
SOLAR IRRIGATION PUMPS: CAN ELECTRICITY BUY-BACK CURB GROUNDWATER OVER-USE?

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ABSTRACT

Groundwater pumping for irrigation has exploded across India since the 1970's largely due to a proliferation of cheap pump sets and highly subsidized energy. In much of Western and peninsular India, aquifers have been overexploited with substantial decreases in water tables leading to even higher amounts of energy used for pumping. As solar irrigation pumps become more effective and affordable, the prospect of uncontrolled solar pumping further exacerbating the unsustainable use of groundwater has led to calls by some for the government to buy back excess electricity generated on farms. Under such a scheme, the buy-back price would have to be high enough to make selling the power more profitable than using it for further irrigation, yet not as high as the price that is charged for electricity from the grid lest an opportunity for arbitrage be created. The correct value for the buy-back price will thus depend on the marginal profitability of water use on the farm with the possibility that the value of water to the farmer may be too high to make the scheme feasible. In this paper, estimates of water and electricity demand are derived for Punjab state and used to inform what an effective buy-back scheme might entail. Results indicate that a buy-back price differentiated by season and location might be an affordable way to promote groundwater conservation.

Keywords: groundwater ; India; solar; irrigation; pump; electricity; buy-back; price; Punjab

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1. Introduction

In all but a few areas of India (notably West Bengal), farmers are charged a flat tariff for electricity, which is often very low and in some key irrigation states is actually zero (Shah, 2012). As a result, groundwater use in India has exploded along with the advent of cheap irrigation pump sets. Currently, the government of India estimates that the total volume of groundwater used for irrigation per year is 221 BCM and that 29% of groundwater blocks are classified as semi-critical or worse with 14% of the total being over-exploited (CGWB, 2014). Whereas many Indian farmers face zero marginal cost of electricity, many others, notably in the Eastern Ganges, have no access to electricity and therefore are forced to either practice rain-fed agriculture or to use very costly diesel pump sets for irrigation. This is one reason that the use of subsidized solar irrigation pumpsets (SIP's) are being touted as a way to lift farmers out of poverty with ongoing trials in several areas (Shah, 2014), (Kishore, 2014).

While the use of SIP's may in time become an effective way to help poor farmers and simultaneously reduce GHG emissions, it begs the question of what will be the net effect on groundwater use. Some such as Shah (2014) have recognized this issue and have called for the establishment of solar buy-back schemes wherein farmers would have their SIP's connected to the grid and therefore be incentivized to sell electricity to the utility instead of engage in excessive irrigation. Although certain factors unique to India may explain why it is experimenting with the use of SIP's, it could be just a matter of time before solar technology advances to such a degree that farmers in many water-scarce regions will find SIP's to be cost-effective without subsidy. At that point, irrigated agriculture world-wide will face the same dilemma: how do you manage groundwater use when irrigators face zero marginal pumping costs? The idea of selling electricity back to the grid is a logical one but currently there is very little theoretical or empirical research that would give guidance on how to determine an optimal buy-back price for such a scheme. This paper takes one step toward understanding this problem by estimating the demand for irrigation water and electricity used for pumping and then relating the price required for buy-back to the estimated values. It is observed that there is a marked difference in the value of irrigation water depending on the season and that the degree of spatial variation is also quite high. The implications of this analysis are that an effective electricity buy-back policy would have to be as targeted over space and time as possible in order to ensure both feasibility and affordability to the electric utility.

2. Methods

Aquifers in Punjab state are severely over-exploited with groundwater draft estimated to be approximately 172% of the sustainable amount (CGWB Dynamic GW Report, 2009). The state also produces a high percentage of India's staple rice and wheat crops and has good potential for solar power. For those reasons, district-level data from Punjab state is used to formulate an optimization model in which it is assumed that farmers are profit-maximizers and that they can choose both the crop grown and irrigation intensity in two seasons (kharif and rabi). Crop water-yield relationships are modelled following Doorenbos and Kassam (1979). The data used is for the year 2009-10 and is calibrated to reproduce the mix of crops grown in the state when water is available in the quantity estimated for the same year. Information on prices and costs for major crops in both seasons is used and the model is constrained in both irrigable land area and water supply. In order to estimate the marginal value of water, the model is solved repeatedly at different levels of water availability, starting with as much water as can be profitably used and lowering by 1% increments until only 1% of the maximum water supply is available. Thus, a water demand curve is estimated separately for both kharif and rabi seasons.

3. Demand Curves

Using the methods described above, water demand is estimated for 16 districts in Punjab state, representing 87% of irrigated land in Punjab in the year studied. An aggregate demand curve is then created by weighting the marginal values calculated for each district by the percentage of irrigated area it represents relative to the total study area. **Figure 1** below shows the resulting demand curves by season.

Looking at the demand curves, there is a striking difference between seasons with the quantity of water demanded during the rabi season being less overall but quite inelastic and that of kharif season being greater overall but very elastic. That is, the value of water is more sensitive during the rabi season, indicating that a change in water supply will have a much greater impact on profits than during the kharif season. Overall, the two demand curves illustrate the interaction of PET requirements, rainfall, and crop choice. Whereas the kharif season receives a lot of rainfall there is still a large demand for irrigation water owing to the high PET rates and the amount of water required by the dominant crop, which is rice. In contrast, the rabi crops require much less water and PET rates are lower but the water that is used is relatively more valuable because there is little rainfall during the season.

The analogous demand curves for electricity for irrigation pumping are given in **Figure 2**. This plot shows how the value of electricity for pumping is a function of the quantity pumped and the depth of the groundwater table. In order to generate

these demand curves, the estimated value of water from above is adjusted for the amount of electricity required for the total lift based on the initial aquifer depth and draw-down. That is, the value of electricity is given as a function of the volume of water it can lift for irrigation. Figure 2 assumes that all irrigation water comes from groundwater, which is obviously not realistic. If the demand curves were adjusted to exclude the estimated surface water use, then the relevant portion of the demand curves would start at approximately Rs 0.7 and Rs 4.5 per kWh (US \$ 0.02 and US \$0.10 per kWh) for the kharif and rabi seasons respectively and proceed down and to the right until the x-axis, where the marginal value of electricity is zero.

The above implies that solar power buy-back would either require a seasonal price or rely heavily on water savings from the kharif season to limit over-pumping. Note that a buy-back price of Rs 2 per kWh (which some have speculated may be sufficient) held constant over both seasons may result in large reductions in pumping but would be economically inefficient, as farmers would theoretically value a given amount of energy much less during the kharif season. However, state-wide analysis is likely to smooth out large variations within the state; it is very unlikely that a uniform buy-back price would induce farmers in different districts to sell back the majority of their power in a given season. The individual district demand curves indeed vary significantly based on local growing conditions, crop mix, reliance on groundwater, and depth of the groundwater table.

To give some indication of the spatial variation, **Table 1** shows the estimated value of groundwater and electricity for pumping under the assumption that groundwater pumping at the district level is restricted to the annual replenishable amount as calculated by the CGWB (Dynamic GW Report, 2009). The value of electricity estimated for each district can be thought of as a conservation price in that theoretically the buy-back price would induce reductions in groundwater pumping sufficient to meet the sustainable levels as estimated by the CGWB. Note that the conservation prices vary from zero to Rs 0.80 per kWh in the kharif season and from zero to Rs 4.49 in the rabi season.

4. Conclusions

Wide-spread SIP adoption would mean that marginal pumping costs effectively fall to zero and, in areas suited for solar power such as much of Western India, could therefore lead to a threat of further groundwater exploitation. One way to address this problem is through electricity buy-back from farmers but the economics of this approach have as yet been little studied. The analysis presented here on Punjab state uses demand estimates for groundwater and electricity for pumping to illustrate some key points about using such a pricing instrument. Firstly, seasonal variations in demand for groundwater pumping imply that a seasonal, or perhaps monthly, buy-back pricing policy could be both effective and affordable. Using a constant buy-back price across seasons may unnecessarily increase the total expenditure by the electric utility for a given quantity of power and may cause issues if a smooth amount of electricity buy-back over the course of the year is desirable. Secondly, spatial variation in the value of groundwater suggests that the buy-back price should be differentiated at the district or, ideally, the block level. A state-wide buy-back price would almost certainly lead to higher levels of conservation than required in some areas while failing to meet those targets in other areas. Moreover, just as in the case of seasonal variation, a spatially differentiated price would be more economically efficient.

While a spatially-differentiated buy-back price could possibly be politically contentious if farmers feel that certain areas are receiving preferential treatment, a seasonal buy-back policy would not seem to suffer in this way. By offering kharif season buy-back price of around Rs 2 per kWh, a rate which has been discussed and would likely be affordable to the electric utilities, significant savings in groundwater pumping could occur. However, large decreases in groundwater pumping are unlikely under the current grain procurement policy, which encourages rice production. If the state of solar technology advances to the point that SIP's are affordable without subsidy then a combination of procurement policy reform and electricity buy-back would almost certainly be required to avoid further stress on the already over-exploited aquifers in Punjab state.

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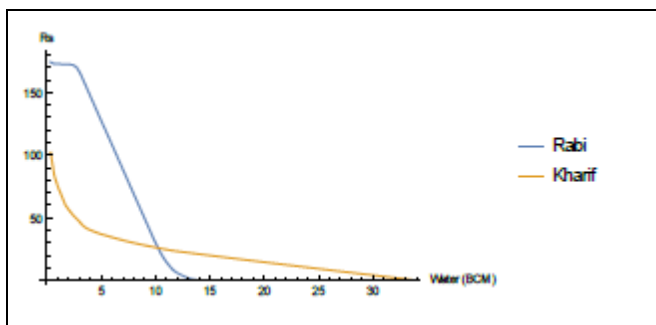


Figure 1: Water demand curve for Punjab state - 2009-10

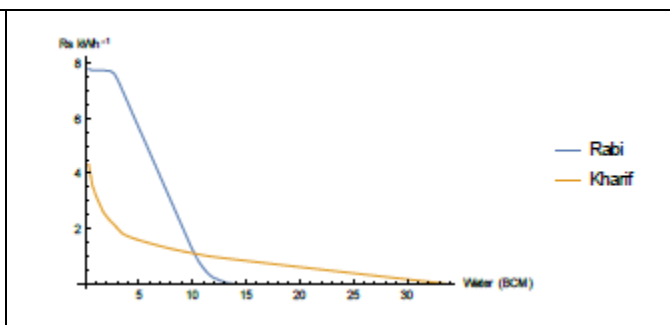


Figure 2: Energy demand curve for Punjab state - 2009-10

District	Water (Rs)	Electric (Rs kWh ⁻¹)	Water (Rs)	Electric (Rs kWh ⁻¹)
Amritsar	5.75	0.22	80.37	3.09
Bathinda	1.22	0.05	14.99	0.63
Faridkot	2.00	0.11	14.37	0.75
Fatehgarh Sahib	19.52	0.70	102.00	3.46
Firozpur	4.38	0.27	45.25	2.79
Gurdaspur	5.55	0.31	55.44	2.89
Hoshiarpur	0.91	0.04	18.52	0.82
Jalandhar	23.96	0.80	142.01	4.49
Ludhiana	18.05	0.70	87.73	3.36
Mansa	4.66	0.20	46.48	2.06
Moga	17.22	0.62	95.26	3.16
Muktsar	0.00	0.00	0.00	0.00
Nawan Shehar	5.39	0.18	30.14	0.87
Patiala	20.04	0.75	109.45	4.05
Rupnagar	5.04	0.29	0.00	0.00
Sangrur	23.23	0.66	113.28	3.32

Table 1: Marginal value of water, electricity by district for Punjab in 2009-10 assuming groundwater pumping is restricted to CGWB target levels.