Falling cost of photo voltaic (PV) cells is making solar irrigation pumps a reality in India. It is only a matter of time before governments begin aggressive promotion of solar irrigation pumps. Several players are already in the market offering a range of solar pumping solutions. This note is inspired by a field visit to some of the solar pumps installed by Claro Energy in Bihar. Its cost structure - which is high on fixed costs and low on variable costs - makes solar pumps ideal for small farmers wanting to double up as Irrigation Service Providers (ISP) to their neighbours. Solar pumps are widely seen as an 'energy' solution; however, in the Indian context, they need to be viewed as a composite energy-and-water intervention that will affect both energy as well as groundwater economies. Aggressive promotion of solar pumps in groundwater abundant Eastern India has the potential to catalyze an ever-green revolution there. The same strategy in Western and Southern India, however, can increase the stress on depleted groundwater resources because solar pump owners face near-zero marginal cost of groundwater. In water-abundant Eastern India, subsidizing capital cost of solar pumps can be part of a sound promotional strategy. Elsewhere, it may be appropriate instead to connect farmers as micro-level Independent Power Producers (IPPs) to the grid and offer attractive price for buying surplus power from them.

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HIGHLIGHT

Solar-Powered Pump Irrigation and India's Groundwater Economy

A Preliminary Discussion of Opportunities and Threats

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Solar-powered Pump Irrigation and India's Groundwater Economy
A Preliminary Discussion of Opportunities and Threats[1]

Research highlight based on the report a field visit in Bihar during October 2012[2]

Solar pumps in Nalanda, Bihar

Solar pumps have been talked about in India for some time. According to one 2005 estimate (Purohit and Michealova 2005), some 7000 were already in operation in the field. However, solar-powered tube wells in actual use by farmers are not easy to find. With the cost of photo voltaic (PV) cells following the More's Law and falling steadily and the price of diesel soaring, solar-powered pumping has emerged as an economically feasible idea. Claro Energy has installed 34 solar pumps of a standard size in Nalanda district of Bihar. An assessment of this program is available as an ITP Highlight (Tiwary 2012). The present Highlight, inspired by a field visit to some of the Claro Energy solar pumps, explores their economics and their implications for groundwater governance.

The design specifics of Claro solar pumps are described in detail in Tiwary (2012). In summary, each had six arrays, each in turn with six panels (each capable of 235 Wp[3]) raised to a height of 5.5 ft. The distance between two arrays is about 22 ft to make sure that when panels are tilted to maximize exposure to sun, they do not shadow each other. Each array can produce 1.4 kWp; and the six array solar-shed can thus produce peak power of 8.4 kWp and operate a 7.5 HP submersible pump. Laying 6 arrays requires 1200 square feet or about 112 m^2 of open space with unrestricted exposure to sun. A Variable Frequency Drive that can use anywhere between 250 to 440 volt power supply, operates the pump at different levels of solar radiation to produce different yields of water output. The days we were in the field were cloudy and rainy as Figure 1 shows. Even so, solar pumps we visited in farmers' fields in Nalanda as well as at the ICAR complex at Patna (Figure 2) managed to generate 270 voltage and pumped water. Each of the community tube wells was around 300 ft deep and had an outlet pipe of 8" diameter. Three buried distribution pipes, each of 300 ft length were provided to convey water to fields all around the tube well. Our general sense was that in Nalanda conditions: [a] the pump can start operating at around 8.30-9 am, achieve peak voltage by mid-day; voltage tapers off by 3.30-4 pm after which the pump would not work bar

Figure 1 Solar array on a cloudy day

Figure 2 A solar pump on the ICAR campus in Patna

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[1]This IWMI-Tata Highlight is based on research carried out under the IWMI-Tata Program (ITP). It is not externally peer-reviewed and the views expressed are of the authors alone and not of ITP or its funding partners - IWMI, Colombo and Sir Ratan Tata Trust (SRTT), Mumbai.

[2]This paper is available on request from p.reghu@cgiar.org

[3]Wp (Watt-peak) is a measure of the nominal power of a PV solar energy device under laboratory conditions.

during peak summer; [b] depending upon the time of the day, 7.5 HP solar pump would deliver 60-80 m^3/hour and take 12-25 minutes to irrigate 1 *katha*, or 16 to 33 hours/ha; [c] it would not work full time on cloudy days during June-October; but during this period, there is little need for irrigation; [d] during the peak wheat irrigation season of winter, the solar pump would not work or work at a low operating factor during a patch of 20-25 foggy days when some alternative to solar power would be needed; [e] it would work at full operating factor for longer hours during summer months during which at present there is little cultivation except for small vegetable gardens; [f] all farmers we met - pump operators, water buyers and others - were happy with the water output of the solar pump but had only fuzzy ideas about the ultimate impact of this new technology.

Socio-technical fit

Claro Energy's solar pumps are embedded into a pre-existing institutional setting that may shroud the full impact of the technology. Claro solar pumps are fitted on community tube wells - on the lines of old Vaishali and Deoria community tube wells studied by Pant (1984) and Ballabh (1987) - established with NABARD support in 2004-05. Each tube well was established on 100-110 m^2 of donated private land whose owner was made the tube well operator. The operator was to serve a group of eight neighboring farmers formed in to a Water Users' Association (WUA), and charge them a government-fixed irrigation service fee (ISF). Many of these tube wells fell into disuse because they were equipped with 15 HP engines that turned out to be highly inefficient. They used around 3 liters of diesel per hour of operation; as a result,

Figure 3 A community tube well in Nalanda with a Claro solar pump

farmers could not afford the water these pumped at an Irrigation Service Fee (ISF) of Rs. 3200-3600/ha/irrigation. Only a few of the community tube wells, which were close to electric cables and could access power - legally or otherwise - remained operational. Claro Energy was invited to install solar pumps to replace the inefficient diesel pumps (Figure 3). The sample of such rehabilitated community tube wells we visited was ready for full-scale operation. The Claro pilot suggests that equipping defunct community tube wells with solar arrays may be an effective approach to rehabilitating them.

However, the working and impact of Claro solar pumps in Bihar are affected both by the old tube wells as well as their institutional model. All operators we spoke to asserted they can irrigate twice the area if the community tube wells were provided longer and better piped distribution system. Some suspected that the old pumps were inefficient, too. Yet, under the prevailing institutional arrangement, operators may not have the incentive to invest their own money in replacing the pump or extending the distribution system. The motivations of the operators are influenced by their relationship with Claro, government as well as water buyers. In our assessment, these 34 solar pumps would perform even better if they were owned and run by farmers acting as independent Irrigation Service Providers (ISPs) because solar pumps can easily beat all competitors in local irrigation service markets. The only tube wells that can compete with solar-powered community tube wells may be those that have access to illegal power connections.

Demand for irrigation service is highly price sensitive. Since fields further away from the pump take longer to irrigate a hectare, ISPs prefer irrigating closer fields rather than distant ones or else charge per hour than per hectare. Since solar pumps have become operational, there is animated activity in land-leasing markets near the pump as well as near the pipe outlets. In Nakatpura village (in Biharsharif tehsil, Nalanda), plots around the solar pump have been leased in at annual rental of Rs. 32000-40000/ha. Arguably, farmers who are happy to pay that kind of a rental must be grossing a revenue 2.5-3 times the rental.

The economics of solar pumps already look attractive given the high cost of electricity and diesel they will replace; and the economics will get better as PV costs fall further. At annual operation of 2000 hours, Claro Energy's 8.5 kW solar pumps costing Rs. 1 million will save some 17000 kWh of electricity each per year valued at

Rs. 85000/year[4]. If solar pumps add new irrigated area, the benefit is larger. If a Claro tube well provides 5 irrigations to 15 ha/year (during *rabi*, summer and paddy-sapling raising season), it provides additional irrigation service valued at Rs. 60000/year (@ Rs. 10/*katha*[5]) - which in turn will enable cultivators of those 15 ha to generate net income that is 4-5 times their payments for irrigation service.

A pertinent aspect of the economics of solar pumps is their 'aerial footprint', i.e., the land taken up by the solar arrays. Solar panels as well as plants compete for sunlight in a field. Therefore, the area taken up by solar panels has few alternative agricultural uses. This is an important 'opportunity cost' in a land-short small-holder agricultural economy. The aerial footprint of a solar pump is directly related with desired water output and pumping head, and inversely with the intensity and hours of solar radiation. In Nalanda, a 10 kW solar pump will have an aerial footprint of 1/60th of a hectare but can irrigate 8-10 ha. In Mehsana district of Gujarat, the same 10 kW pump will have a larger aerial footprint but irrigate less than 2 ha thanks to large pumping head.

Demand for solar pumps

The solar pump has a unique cost structure with very high capital investment and near-zero marginal cost of pumping. This makes it very similar to electric pump owners who face high flat tariff but unlimited use of power (when available) at zero marginal cost. This cost structure will drive away small farmers who want to irrigate only their own little field; but it is ideal for potential ISPs. A solar-pump driven groundwater economy will also promote competitive groundwater markets with highly beneficial outcomes for water buyers who will gain even more with buried pipeline distribution networks such as those obtaining in central Gujarat (Shah 1993). Buried pipe distribution systems can greatly leverage the profitability of investments in solar pump as well as the beneficial impacts of solar pump ISPs. For all these reasons, solar pumps may be ideal for groundwater abundant areas such as North Bihar, coastal Orissa, North Bengal, Assam, and Eastern Uttar Pradesh.

However, the demand for unsubsidized solar pumps will remain muted where agricultural electricity supply is free and power supply conditions are good. Poor control on farm power theft may also dampen farmer interest in solar pumps without subsidies especially as farm power supply hours improve. On positive side, since much groundwater irrigation in Bihar depends on diesel pumps, solar pumps will have a strong appeal especially where power theft is hard. West Bengal too will be an ideal market for solar pumps. Much irrigation here is by diesel pumps. Farm power supply of reasonably good quality is available 24*7 but at near commercial metered tariff. Over 90 percent of West Bengal's demand for pumping groundwater is for irrigating *boro* rice in summer months when solar pumps will operate at high operating factor. Moreover, farmers compelled to use cheaper night power for irrigation will prefer solar pumps because they let them irrigate during the day. A marketing strategy for solar pumps supported by a well-designed loan product and a reasonably priced maintenance contract should rapidly grow the solar pump market in West Bengal, Bihar, Assam and Bangladesh.

Solar pumps' future impact on irrigated farming

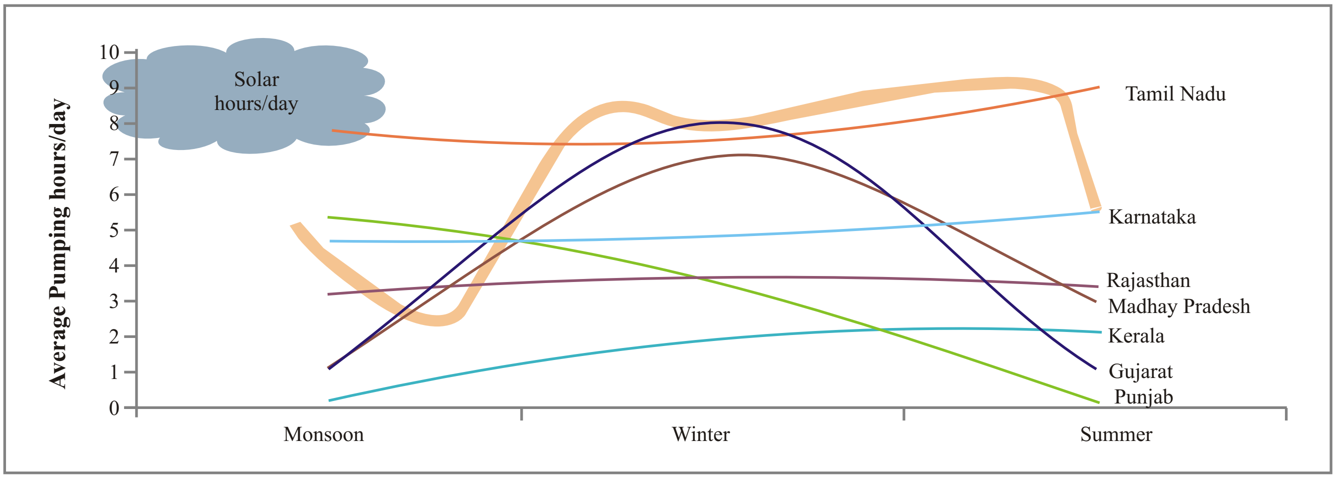
Near term demand for solar pumps will be dictated by existing cropping patterns. In Bihar, Uttar Pradesh, and Madhya Pradesh, where over 85-90 percent of the energy demand for pumping groundwater is concentrated in winter season for wheat irrigation, demand for solar pumps will be high for wheat. In West Bengal and Bangladesh, it will be high for summer paddy irrigation. In Punjab and Haryana, where demand for energy for pumping peaks during *kharif* season, farmers will be lukewarm towards solar pumps because their operating factor will be the lowest during the months when pumping demand is the highest. Figure 4 shows the differential seasonal trends in farmers' demand for daily hours of power supply for pumping groundwater (Shah et al. 2012) based on current cropping patterns. These will influence demand for solar pumps in the short run.

In the medium to long run, however, solar pumping itself may have far reaching impacts on cropping regimes. Throughout Western India, *rabi* season has gradually replaced *kharif* as the main farming season. Indeed, agricultural growth in Indian states has been strongly associated with expansion of *rabi* and summer cultivation, which in turn has been made attractive by free or flat power tariff. West Bengal's agrarian revival has ridden on the plank of pre-summer *boro* rice which is heavily pump-irrigated. Rapid stride in wheat production in the Indo-Gangetic basin, Madhya Pradesh and Gujarat, is founded on winter irrigation. The Bt cotton revolution in Gujarat, Maharashtra, Andhra Pradesh too is fed by subsidized electric pump irrigation. Solar pumps with their high fixed cost (in the form of depreciation, interest, maintenance

[4] At a financial cost-to-serve power of Rs. 5/kWh and annual operation assumed to be 2000 hairs; the economic cost will be more if we factor in the carbon footprint of thermal power.

[5] 32 katha make an acre and 80 katha make a ha.

Figure 4 Seasonality in demand for pumping energy in a selection of Indian states



and repair; cost of protection from theft and vandalism) but very low marginal (or variable) cost of pumping will accelerate this process. As solar pumps proliferate, cropping regimes will change to make the best use of solar energy for pump irrigation. Winter cropping will certainly expand; but even summer cropping will grow, further reducing the centuries-old predominance of *kharif* cropping.

The financing of solar pumps will also leverage these impacts. In Nalanda, from the log books kept by operators, we found many pumps were shut off during summer and monsoon because operators got them free and their irrigation service business enjoyed low operating leverage[6]. But if they had borrowed Rs. 10 lakh[7] for installing the solar arrays, they would be under pressure to run the pump whenever sun light was available to generate revenue to pay their instalments and interest. Much the same kind of pressure felt by electric tube well owners in West Bengal subject to high flat electricity charges intensified competition among them and created a buyers' irrigation service market in which tube well owners provided high quality irrigation service at very competitive prices (Mukherji 2007a; Mukherji 2007b).

Solar pumps and groundwater governance

For water-abundant, especially flood-prone areas of Eastern India, solar pumps can be a God-send. They can generate massive livelihoods, improve the finances of bankrupt power utilities, create an ever-green revolution and even ease the flood intensity in Eastern UP, North Bihar, North Bengal and Bangladesh by creating room in aquifers to absorb monsoon flood waters.

A solar-pump based groundwater economy in India would be harder to govern than diesel or electricity driven groundwater economy. Soaring diesel prices are a natural regulator that ensures efficient use of energy as well as groundwater. In the case of power, even when it is free or highly subsidized, the use of groundwater as well as energy is getting regulated by rationing of power supply as well as by gradual de-electrification. In the case of solar pumps, once installed, there is no way of external control of its operating hours. If a solar pump can operate for a maximum of 2500 hours/year, the central tendency of a solar pump will be to approach the maximum because it is subject to free energy as well as groundwater. Throughout India's western corridor, replacing electric and diesel pumps by solar pumps can result in accelerated withdrawal (and depletion) of groundwater.

Therefore, the promotional strategy for solar pumps needs to explicitly factor in the fact that solar pumps are not just an energy solution but a composite *energy-and-water* solution; and that while solving the energy problem, solar pumps can aggravate the water problem. The only lever India has for demand-side management of groundwater resource so far is electricity pricing and supply policies. The coming of solar - which can put abundant energy in

[6]In the world of corporate finance, operating leverage is the relationship between fixed and variable costs of a business and is defined as Operating leverage = fixed cost/contribution unit, where contribution is the difference between the price of the product/service and variable cost. When fixed costs are high relative to contribution/unit, the business is under pressure to expand sales, even if it involves reducing the price. This business has high operating leverage and exemplifies electrified tube well owner subject to high flat power tariff per month or a solar-powered tube well operator. A tube well operating using a cheap Chinese-make diesel engine or an electric tube well operator subject to metered tariff, in contrast, enjoys low operating leverage, and is under less pressure to expand sales.

[7]One lakh = 0.1 million

the hands of the farmer at zero incremental cost - will blunt the power of electricity pricing and supply policy as a tool for groundwater demand management. And because the problems of power sector are more immediate and pressing for policy makers compared to those of groundwater depletion, chances are that governments will enthusiastically promote and subsidize solar pumps. Rajasthan government has already offered 86 percent subsidy on the capital cost of solar pumps (Kishore 2012). Tamil Nadu has decided to install 20000 solar pumps in 3 years. Bihar, as we saw in Nalanda, is giving solar pumps free to farmers. The practice will soon spread to other states. There are many important issues in the design of subsidies to minimize self-defeating and perverse impact - as, for example, has been the case with micro-irrigation subsidies which have done more to enrich micro-irrigation companies than to promote micro-irrigation. However, in the case of solar pump promotion, a more pertinent issue is of putting in place an effective groundwater demand side management regime before replacing a significant proportion of diesel-electric pumps by solar pumps.

Alternate subsidy designs

Two approaches are in vogue to incentivize investment in solar power in India today. First, used by governments in Bihar and Rajasthan, is a capital cost subsidy similar to subsidy programs to promote drip irrigation among farmers. If past experience is any guide, such subsidies may lead to gold plating of solar pump costs, limit the emergence of open market for solar pumps without subsidy, paper-sales, and poor after sales technical support. Such problems can be minimized through smarter subsidy design and administration. However, capital cost subsidy will stimulate competitive water market, accelerate groundwater irrigation and expand irrigation opportunities for the poor.

The second approach is of guaranteed buy-back of solar power at an attractive price for grid-connected solar power producers. This is the route used by the National Solar Mission to incentivize large-scale solar power generation (Kandhari 2011). We saw earlier that a major risk factor for farmers in investing in solar pumps is of solar power generated when there is no demand. A farmer would be more willing to invest borrowed funds in a solar pump if he was offered a guarantee of buy back of surplus power at a remunerative price. Gujarat government has offered a guaranteed buy-back of solar power at Rs. 15/kWh for the first 13 years (GEDA n.d.). National Solar Mission invited bids from private power producers who whittled the price down to around Rs. 7.60/kWh (Kandhari 2011). For a solar pump owner with capacity to produce 20000 kWh/year of solar power, a guarantee to purchase surplus solar power at say Rs. 10/kWh would

Table 1 Capital subsidy *versus* guaranteed power buy back

		Well-implemented capital cost subsidy	Attractive power purchase guarantee
1	Stimulus to demand for solar pumps	Strong	Strong
2	Solar pump owner operates as	ISP	Grid-connected Independent Power Producer
3	Burden of maintenance and upkeep	Equipment supplier for some initial years	Owner
4	Pump irrigation market	Highly competitive	Highly limited and monopolistic
5	Solar pump owner's incentive to invest in piped water distribution to sell irrigation service	Very high	Low
6	Water price in village water market	Very low	High, determined by guarantee price for power purchase
7	Aggregate groundwater use in the village	High	Moderate, limited to own irrigation
8	Appropriate for	Groundwater abundant areas, such as Eastern India	Western and Southern India

assure a minimum revenue of Rs. 2 lakhs/year and encourage farmers to invest in solar pumps as a business proposition.

The two alternative schemes can have dramatically different impacts on farmer incentives as well as the shape of local groundwater economies, as suggested in Table 1.

Conclusion

With rapidly falling prices of PV cells, solar pumps are likely to open a new chapter in India's irrigation economy in the years to come. With appropriate promotional strategy and incentives, solar pumps can attack India's invidious nexus between energy and groundwater irrigation and change it for the better. The cost structure of solar technology - with high fixed costs and low variable costs - imparts high operating leverage to its economics. Rising diesel prices and dwindling hours and quality of farm power supply are likely to stimulate demand for solar pumps. Aerial footprint may also influence the demand for solar pumps. In areas of high pumping depth of groundwater, capital cost and land taken up by solar panels will make solar pumps less attractive than in large swathes of Eastern India where solar pump offers an ideal technology. Subsidizing capital investment in solar pumps and buried distribution systems, which will create competitive groundwater markets benefitting the poor, may be suitable for Eastern India. In Western and Southern India, a better option may be to connect solar pumps with grid, treat farmers as independent power producers and offer them guarantee to buy surplus power at an attractive price.

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About the IWMI-Tata Program and Water Policy Highlights

The IWMI-Tata Water Policy Program (ITP) was launched in 2000 as a co-equal partnership between the International Water Management Institute (IWMI), Colombo and Sir Ratan Tata Trust (SRTT), Mumbai. The program presents new perspectives and practical solutions derived from the wealth of research done in India on water resource management. Its objective is to help policy makers at the central, state and local levels address their water challenges – in areas such as sustainable groundwater management, water scarcity, and rural poverty – by translating research findings into practical policy recommendations. Through this program, IWMI collaborates with a range of partners across India to identify, analyze and document relevant water-management approaches and current practices. These practices are assessed and synthesized for maximum policy impact in the series on Water Policy Highlights and IWMI-Tata Comments.

Water Policy Highlights are pre-publication discussion papers developed primarily as the basis for discussion during ITP's Annual Partners' Meet. The research underlying these Highlights was funded with support from IWMI, Colombo and SRTT, Mumbai. However, the Highlights are not externally peer-reviewed and the views expressed are of the author/s alone and not of ITP or either of its funding partners.

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