where electricity is not available and internal-combustion engines are expensive to operate (Thompson, 2003).

Solar Photovoltaic groundwater pumping system

In SPV water pumping system main components are the solar array, power conditioning unit, solar tracking structure, and pump. The simplest PV water pumping system PV array is directly connected to the pump. For deep, a submersible pump is used, however, for shallow depth, a surface pump is a better option. The surface pump can pump water out only from a few meter depth.

In SPV water pumping, there could be configurational differences. 1) A *surface* or *submersible* pump can be used to fill an *overhead* tank. This tank serves as an energy store and supplies pressured water to the pressurized irrigation system. Stored water can serve as a reservoir during low insolation periods. In another configuration, water is directly injected into the irrigation system for irrigation without any overhead tank. In the third type, water is pumped into a grounded tank and this tank serves as a water reservoir for aquaculture with an additional pump to deliver water to fields to irrigate crops either by flood method or by pressurized technique (Fig. 1). The advantage of this configuration is that the water from the reservoir can be delivered to distant fields at comparatively higher pressure and discharge as this delivery pump encounters a low suction head. In this configuration more water can be abstracted and a large area can be covered under irrigation per day, as pumping and delivery units are already decoupled. Whereas, in direct feeding, the total dynamic head is large which substantially reduces the delivery head.

Further, solar arrays are mounted on dual-axis sun-tracking structures to put the PV array to face incoming sunlight directly. Since it is not possible to adjust all the panels on a single structure if the pump

Fig. 1. The schematic of solar photovoltaic groundwater pumping system

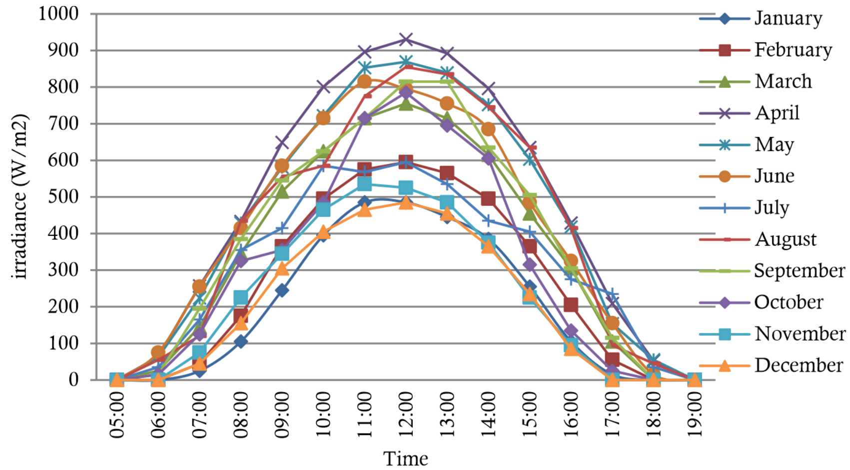

Fig. 2. Mean monthly averaged solar irradiance on cloud free day in Eastern region

capacity or the solar panel size is large, then more than one mast to support the modules is used. It is better to put the mast of the structure along NW-SE diagonally instead of straight E-W or N-S to avoid the shadow effect of one array on other arrays.

In India, new policy frameworks and financing schemes are pushing investments into solar energy projects. Some of the Indian states weaved in their policies to promote solar energy by giving subsidies of up to 90% on solar pumping systems. Across many states such as Bihar, Uttar Pradesh, Madhya Pradesh, Chhattisgarhi, Jharkhand, and West Bengal the most popular subsidized solar system is a 3.0 HP water pumping system, operated by a 3.0 kWp solar array. This paper describes the performance evaluation of a 3.0 HP submersible solar pumping system with a 3.0 kWp solar array at the experimental farm of ICAR Research Complex for Eastern Region, Patna, under the prevailing solar radiation condition and groundwater regime to evaluate the fusibility and suitability of this system and its utility for smallholders irrigation.

MATERIAL AND METHODS

Solar radiation

The mean monthly averaged solar *irradiance* and *solar global radiation* measured on a bright sunshine day for different months over the Eastern region of India is shown in Fig. 2 and Fig. 3. The irradiance on a cloud-free day is raged from 200- 930 W/m^2 and the solar global radiation is from 3.3- 6.4 $kWh/m^2/day$. The highest irradiance and solar global radiation was observed in April while the lowest was observed in December.

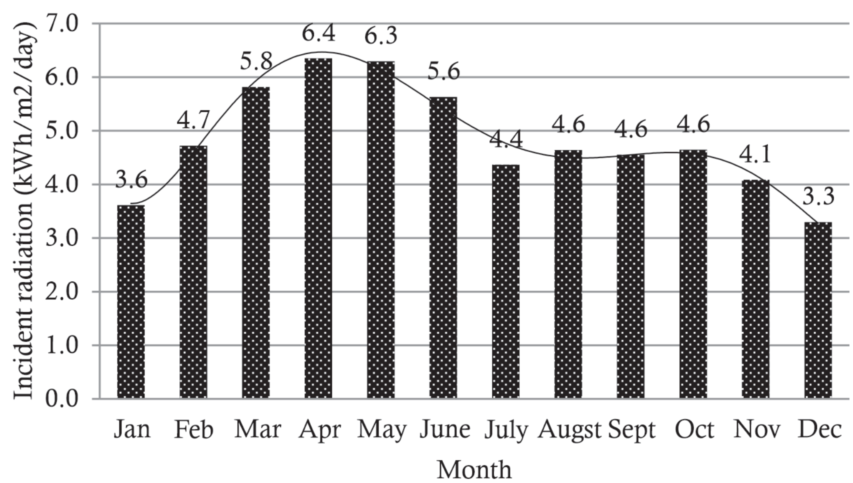

Fig. 3. Mean monthly averaged *global solar radiation* on a cloud free in eastern region of India

Table 3. Attributes of solar panels, used for submersible and centrifugal pumps

S. N.	Attributes	description
1	Pump type	Solar submersible with shut-off head 35m
2	Array size	3.0 kWp±3%
3	No. of modules	10
4	Material of cells	C-Si
5	Module size	0.3 kWp
6	Efficiency	15.4%
7	Open circuit voltage (V_{oc})	44.64V
8	short circuit current (I_{sc})	8.75A
9	Voltage at maximum power (V_{mp})	35.93V
10	Current at maximum power(I_{mp})	8.35A
11	Temperature coefficient W/ ^{0}C	± 0.4% / °C

Solar Array parameters

Attributes of selected solar modules and array size used to energize the 3.0 HP solar submersible water pumping system are reported in Table 3. The modules were connected to match the V-I requirement of the selected solar pump.

Power output from 3.0 kWp solar array

The instantaneous power output from a 3.0 kWp solar array used to operate on a 3.0 HP solar pump on a bright day for different months with 3 times manual tracking, i.e., at 7.00 AM (Eastward 45° from vertical) 9.30 AM (flat) and 2.30 (Westward tilt 45° from vertical) and for seasonal variation (November to February) 35° from vertical to Southward and flat in the rest months) was measure and presented in Fig. 4. The Figure 4 showed that between 9.0 AM -2.30 PM, the power availability to the pump was ranged from 1.6 -2.5 kW. This means the 3.0 HP pump with a rating of 2.2 kW performs at its rated value only over a certain time band on a day in some months otherwise it operated below its rated value.

Groundwater depth regime of the site

The groundwater depth regime below ground level is an important parameter that greatly affects the discharge of the pump. The prevailing groundwater depth regime in the Eastern region, in general, is ranged between 2 - 10 m with annual water level fluctuations ranging from ±2 to ±4m (GWB, 2019).

RESULTS AND DISCUSSION

The average groundwater abstraction by a 3.0 HP solar submersible pump per day for different months on a bright sunshine day and the corresponding average irrigable area per day by flood method in the Eastern region of India are reported in Table 4. These figures were derived by dividing the water availability per day by the average water depth require per irrigation by flood method. In general, the depth of water for flood irrigation is about 5.0 cm.

The operational threshold irradiance of 3.0 HP solar pumps was found to be 0.2 kW/m^2. During

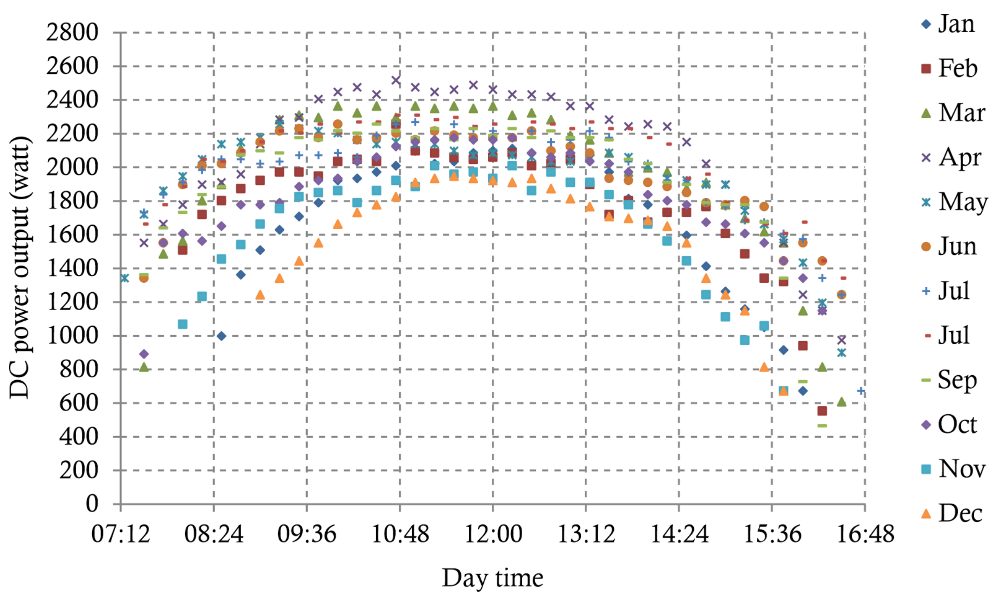

Fig. 4. Power output from 3.0 kWp operating solar array in Eastern region of India

Table 4. Performance of 3 HP solar e pumping system in different months under manual tracking of solar array on a cloud free day

Months	Sep-Nov	Dec-Jan	Feb	Mar-June
Water yield per day (m^3/day) from a solar pump on a cloud free day	135- 120	85-80	90-115	160-135
Irrigable area per day (m^2/day) from a solar pump on a cloud free day	2250-2000	1420-1330	1500-2250	2650-2250
Monthly averaged weekly irrigation command area (ha)	1.5	1.1	1.4	1.7
Yearly averaged weekly irrigation command area (ha)		1.4		
Monthly averaged fortnightly average irrigation command area (ha)	3.0	2.0	2.8	3.4
Yearly averaged fortnightly irrigation command (ha)		2.8		

low insolation months, the functional time band was ranged from 8.0 AM to 3.0 PM; whereas, in the remaining months it was from 7.30 AM to 4.30 PM. During this period fixed solar array and non-tracked solar array of same size gave almost equal power output. However, a tracked solar array, compared to the non-tracked array, was found effective before 9.00 AM and after 2.00 PM. The whole-day operation of solar pumps equipped with a manually tracked solar array option was found more useful in maintaining standing water depth in fish ponds.

From 9.00 AM to 2.30 PM, the 3.0 HP pump discharge was good and waterfront movement over the soil surface was faster. This provides improved irrigation efficiency in flood method of irrigation as transition time was less and deep percolation was to minimum. For pressurized irrigation, 9.00 AM- 2.00 PM was the most appropriate time band. For exclusively irrigation purposes farmers can opt fixed array to reduce the cost. However, the groundwater output over a day with manually tracked arrays was 17-21 percent more compared to fixed solar system. The excess water abstraction with tracked array was due to the more operational hours over a day contributed by early morning and late afternoon hours.

Further, the delivery head availability was measured between 9.00 AM to 2.0 PM for different months and it was found in the range of 0.8 -1.5 kg/cm^2. The maximum corresponded to March and April months. This pressure range enables the farmers to operate drip and micro irrigation successfully and farmers can grow horticultural crops under micro irrigation system to increase production with improved water productivity. Further, for pressured irrigation farmers should opt high head low discharge pumps.

The command area of irrigation with this capacity pump under the conventional method of irrigation for vegetable crops under a weekly schedule was about to 1.5 ha, whereas for fields crops with fortnightly irrigation scheduling was 2.5 ha.

CONCLUSIONS

This solar water pumping system is highly suitable for farm owners with operational land holdings sizes of 1.5-2.5 hectares. Irrigation using a solar pump is restricted to daylight hours, allowing for a limited volume of water to be extracted per day. Consequently, the irrigated area is also constrained to a specific size within a day. Therefore, when utilizing solar pump irrigation, crops must be cultivated using diversified modes which differ in irrigation scheduling.

For instance, if farmers adopt a weekly irrigation schedule, the effective coverage area of a single pump is confined to approximately 1.5 hectares. However, with a fortnightly scheduling, this coverage area can be extend up to 2.8 hectares. This applies when flood irrigation method with an irrigation depth of 5.0 cm.

REFERENCES

Agriculture Census (2011). Department of Agriculture and Cooperation, GOI.

Lipton, M. (2006). Can Small Farmers Survive, Prosper, or be the Key Channel to cut Mass Poverty. Journal of Agricultural and Development Economics. 3(1), 58-85.

Bardhan, P.K. (1973). Size, Productivity and Returns to Scale: An Analysis of Farm-level Data in India Agriculture. Journal of Political Economy, 81(6), 1370-86.

Berry, R.A. (1972). Farm Size Distribution, Income Distribution and the Efficiency of Agricultural Production: Colombia. American Economic Review, 62 (1), 403-08.

Dhawan, B.D. (2000). Drip irrigation: Evaluating returns. Economic and Political Weekly, 35(42), 3775-3780.

Dunlop, E.D., Halton, D. and Ossenbrink, H.A. (2005). 20 years of life and more: where is the end of life of a PV module? Photovoltaic Specialists Conference05. Conference Record of the Thirty-first IEEE Proceedings, 1593 - 1596..

Held, I.M., Delworth, T.L., Lu, J., Findell, K.L., Knutson, T.R. (2005). Simulation of Sahel drought in the 20th and 21st centuries. Proc Natl Acad Sci USA, 102, 17891–17896.

Hillel, D. (1989). Adaptation of modern irrigation methods to research priorities of developing countries. In: Le Hillel, D.1989. Adoption of modern irrigation methods to research priorities of developing countries. In.Le Moigne G, Barghouti S, Plusquellec H(eds).Technological and institutional innovation in irrigation. World Bank Technical Paper No.94. World Bank, Washington, D.C., 88-93

Jaswal, A.K. (2009). Sunshine duration climatology and trends in association with other climatic factors over India for 1970 2006. Mausam, 60,437 54.)

Keller, J., Adhikari, D.L., Petersen, M.R. and Suryawanshi, S. (2001). Engineering low-cost micro-irrigation for small plots. In: Keller K (ed) The Kenya Case Study. Swiss Agency for Development and Cooperation, Berne. The decision to develop this paper evolved during a Fact Finding Study conducted in Kenya, India, and Nepal in March 2001. The Study was funded by the Swiss Agency for Development and Cooperation under a program championed by Dr. Urs Heierli)

Lobell, D.B., et al. (2008). Prioritizing climate change adaptation needs for food security in 2030. Science, 319-607.

Martin, A.. Green, K. E., Yoshihiro, H.and Warta, W. (2011). Progress in photovoltaics: research and applications. Prog. Photovolt: Res. Appl., 19, 84–92

Mazumdar, D.(1965).Size of Farm and Productivity:A Problem of Indian Peasant griculture. Economica, 32, 161-73

Namara, Regassa E., Upadhyay, B. and Nagar, R. K.(2005) Adoption and Impacts of Micro irrigation Technologies : Empirical Results from Selected Localities of Maharashtra and Gujarat States of India, Research Report 93, International Water Management Institute, Colombo, Sri Lanka.

Narayanamoorthy, A. (1997). Drip irrigation: A viable option for future irrigation development. Productivity, 38 (3), 504-511.

Narayanamoorthy, A. (2004a). Impact Assessment of Drip Irrigation in India: The Case of Sugarcane. Development Policy Review, 22 (4), 443-462.

Narayanamoorthy, A. (2004b). Drip irrigation in India: can it solve water scarcity? Water Policy, 6, 117-130.

NCEUS, National Commission for Enterprises in the Unorganised Sector. (2008). A special programme for marginal and small farmers. New Delhi, India.

Polak, P., Yoder, R. (2006). Creating wealth from groundwater for dollar-a-day farmers: Where the silent revolution and the four revolutions to end rural poverty meet. Hydrogeology J, 14, 424–432.

Quaschning, V. (2010). Renewable energy and climate change. John Wiley & Sons Ltd.ISBN-978-0-470-74707-0, 90.

Qureshi, M.E,, Wegener, M.K., Harrison, S.R. and Bristow, K.L. (2001) Economic evaluation of alternate irrigation systems for sugarcane in the Burdekin delta in North Queensland, Australia, In: Water Resource Management, Eds: C.A. Brebbia, K. Anagnostopoulos, K. Katsifarakis and A.H.D. Cheng, WIT Press, Boston,pp. 47-57.

Sen, A.K. (1964). Size of Holdings and Productivity. The Economic Weekly, 16 (5-7), 323-26.

Sen, A.K. (1962). An Aspect of Indian Agriculture. The Economic Weekly, 14 (4-6), 243-46.

Sharma, N.K., Tiwari, P.K, Sood, Y.R. (2012). Solar energy in India: Strategies, policies, perspectives and future potential. Renewable and Sustainable Energy Reviews, 16, 933 41.

Sivanappan, R.K. (2002). Strengths and weaknesses of growth of drip irrigation in India, In: Proc. of Micro Irrigation for Sustainable Agriculture. GOI Short–term training19-21 June, WTC, Tamil Nadu Agricultural University, Coimbatore

Thompson Marry, A. (2003). Reverse-Osmosis Desalination of Seawater Powered by Photovoltaics Without Batteries Doctoral Thesis, Loughborough University.

Shah, T. (2009).Climate change and groundwater: India's opportunities for mitigation and adaptation. Environ. Res. Lett. 4 (2009) 035005.

WDR, World Development Report (2008). Agriculture for Development (World Bank, Washington.