Here Comes The Sun - With Water and Enterprise

Catalysing Competitive Solar Irrigation Service Markets

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Acknowledgement: This paper is based on a solar powered irrigation project sponsored by the International Water Management Institute – Tata (IWMI- TATA) Water Policy Research Programme and Consultative Group for International Agricultural Research (CGIAR) Research Programme on Water, Land and Ecosystems and executed by the Aga Khan Rural Support Programme (AKRSP).

1. Introduction

Bihar has fared comparatively poorly compared to West Bengal in the development of ground water irrigation, despite having similar natural resource endowments, primarily due to the unavailability of adequate grid electricity supply (Durga et al, 2016). The Bihar Government tried to subsidise the price of diesel for paddy cultivation in drought prone areas to get around this problem but due to limited resources the cash transfers did not take place timely and the scheme also suffered from poor targeting and did not reach the poor farmers (Kishore et al, 2015). Subsequently, the Bihar Government launched a scheme for solar irrigation in 2008, Bihar Saur Kranti Sinchai Yojana (BSKSY), to solve this problem of lack of adequate electricity for irrigation. Under this scheme, 2KWp solar panels were used to energise small pumps and provided to small farmers but this too did not succeed because the pumps were too small to irrigate all the lands of the farmers situated in various non-contiguous fragments and there was not enough water in the shallow aquifer for these pumps to be operable throughout the winter and summer seasons (Durga et al, op cit). Later in 2012, the Government launched a pilot project to provide solar power to 34public tubewells tapping the deep confined aquifer run by water user groups of eight farmers each in Nalanda District, that had been installed earlier by the Minor Irrigation Department (MID) but had fallen into disuse because of lack of grid electricity supply and the high price of diesel. The pumps became operational but failed to provide water to small farmers because the operating model was that of a single operator supervised by the MID who was to be paid a salary from the earnings made from selling water and these water revenues would also take care of maintenance of the system. However, despite improving the operation of the public tubewells and providing irrigation, due to inadequate supervision by the MID leading to both technical and financial problems, the full potential of these solarised public tubewells in Nalanda in increasing irrigation and distributing it equitably have not been realised (Kishore et al, 2017).There is evidence that water markets in Bihar, for water sold by large farmers, provides greater overall irrigation than would be possible without them because there are a large number of marginal and small farmers who cannot develop their own irrigation.However, since these markets are dominated by the big farmers who earn a monopoly rent, the earnings of the small farmers who buy water from them are greatly reduced leading to inequity in the distribution of irrigation benefits (Shah and Ballabh, 1997). Moreover, the ever increasing price of diesel tends to make the rentals sticky as even if the price of diesel falls later, the rentals don't, further inconveniencing small holders(Shah, 2007).

Combining the insights from the above studies, theInternational Water Management Institute (IWMI) proposed a new tweak for the BSKSY to improve both its operationality and the equity of irrigation (IWMI, n.d.).This involves the introductionof Solar Irrigation Service Providers (S-ISP) who would make some investment in installing solar powered deep tubewells, the rest being provided as a grant by the Government and then sell the water to farmers. The S-ISPs would be chosen in such a way that their command areas overlapped so as to avoid the creation of monopolies leading to the earning of rent by them to the detriment of the smallholders. IWMI,in association with Aga Khan Rural Support Programme (AKRSP), has implemented a solar powered irrigation piloton an entrepreneurship model in Chak Haji village in Samastipur District in Bihar from the Winter sowing season of 2016 to test the viability of this new policy. Fig. 1 shows the location of the pilot.This paper evaluates the operation of this pilot to testthe validity of its premises.

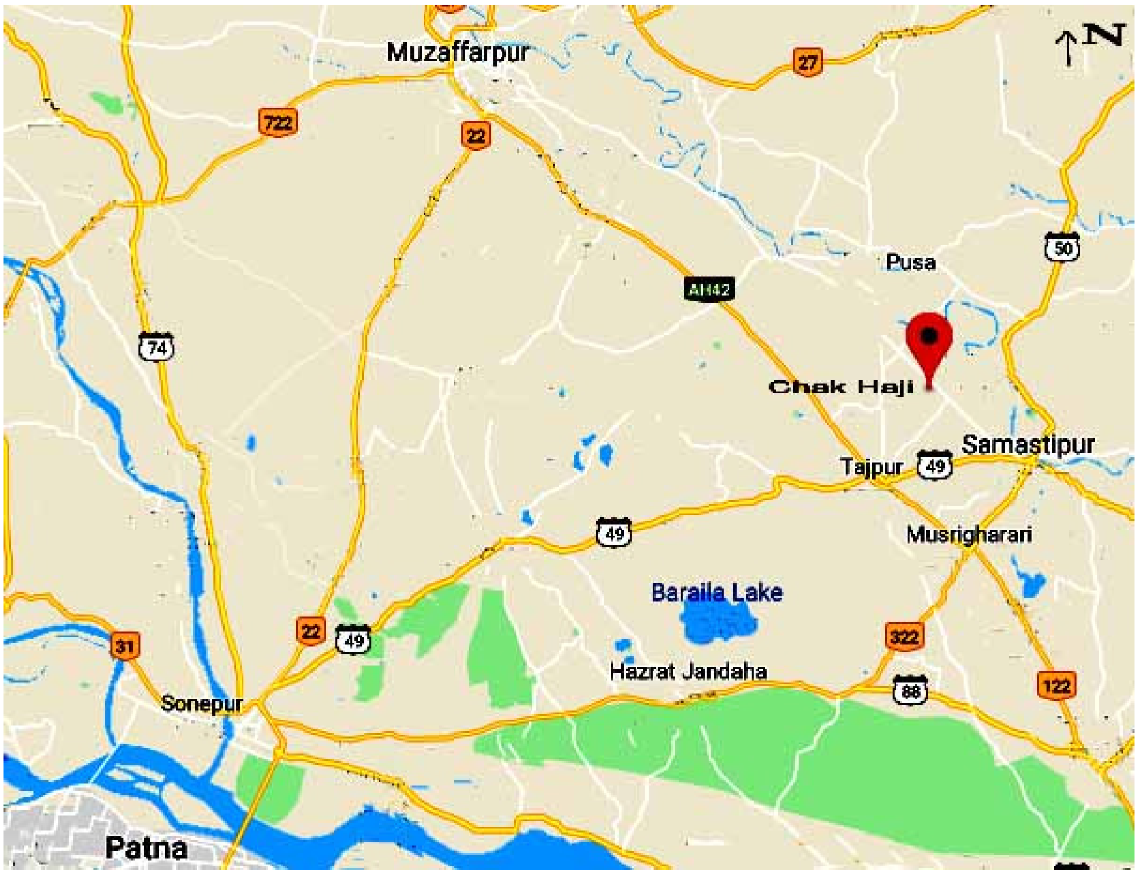

Fig.1 : Map showing Location of Chak Haji Village

2. The Features of the Solar Irrigation Service Pilot

The main features of this policy pilot,which has been designed keeping in mind the need to test the hypothesis that the S-ISP model can better irrigation and equity outcomes, are as follows -

1. Six irrigation systems consisting of 5 HP submersible water pumps in borewells tapping the confined aquifer powered by solar photovoltaic panels of 5KWpand catering to a command area of about 12 Ha and 100 farmers each through an underground pipeline that is about 300 m long have been installed in Chak Haji village of Samastipur District in Bihar.The unconfined aquifer in Chak Haji does not have enough water for providing irrigation through shallow borewells and ponds for three cropping seasons to all the agricultural land and so the unconfined aquifer has been tapped through deep borewells to extend and diversify agriculture in the village.

2. The irrigation systems have been installed under a model wherein individual farmers have been designated as Solar Irrigation Service Providers (S-ISP) and made their owners.The S-ISPs have had to get the borewells dug at their own cost and will have to pay Rs 2 Lakhs in installments towards the capital expenditure of the irrigation system, the rest being provided as a subsidy by IWMI. They will provide water through the pipeline to the farmers in their command areas at a charge that will cover their installment payments, operating costs and provide a profit.The S-ISPs will operate and maintain the system.
3. The command areas have been so chosen as to overlap each other so that there is competition between the S-ISPs and the water buyers do not face a monopoly situation that might lead to a rise in charges and drop in the quality of service.
4. The AKRSP had set up a group irrigation system in Chak Haji run jointly by the farmerswith a 5 HP deep borewell pump powered by grid electricity and diesel engine earlier and this too was energised with 5KWp of solar panels and a pipeline laid in its command when the S-ISP model was installed. This system too replicates the S-ISP model in that the farmers' group has contracted the operation and maintenance of the system to a farmer who pays the installment amount for payback of the installation to the group while covering his operation costs and profit from the rest of charges paid by the water users.
5. Aperson has been employed by the AKRSP to oversee the smooth operation of the pilot and ensure successful outcomes on a long term basis.The experience of the solar powered public tubewell project in Nalanda shows that left to themselves the water user groups and the operators do not function optimallyresulting in lesser irrigation development and equity. Therefore, there is a need for oversight in the initial stages for a few years.

3. Objectives of the Evaluation

The objectives of the present evaluation are as follows -

1. To estimate to what extent agriculture in the project area has been extended and diversified due to the operation of the Solar ISP system so as to test the hypothesis that this policy will improve agricultural productivity.
2. To estimate the economic performance of the irrigation system from the point of view of the water buyers, the Solar ISPs and the pilot as a whole so as to test the hypothesis that this policy will improve the equity in the sharing of the benefits ofirrigation development.
3. To suggest measures for further improving the operation of the pilot on the basis of the insights gained from the evaluation.

4. Methodology of Evaluation

The principal method of evaluation has been to compare the area irrigated and the water use after the implementation of the project with that prevailing before. This has been done by comparing the data collected regarding water use, cropping area and cropping pattern in a baseline survey conducted prior to the implementation of the pilot in 2016 with that collected for the same parameters by the S-ISPs during the operation of the pilot. In addition to this group discussions have been held with a sample of farmers catered to by each of the S-ISPs, the S-ISPs themselves and the AKRSP staff supervising the operation of the pilot regarding various aspects of the pilot.

5. Cultivated Area,Cropping Pattern and Water Usepre and postPilotImplementation

Preliminary discussions with the S-ISPs and the AKRSP supervisor revealed that there had already been considerable irrigation coverage during the winter season powered by diesel engines and grid electricity in the area and this was confirmed by the results of the baseline survey which indicated the proportion of irrigatedarea for those surveyed during the Winter season to be 99.7 per cent of thenet cultivated land area in 2015-16. The irrigated area during the winter and summer seasons before the implementation of the pilot in 2016 and after in 2018have been compared to determine the change resulting from the implementation of the S-ISP pilot in Chak Haji village.

There were 415 respondents in the baseline survey and there are a total of 794 water users in 2017-18. The S-ISPs could identify 180 farmers who were there both in the baseline survey and in the list of current water users. So the before - after comparison was done for these 180 farmers as follows -

- For 2015-16, the irrigated area, water use in hours of watering and cropping pattern data were taken from the baseline survey.
- For 2017-18 these were taken from the digitised version of the operational logs maintained by the S-ISPs for 2017 and 2018 which have the data on the same parameters.

This comparison revealed the following -

1. Out of 180 farmers,only 97(53.9%) were doing summer cultivation in 2016 but all of them were doing so in 2018.
2. Out of the 97 farmers who were doing summer cultivation in 2016, as many as 65 (67%) had increased their area of cultivation in 2018while 16 (16.5%) were cultivating the same area.
3. Only 16 (16.5%) farmers of the 97 who were cultivating in 2016,were cultivating less in 2018 than what they were cultivating in 2016.
4. During the year, the area being cultivated in winter season is the highest and for various reasons like waterlogging, the area being cultivated during the monsoon season is less than the winter acreage. The irrigation requirement during the monsoons is much less as it is used only for protective purposes. The area being cultivated by these 180 farmers in the 2015-16 winter season prior to the implementation of the pilot was 43.8 Ha which increased to 52.5 Ha in the 2018 winter season.This is an increase of 19.8 percent over the winter irrigation prevailing in 2016. Thus, solar irrigation had not only replaced diesel irrigation during the winter season but has extended cultivation to fallows.
5. The cumulativearea cultivated in the summer season by these 180 farmers increased from 14.3 Ha in 2016 to 32.5 Ha in 2018 which is an increase of 127.2 per cent.
6. Thus, the proportion of area cultivated in summer to that cultivated in winter, which latter is equal to the net cultivated area since it is the highest of the three seasons, was 32.6 per cent in 2015-16, this rose to 61.9 per cent in 2017-18.

Some of the above results have been tabulated in Table 1 below for ease of comparison.

Table 1: Change in Area of Cultivation Due to Solar Powered Irrigation Pilot in Chak Haji

Sl. No.	Parameter	2015-16 Winter			2017-18 Winter			Change in Winter Area (%)	2015-16 Summer			2017-18 Summer			Change in Summer Area (%)
		No.	%	Area (Ha)	No.	%	Area (Ha)		No.	%	Area (Ha)	No.	%	Area (Ha)	
1	Farmers doing Cultivation	149	82.8	43.8	180	100.0	52.5	19.8	97	52.5	14.3	180	100.0	32.5	127.2

The increase in area under cultivation in the summer season has been much more significant than that in the winter season. This has been studied further. The number of farmers, distributed by the area of land under cultivation, for the summer seasons in 2015-16 and 2017-18are shown in Table 2.

Table 2: The Number of Farmers by the Area of Land Cultivated in 2015-16 & 2017-18 Summer

Cultivation Season	Area Under Cultivation (Kathas)*								Total No. of Farmers
	0	≤5	≤10	≤15	≤20	≤25	≤30	>30	
Summer 2015-16	83	43	36	9	1	7	1	0	180
Summer 2017-18	0	58	54	40	13	7	5	3	180

*(The Katha is a local measure of area that varies in size and in Samastipur, 1 Ha = 55 kathas)

Fig.2 below illustrates this significant improvementin the area cultivated in the summer season in 2018as compared tothat of 2016 very well. Notably, all the farmers are cultivating less than 2 Ha of land each and so are marginal farmers.

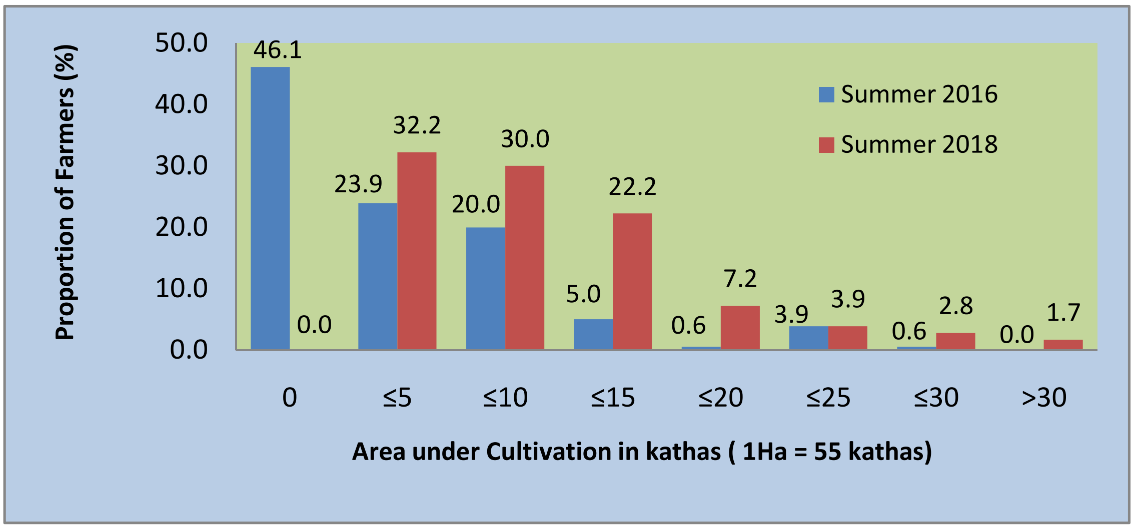

Fig. 2 : Distribution of Farmers Cultivating in the Summer Season by Area Under Cultivation

A comparison was also made of the cropping patternin the two years to see if there has been any significant change in the diversity of cultivation. The comparison has been tabulated in Table 3.

Table 3: Cropping Pattern in Chak Haji Before and After Project Implementation

Year	2016		2018	
Crop	No. of varieties	Prop. Of Gross CultivatedArea (%)	No. of varieties	Prop. Of Gross CultivatedArea (%)
Flower			1	0.23
Green Fodder	1	2.67		
Vegetables	33	51.85	32	59.76
Spices	4	1.52	5	3.53
Seed			1	0.1
Pulses	2	7.37	3	0.53
Cereals	5	35.56	4	34.14
Til	1	0.19		
Fruit	2	0.32	5	0.8
Tobacco	1	0.52	1	0.91
Total	**49**	**100**	**52**	**100**

There was already considerable variety in cultivation in the village and there has not been much change in the number of varieties cultivated. However, there has been a significant increase in the area under vegetable cultivation which provides greater income and this has come from a reduction in the area under pulses and green fodder. Green Fodder is mainly cultivated for milk production by dairy cattle and since dairying is less remunerative than vegetable cultivation and there is better demand for vegetables in the market than for milk and pulses,fodder and pulses cultivation has given way to vegetable cultivation.

Earlier the total time required over a number of waterings to irrigate one katha (1Ha=55 Kathas) of land over the whole crop lifeaveraged across all seasons, soil type, terrain and crops was 2.3 hours in 2016 and this has come down to 1.3 hours from the solar powered pumps in 2018. Thus, the solar pumps used in the pilot are considerably more efficient than the diesel pumps used earlier. This has also been confirmed by another impact assessment survey carried out on a sample of 32 beneficiary farmers in Chaka Haji village (DMI, 2017).

Additionally, the correlation coefficient between the area cultivated and the water used for the baseline farmers in 2016 was a weak 0.127 which means that in 2016 the higher the area of land cultivated the less was the use of water indicating that due to lack of water and its high price those cultivating larger tracts of land had to make do with less amount of water and so had lesser yields.However, for these same farmers with the benefit of solar powered pumps in 2018,the correlation coefficient was fairly strong at 0.733 indicating a much greater use of water for growing crops. Thus, not only has theefficiency of pumpingimproved from solar powered pumps butdue to the S-ISP entrepreneurship model,the cumulative amount of water accessed by farmers has also increased leading to better land utilisation.

6. Comparison of the Operational Performance of the Solar Irrigation Service Providers

The first year of the operation of the solar irrigation pilot in 2016-17 was one of experimentation and the operation stabilised only in the second year in 2017-18.

Table 4: Performance of S-ISPs in the Project Area

Solar ISP	Design Command Area Adopted Initially (Ha)	2017-18 Winter Season		2017-18 Summer Season		Total Water Supply for 2017-18 (Hrs)	Water Supply/ Net Culti-vated Area 2017-18 (Hrs/Ha)*	Propor-tion of Summer Area to Winter Area (%)	Proportion of Net Cult. Area to Design Command Area (%)
		Total Water Users	Culti-vated Area (Ha)	Total Water Users	Culti-vated Area (Ha)				
Yatin Kumar	9.7	100	11.6	100	14.4	790.6	55.0	124	148
Lalan Singh	9.1	104	13.2	106	12.3	887.1	67.2	94	145
Sanjeet Singh	10.3	91	30.7	55	21.7	1418.3	46.2	71	298
Rajkishore Singh	11.9	132	17.0	98	10.9	1083.3	63.7	64	143
Neelkamal Prasad	14.2	124	22.5	90	12.2	1124.1	50.0	54	158
Bhola Singh	10.2	131	16.6	110	12.9	813.5	49.0	78	163
SVSCC		112	11.3	94	9.7	646.3	57.2	86	

* The net cultivated area has been assumed to be the higher of the area cultivated in one season either winter or summer. Except for Yatin Kumar, all the other ISPs have recorded greater cultivation in the Winter season.

One more S-ISP, Bhola Singh, was added to the pilot in the second year and the water supplied by the original six S-ISPs increased by 80 percent in the second year over the first. The evaluation of the performance of the six S-ISPs and the existing group irrigation scheme that was solarised has been analysed for 2017-18. In this the cultivation during the winter and the summer seasons have been analysed as there is not much irrigation done in the monsoon season due to the the solar pumps not working due to the cloud cover and also lesser need for irrigation because of the rains. The results of the performance analysis have been summarised in Table 4 above.

The major review points regarding the operation of the S-ISP pilot that emerge from the above performance analysis table are as follows -

1. The project was designed in such a manner that each S-ISP initially had a command area of roughly around 10 Ha that could be catered to by the 5Kw pump and 300 meters of pipeline.The command areas of adjoining S-ISPs overlapped so that there was competition among them to cater to more farmers. Thus, due to the enterprise of the S-ISPs to get more water buyers and that of the water buyers to cultivate more land than they had done earlier, combined with investments made by the S-ISPs in getting collapsible plastic pipes to extend the command area, all the S-ISPs have exceeded the designed command areas with Sanjeet Singh having done so the most by serving triple the area in winter. Rajkishore Singh has the lowest command area primarily because he is a government teacher and employs another person to handle the operations and so is not as proactive as the others.
2. The group irrigation scheme under performed in the first year because they had employed a person to run the pump. They switched to the entrepreneurship model by contracting out the operations to an individual who had to pay Rs 50,000 per year to the group for repaying the installment of the solar system. This had a salutary effect as the water supplied increased considerably from 71.8 hours in 2016-17 to 646.3 hours in 2017-18. Thus, the S-ISP model has succeeded in ensuring greater area of irrigation by fostering competition among the solar irrigation service providers and encouraging the farmers to bring more land, that earlier used to lie fallow, under irrigated cultivation.
3. There was a considerable flux among the water users of an S-ISP with about 70 percent of the water users changing across all S-ISPs from 2016-17 to 2017-18.The highest churn took place in the command areas of Lalan Singh, Sanjeet Singh and Neelkamal. This is partly due to the fact that the former does not supply water properly and demands immediate payment and the latter twoare very pro-active in seeking out more water buyers to increase their earnings. Indeed Sanjeet Singh is so happy with his enterprise performance that he has expressed the desire to invest in another solar powered irrigation system if he is chosen for the same. Thus, this too confirms the efficacy of having overlapping commands with the intention of generating competition among the S-ISPs.
4. The depth of irrigation has been estimated by the ratio of the amount of water use per hectare was calculated by the dividingthe total hours of water supply per net area of cultivation for each S-ISP.The area under winter cultivation in 2018 has been taken as the net area for this purpose as it is higher than the summer cultivation area except in the case of Yatin Kumar.Yatin Kumar said that due to other commitments he was not able to operate the pump at full capacity during the winter and so the water supplied was less in that season as compared to the summer. There is a great variance with the highest depth

in the command of Lalan Singh and the lowest in that of Sanjeet Singh. The reasons for this as enumerated by the S-ISPs are as follows-

i. Differences in soil quality and terrain
ii. Differences in crops cultivated
iii. Lesser efficiency in cleaning and aligning the solar panels
iv. Distances of plots from the pipeline leading to losses in the collapsible pipes used to carry water to them

5. The S-ISPs reported that due to the successful operation of the project diesel powered pumps have been rendered redundant as mostly farmers use the cheaper and greater supply of water from the S-ISPs. Thus, even during the winter season when there is enough water for irrigation in the shallow aquifer, the farmers use the water from the S-ISPs which comes from the deep aquifer. A few owners of these diesel pumps use them occasionally on their own farms when they urgently need water.

7. Evaluation of Economic Performance

The economic performance of the whole intervention has been evaluated separately at the level of the water user, the S-ISPs and the project using different parameters.

7.1 Water Users

The efficiency of water use has increased as noted earlier from an average of 2.3 hours of total irrigation for a katha of land with diesel pumpsets to 1.3 hours for solar pumpsets. Simultaneously the cost of irrigation has gone down from Rs 120 per hour to Rs 100 per hour in 2018. Thus, on each katha of land cultivated on an average the farmer saves Rs 120 x 2.3 - 100 x 1.3 = Rs 146. This along with the greater availability of water has led to farmers increasing theland under cultivation which has gone up in both the winter and the summer seasons. While the increase in cultivated area for the sample of 180 farmers has been 19.8 percent in the winter season it has been 127.2 percent in the summer season. This has increased the productivity of all the farmers who are water buyers from the S-ISPs and led to a significant improvement in the income of the farmers which can be roughly estimated as follows -

The ratio of land cultivated in winter due to solar irrigation in 2018 as compared to diesel irrigation in 2016 as derived earlier from a comparison between the 2016 baseline survey and 2018 for 180 farmers was 1.20. Taking this ratio to be representative of the whole pilot implementation we get the amount of additional cultivation in winter over the whole pilot area due to solar irrigation as -

$122.9/(1 + 1/(1.2)) = 67.0$ Ha

Similarly the ratio of land cultivated in summer due to solar irrigation in 2018 as compared to diesel irrigation in 2016 as derived from a comparison between the 2016 baseline survey and 2018 for 180 farmers was 2.27. Taking this ratio to be representative of the whole pilot we get the amount of additional cultivation in summer over the whole pilot area due to solar irrigation as -

$94.2/(1 + 1/(2.27)) = 65.4$ Ha

This additional area has mostly been deployed in vegetable cultivation because it is more remunerative.The net income earned from various kinds of vegetable cultivation in Chak Haji on the basis of analysis of the baseline data are given in Table 5 below–

Table 5: Net Income from Vegetable Cultivation in Chak Haji

Vegetable	Brinjal	Cauliflower	Chilli	Coriander	Karela	Okra	Parval	Todi
Income in Rs/Ha	45100	82885	95150	41250	67100	168300	66550	67100

Thus, the average returns for vegetable cultivation turns out to in Chak Haji turns out to be Rs 79,179 per hectare for one crop. Two crops have been taken in winter and summer and so we can conservatively take the net returns from vegetable cultivation for our estimation to be Rs 75,000 per Ha per crop per year. Therefore, the cumulative additional income generated by vegetable cultivation throughsolar powered irrigation in the winter season of 2017-18 is at least -

67 x 75,000 = Rs 50,25,000

794 farmers did winter cropping, so the average additional income per farmer was Rs 6,329.

Similarly the cumulative additional income generated by vegetable cultivation through solar powered irrigation in the winter season of 2017-18 is at least -

65.4 x 75,000 = Rs 49,05,000

653 farmers did summer cropping, so the average additional income per farmer was Rs 7,511.

Thus, a farmer who did both winter and summer cropping earned Rs 13,840more.

Another, indirect indicator of this economic improvement of farmers is the fact that leasing out rates for land in Chak Haji have gone up from Rs 1000 per katha earlier to Rs 2000 per katha now whereas the rates have remained the same in other villages nearby where solar irrigation is not available.

7.2 Solar Irrigation Service Providers

The economic performance of the S-ISPs is summarised in Table 6. The revenue has been calculated by multiplying the total water sold with the price which was Rs 90 per hour in 2016 and Rs 100 per hour in 2018. The Expenditure has been calculated by multiplying the total water sold by Rs 20 and adding Rs 10000 per year for maintenance and buying of the collapsible pipes which have to be used to take water from the underground pipeline standposts to the farmers' fields. Sanjeet Singh has earned the most income as he has sold the most amount of water followed by Neelkamal Prasad and Rajkishore Singh. Yatin Kumar has earned the least which he says is because he has not sold enough water in the winter months and also he counts less hours when the pump is not functioning at full flow due to lesser solar output from the panels.

Table 6: Economic Performance of S-ISPs in the Pilot

	2016-17			2017-18		
Solar ISP	Revenue (Rs)	Expenditure (Rs)	Income (Rs)	Revenue (Rs)	Expenditure (Rs)	Income (Rs)
Yatin Kumar	46,773	20,394	26,379	71,156	25,812	45,343
Lalan Singh	43,790	19,731	24,059	79,836	27,741	52,095
Sanjeet Singh	77,973	27,327	50,646	1,27,643	38,365	89,278
Rajkishore Singh	47,747	20,610	27,136	97,497	31,666	65,831
Neelkamal Prasad	71,565	25,903	45,662	1,01,168	32,482	68,686
Bhola Singh				73,217	26,270	46,946

There is also the problem of untimely payments of the water charges by the buyers. Except for Lalan Singh who insists on immediate payment, all the others take only about 30 per cent of the charge at the time of the watering and the rest is paid in installments. Yatin Kumar is offering water at Rs 90 per hour this year instead of Rs 100 if the whole payment is made immediately.

The internal rate of return or IRR for the S-ISPs has been calculated assuming the average water hours sold by them in 2017-18 and a life time of 20 years for the solar panels.It has also been assumed that the Variable Frequency Drive (VFD), submersible pump and the underground pipes will require replacement or substantial repairs after 10 years and this for simplifying the calculations will be introduced as an annualised cost of Rs 10,000 each year to be deducted from the cash flow. The formula for IRR is : $0 = \sum^{T}_{t=1} C_t/(1+r)^t - C_0$

where C_t is the net cash inflow during the period t, C_0 is the total initial investment cost, r is the IRR and t is the number of time periods over which the initial investment will give returns.

C_0 in this case is the sum of the initial down payment of Rs 50,000 for the system, 60,000 for the digging of the borewell and Rs 20,000 for the pumphouse, a total of Rs 1,30,000, t = 20 and C_t is the net income from water sale less the annual maintenance costs which are to include an annualised cost of replacement of the VFD, pump and pipeline of Rs 10,000 and another Rs 10,000 for repairs and replacement of the collapsible pipes. In the first three years the installment payments of Rs 50,000 each will also have to be deducted from C_t.Thus, the annual income C_t is Rs 11,558 in the first three years and then Rs 61,558 for the rest of the time period.

By iteration for these values we get a very high IRR =27 percent which is much higher than the market rate for capital of about 15 percent.

Thus, because of the substantial subsidy given to the S-ISPs, their investment is very sound financially and consequentlytheoperation of the solar powered irrigation system has enthused the S-ISPs considerably and they are thinking of ways to further increase the number of water hours. The only problem is the delay in payments for water use by the water buyers.Therefore, new employment has been created as a result of the pilot in the form of the S-ISPs and their operators which will increase considerably if the project is scaled up.

7.3 Pilot

The major economic gains for the project are the increase in water use, especially in the summer season but also in the winter season, which has increased the gross area under cultivation and the replacement of diesel with the sun as the source of energy leading to reduction in irrigation costs and also carbon emissions, for which latter, the equivalent carbon credit price can be estimated.

The total solar water hours in 2017-18 was 6763. Since the comparison between solar irrigation and diesel irrigation done earlier has shown that the ratio of time for irrigating a particular area between diesel and solar is 1.77, the diesel water hours for irrigating the same amount of land would be 6763 x 1.77 = 11,970. Thus the savings generated from the lower cost of solar irrigation in 2017-18 was -

11970 x 120 - 6763 x 100 = Rs 7,60,100.

Assuming that 1 litre of diesel is burnt in 1 hour, there is a saving of 11,970 litres of diesel which amounts to a carbon emission reduction of 32 MT. The Social Cost for carbon emission reduction is$45 per 1 MT (Rose et al, 2017). Thus in Rupee terms the carbon credit amounts to -

32 x 45 x 70 = Rs 1,00,800.

The annual cumulative value addition to the water users as calculated earlier is Rs 99,30,000.

The cumulative annual incomes earned by the S-ISPs are also a contribution of the pilot and these are 80,906 in the first three years and then Rs 4,30,906 in the following years.

Thus, the total annual economic value addition due to the project is Rs 1,00,10,906 in the first three years and Rs 103,60,906 for the rest of the years.

We can now calculate the IRR for the pilot as a whole with the same formula as before :

$$0 = \sum_{t=1}^{T} C_t/(1+r)^t - C_0$$

The initial cost of each solar pump system was Rs 5,12,000 and the pipeline was Rs 1,20,000. For the SVSCC group only the panels, VFD and pipeline were provided, as there already was a pump, at a cost of Rs 5,10,000. The six S-ISPs and the SVSCC made an initial contribution of Rs 50,000 each. Therefore the total initial installation cost was -

C_0 = 5,12,000 x 6 + 1,20,000 x 6 + 5,10,000 - 7 x 50,000 = Rs 39,52,000

The recurring cost is that of supervision, monitoring and evaluation and we can put that roughly at Rs 6,00,000 per year including all the time and resources of IWMI and AKRSP. This is a very important component of such policy interventions because of the immense amount of work that has to be put in to mobilise the community, both farmers and S-ISPs, to adopt this new system and then cooperate to run it properly. This very necessary expense has to be deducted from the cash flow which apart from the economic value calculated earlier will also include the Rs 3,50,000 to be paid by the S-ISPs and SVSCC for the first three years -

C_t=1,00,10,906-6,00,000+3,50,000(for first 3 years)=97,60,906=1,03,60,906 - 6,00,000 for the rest.

By iteration for these values we get a very high IRR = 247 percent which is 16 times higher than the market rate for capital of about 15 percent and completely justifies the project in economic terms when all the benefits accruing from it are taken into account. Moreover, it iscatering to a gross irrigated area of about 240 Ha including the protective irrigation during the monsoons at a capital investment, including that made by the S-ISPs in digging borewells, of Rs 47,22,000.This works out to a very reasonable investment of Rs 19,675 per Ha only.

Assuming that most of the additional income generated by this pilot is spent on household and agricultural consumption and taking the average indirect tax rate to be 15 percent (GoI, 2015) we arrive at a cumulative annual tax revenue for the Government of - 97,60,906 x 0.15 = Rs 14,64,135.Thus, if the Government, were to make the initial investment to implement this policy, it would recover it within 3 years and thereafter it would have surplus revenues for the next 17 years.

8. Improved Water Management in the Basin

The alluvial soils in Samastipur combined with high annual rainfall of 1100 mm,result in a very high average water table in the shallow aquifer of 5 m below ground level which reduces to 3m post monsoon (CGWB, 2013). Consequently, due to this high water table the monsoon rains are not recharged and the runoff creates floods when there are heavy rainfall events in short spans of time. The pilot by tapping the deep aquifer extensively during the winter and summer seasons and draining it, creates a situation where water from the shallow aquifer seeps more readily into the deep aquifer during the following monsoons increasing recharge and reducing runoff (IWMI, op cit). The more the competitive market for solar powered irrigation is increased the greater will be the drawal from the deep aquifer and so the monsoon recharge will also increase. There is of course the possibility that the cheap and abundant supply of electricity might eventually lead to excessive groundwater withdrawal and its attendant problems as has happened elsewhere (Shah and Verma, 2008). However, this problem can be averted by promoting a further policy of generation of excess solar power by a cooperative of the S-ISPs to sell to the grid which is more remunerative than over exploiting the groundwater for agriculture as shown by another pilot being implemented by IWMI in Gujarat (Shah et al, 2017). Thus, solar powered irrigation in a competitive market environment has the potential to foster more sustainable management of water resources also, in addition to improving agricultural outcomes.

9. Competitive Solar Irrigation Service Markets in The Ganga-Brahmaputra-Meghna Basin

Agriculture in Bihar has languished primarily because of high input costs and especially that of energy, due to inadequate grid electricity supply and the high price of diesel (Kishore, 2004). Given that rural electrification through grid supply is not happening in Bihar due to lack of public investment and the existing ground water markets are neither increasing irrigation nor achieving equity, there is a need for an alternative. IWMI has not only proposed an alternative involving solar powered irrigation and competitive ground water markets but also implementeda pilot in Chak Haji village to demonstrate the suitability ofthis policy. The main features of this alternative policyare (IWMI op cit) -

a. Create a competitive watermarket offering pump-less farmers irrigation service at an affordable price;
b. Create 6-15 full time jobs/village;
c. Crowd out diesel tubewells;
d. Expand irrigated area, promote intensification and diversification of the farming system;
e. Improve utilization of solar pump capital;
f. Allowsmall farmers toirrigate their plotsby buying waterfrom an S-ISP close to each plot;
g. Incentivize S-ISPentrepreneurs tocontribute to capitalinvestment.

The foregoing quantitative analysis clearly shows that all these objectives have been met and the pilot has a very high internal rate of return and tax revenue potential.Therefore, the policy can be adopted on a large scale because of its excellent economic efficiency, environmental sustainability and equity features, not only in Bihar but in the entire Ganga, Brahmaputra and Meghna basin which has similar characteristics as that in Samastipur.However, before scaling up this pilot as a policy intervention for catalysing competitive solar irrigation service markets on a large scale there are a few critical points that need to be addressed as follows -

1. First and foremost the capital cost is much higher than what it should be. The solar panels have been sourced from PV Powertech which is not a Tier 1 company yet it has priced them at Rs 34.50 per Wp when Tier 1 panels in 2016 cost only Rs 27 per Wp. Most probably PV Powertech has given lower than Tier 1 quality panels which cost even less. Moreover, Claro the supplier has charged Rs 17,000 over and above this for transportation when for such a big order transportation to site is generally given free. Similarly a charge controller and Balance of Solar system have been together priced around Rs 70,000 when a single Variable Frequency Drivewould have sufficed at a cost of Rs 25,000. The 5 Hp submersible pump from Shakti should not have cost more than Rs 35,000 instead of the Rs 52,000 or so that has been charged. The structure cost also, given the kind of flimsysteel sections that have been used, should not have been more than Rs 30,000. Since the company is marking a profit of 15 % on the cost of goods and services, the installation cost should also have been much less than the Rs 32,000 that has been charged. Thus, inclusive of profit and taxes the total cost of the 5KWp solar pump system should not have been more than Rs 3,10,000 instead of the Rs 5,11,305 that has been charged. The pipeline should not have cost more than Rs 90,000 instead of the Rs 1,20,000 that has been charged.There have been many other instances of such overcharging by solar equipment suppliers and in some cases Governments have cancelled the tendering process due to this (ET, 2016).
2. For large scale implementation, proper market study should be done and the solar panels and other accessories sourced from Tier 1 companies at competitive prices given the fact that bulk purchases are being made. The S-ISPs can themselves be trained to acquire and assemble the systems once quality parts are sourced. This will create a pool of talent to both do the implementation locally and take care of future service requirements.
3. For large scale implementation, android based mobile data collection applications should be designed and linked to a cloud based Management Information System for authentic data collection and real time insights into the operation of the system. All plots should be geo-tagged and their areas properly noted and all farmers given identity numbers. There is considerable leasing in and out of land and so for proper tracking of water use, agricultural production, economic efficiency and equity outcomes, recourse must be had of technology.
4. The water users had two main complaints to make regarding the operation of the system -
    i. The last mile connectivity from the pipeline to the farms through collapsible pipes causes a considerable loss of water, time and energy.
    ii. Vegetable cultivation often requires water in the evenings and this is not possible as the solar pump system cannot operate in the evenings.

   Given that the IRR of the pilot is very high and there is a leeway for making higher investments and that proper market survey will bring down the capital cost of the solar pump system considerably, in future the underground pipeline system should be made more extensive so as to cover most farmers in the command area and provisions should be made for distributed storage in staged tanks to cater to a small cluster of farm plots which can be filled up during the day by the farmers to be used in the evenings. The AKRSP has installed such anoverhead water storage system in village Chandauli next to Chak Haji in a group solar pump system implemented by it.
5. None of the ISPs are calculating the income that they are earning from their systems. Consequently they are not aware of their financial position. Yatin Kumar was extremely disappointed to learn that he was doing financially the worst among all the ISPs. He is quite

well trained and has a good grasp of the technical and financial aspects of project implementation being a small scale plumbing contractor himself. Yet he is not tracking the financials of his solar pump system. The others too came to know how much they had earned only after the analysis of their water sale data was done. Therefore, there is a need to give training to the S-ISPs to use the android based application that must mandatorily be developed for future scaling so that both the S-ISPs and the supervisors have a clear idea as to what is going on and take corrective measures in case of lapses.

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