SUBJECT I
DEVELOPMENT OF DRYLAND AGRICULTURE: TECHNOLOGICAL,
INSTITUTIONAL, INFRASTRUCTURAL AND POLICY IMPERATIVES

Raising Agricultural Productivity, Reducing Groundwater Use and Mitigating Carbon Emissions: Role of Energy Pricing in Farm Sector

M. Dinesh Kumar*

ABSTRACT

The growing dependence of India's farm sector on groundwater threatens water resources sustainability and power sector viability. Sustaining India's rising prosperity rests on managing groundwater. This study shows that raising power tariffs in the farm sector to achieve efficiency and sustainability of groundwater use is both socially and economically viable. The farmers, who are confronted with positive marginal cost of electricity and groundwater, obtain higher water productivity in their farming operations (Rs./m^3 of water), use less amount of groundwater per unit area of farm (m^3/ha), yet secure higher net return per unit of land (Rs./ha of land).This paper shows that establishing an energy quota for farms based on groundwater sustainability considerations, and metering and charging for power on pro rata basis using pre-paid meters are the best options to manage groundwater and the energy economy. The social benefit of reduced carbon emission, achievable through efficient electricity pricing, was estimated to be Rs. 709 crore per annum.

Keywords: Agricultural productivity, water productivity, energy use efficiency, energy quota, carbon emissions, sustainable groundwater use.

JEL : O13, Q15, Q16, Q56

I

INTRODUCTION

The semi-arid tropical regions of India are primarily dependent on groundwater for irrigated agriculture. In such regions, energy and water security are inextricably linked. Agriculture accounted for almost 21 per cent of the total power consumption in India. But, for states such as Haryana, Gujarat and Punjab, it was as high as 40.6 per cent, 29.6 per cent and 27.4 per cent, respectively (www.cwc.nic.in/Water_Data_Pocket_2006/TB.2find.pdf). As irrigation becomes increasingly energy intensive, energy security is critical for ensuring agricultural water security whereas our ability to provide reliable and adequate energy supplies for the other sectors of the economy is heavily dependent on how efficiently water for crop production is managed. Unmanaged water demand for irrigated agriculture can pose serious

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*Executive Director, Institute for Resource Analysis and Policy, Hyderabad - 500 082.

challenge to energy security in India, which is the world's fourth largest energy consumer (www.eia.gov/EMEU/cab/India/pdf.pdf).

India's farm sector provides livelihood for hundreds of millions of rural people, ensures food security for well over a billion, and faces serious management challenges for land, water and energy resources. Sustaining agricultural growth rests on getting the groundwater equation right. Enduring social and economic equity nationally and minimising inter-regional disparities will require continued growth of agriculture. At the same time, the farm sector must internalise its share of the effects of groundwater depletion and bankrupt power utilities. Agricultural power must increasingly be managed as a scarce input (World Bank, 2001).

In the arid and semi-arid regions of India, uncontrolled withdrawal of groundwater for crop production, which is supported by subsidised electricity in the farm sector, leads to rapid decline in water level in many parts of the country (Kumar, 2007; World Bank, 2010). As irrigation is the main user of groundwater in the country, raising water productivity in groundwater irrigated areas to reduce total water use is essential for arresting groundwater depletion (Amarasinghe *et al*., 2005; Kumar, 2007).

Electricity to the farm sector in India is subsidised under both flat rate and pro rata tariff systems (Scott and Sharma, 2009). The subsidy in terms of sale to agricultural consumers was estimated to have increased from Rs. 15586 crore in 1996-97 to Rs. 30462 crore in 2001-02 at constant prices (Government of India, 2002). In most states, farmers pay electricity charges based on connected load and not on the basis of units of power consumed. Some of the Indian states are providing electricity to the farm sector free of cost, though with ever-decreasing hours of supply and deteriorating quality of power. The modes of electricity pricing under which the charges paid by the farmers do not reflect actual consumption, creates incentive for inefficient and unsustainable use of both power and groundwater (Kumar, 2005).

There have been some developments in metered power supply. For instance, since 2001, the Government of Gujarat has only provided metered connections for agriculture. Nearly 12,000 farmers thus have metered power connections in North Gujarat alone. In West Bengal, the state power board has installed electronic meters in all farm wells and started charging for electricity on the basis of the actual number of units consumed. But, empirical studies on the impact of such policy interventions on efficiency, equity and sustainability in resource use were lacking. Many Indian states are contemplating re-introduction of electricity metering in the farm sector to manage groundwater demand. Such proposals face fierce resistance from farmers' lobby. Further, political parties and scholars alike argue that it will lead to a collapse of farming and the loss of rural livelihoods in many water-scarce regions due to reduced net farm returns, making electricity metering in the farm sector socially and economically unviable.

II

ENERGY AND CARBON FOOTPRINT OF IRRIGATED AGRICULTURE IN INDIA

India is one of the largest consumers of electricity in the agricultural sector. The largest user of electricity in agriculture sector is groundwater irrigation, the other being pumping of water from canals and rivers and ponds/tanks. Electricity consumption in agriculture has been steadily going up due to rapid increase in groundwater abstraction for irrigation and gradual decline in water table in areas where energised pump sets largely exist. However, the increase has been exponential since 1985-86 and this growth continued till 1998-99, when it peaked. Since then, it has shown some decline till 2001-02, and then gradually picked up to reach 107.77 billion units in 2008-09. But, in percentage terms, the agricultural electricity consumption has begun to decline sharply and consistently since 1998-99 from a highest of around 31.4 per cent of the total consumption in various electricity consuming sectors in the country. The reason for this is the exponential rise in power consumption in the manufacturing sector, which grew at a rate of 7.4 per cent per annum since 1992-93, coinciding with the year of economic liberalisation.

Though declining in percentage terms, agriculture continues to be a major source of India's energy footprint and its contribution in aggregate terms is on the rise, with the total electricity consumption in that sector going up. This poses a huge environmental challenge. We have estimated the total carbon emission for fossil fuel based electricity generation to be 28 million metric tonnes per annum.[1] While efficiency improvements in electric pump sets, which is quite low at present, can reduce this footprint, one reason why this does not happen is that farmers do not pay for consumption of electricity on the basis of consumption. But, if the farmers have to pay for electricity on pro rata basis, then they would have the incentive to use both electricity and water efficiently. What is important to note is that water use efficiency improvements in irrigation can reduce electricity consumption significantly. Whereas pump efficiency improvements through technical interventions will not guarantee water use efficiency improvements, and on the contrary farmers would be tempted to pump more water. Hence, from the point of view of reducing carbon emissions, efficient pricing of electricity in the farm sector is important.

III

RESEARCH OBJECTIVES, STUDY LOCATION, APPROACH AND METHODOLOGY

The broad objective of this research study is to analyse the socio-economic viability of pro rata pricing of electricity in agriculture and to assess the various technological options for implementing energy pricing policies. The specific objectives are: (1) to study the impact of the shift from flat rate power supply to metered supply on the efficiency and sustainability of groundwater use by well owners; (2) to analyse the overall impact of electricity pricing on the farming system

of well owners, including the economic returns from farming; and, (3) to discuss the various alternatives for implementing energy pricing policies and their likely outcomes vis-a-vis sustainability and efficiency of groundwater use, and equity in access to groundwater.

North Gujarat, which is a water scarce region, and the eastern plain regions of Uttar Pradesh (UP) and south Bihar, which are water rich regions, are the study locations. Water rich regions of UP and Bihar were selected for the study due to the reason that there were no other locations in India where comparison could be made between farmers who are confronted with marginal cost of using energy and groundwater for irrigation, and farmers who are not confronted with, other than Gujarat. The semi-arid north Gujarat region receives a mean annual rainfall of 735 mm. Grey brown, coastal alluvium types of soils are found in this region. The mean annual precipitation in the eastern plain region of UP is about 1025 mm and the region's climate varies from dry sub-humid to moist sub-humid. The soil type in this sub-zone is light alluvial and calcareous clay. South Bihar plains receive a mean annual rainfall of 1103mm and the climatic condition of the region varies from dry to moist sub-humid. The soil types found in the region are old alluvium sandy loam to clayey and the larger areas under traditional water storage and irrigation systems called *Tal* and *Diara*.

Primary and secondary data relating to crop and livestock production were obtained through surveys. The primary data included: quantum of crop inputs and outputs and their prices; cropping pattern; electricity prices; diesel consumption and price; well command area; number of water buyers and sellers; quantum of livestock inputs and outputs, and unit price of inputs and outputs. Banaskantha district in North Gujarat, Mirzapur and Varanasi districts in Eastern UP, and Patna district in South Bihar were selected for the study. The details of the sample design for each location are given in Table 1. At the time of undertaking this study, there were very few locations in India where farmers paid for electricity based on consumption. Gujarat was one such state. Therefore, to analyse the potential impacts of introducing pro rata pricing of electricity in the farm sector in the other states, farmers using diesel pumps for groundwater irrigation and water buyers were selected as a proxy for pro rata tariff.

TABLE 1. SAMPLING PROCEDURE AND SAMPLE SIZE

Name of the region	Name of the district	Type of energy tariff				Diesel pump		Total sample size
		Flat rate		Pro rata				
		Well owners	Water buyers	Well owners	Water buyers	Well owners	Water buyers	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
North Gujarat	Banaskantha	60	-	60	-	-	-	120
Eastern UP	Varanasi and Mirzapur	60	60	-	-	60	60	240
South Bihar	Patna	60	60	-	-	60	60	240
Total		180	120	60	-	120	120	600

The efficiency impact of change in the mode of pricing was analysed by comparing water productivity of crops in physical terms. The impact of change in the mode of pricing on economic viability of farming was analysed by comparing the overall water productivity of crops, livestock and farming system in economic terms under the two conditions. The net return from unit area of land farmed was also considered. The net return was based on the cost A_2. The net income was estimated by subtracting "Cost A_2" from gross income from the crop (crop produce in kg x price received by the farmers/kg). Cost A2 is Cost A1 + rent paid for leased in land. Here, Cost A_1= wages of hired, contract and permanent labour + hired bullock labour/imputed value of own bullock labour + charges of hired machinery/imputed value of owned machinery + market rate of organic manure and fertilisers + market rate of seed/imputed value of owned seed + imputed value of manure + market value of insecticide, herbicide + irrigation charges + Land revenue, cess and other taxes + depreciation of machinery, implements, equipments, irrigation structure + interest on working capital + miscellaneous expenses.

The sustainability impact of price changes is analysed by looking at the changes in groundwater withdrawal per unit irrigated area by well owning farmers.

The physical water productivity for a given crop (kg/m^3) is estimated using data on crop yield and the estimated volume of water applied for all sample farmers growing that crop. The volume of water applied to the crop was estimated from the discharge of the wells owned by the farmers (including those who sell the water) (Q); number of irrigations given to the crop (n); and duration of watering per irrigation (t) as Q X n X t. The discharge of the wells was measured in the field using a stop watch and a bucket with known capacity, by allowing the output of the well to fill directly in the bucket and then noting the time required to fill the bucket. The combined physical and economic water productivity in ₹/m^3 is estimated using data on net returns from crop production in ₹/ha and estimated volume of water. To estimate the net income from a particular crop, the data on inputs for each crop were obtained by primary survey of farmers. These included cost of seed, labour, fertiliser, pesticides and insecticides, irrigation, ploughing, harvesting and threshing.

The physical productivity of water in milk production for livestock is estimated using the methodology presented in Kumar (2007) and Singh (2004). The water productivity in farming operations, including crops and dairying is estimated using the methodology presented in Kumar *et al.,* (2008), which was used for estimating the economic value of irrigation water in agriculture for individual farms.

IV

RESULTS AND DISCUSSION

4.1 *Distribution of Land Holdings*

In North Gujarat, the average size of land holding is higher for tube well owners who are paying power tariff on connected load basis (3.45 ha) as compared to their

counterparts with metered connections (2.95 ha). About 90 per cent of the area is under irrigated crop production and remaining 10 per cent area is cultivated under rainfed condition.

In Eastern UP, the average size of land holding is larger for diesel well irrigated farms as compared to electric well commands. Differences are significant between well owners and water buyers. Diesel pump owners have average land holding size of 1.35 ha while their water buyers have landholding size of 0.94 ha. The average size of land holding for electric pump owner is 1.30 ha, whereas their water buyers have an average land holding size of 0.56 ha.

In south Bihar, the average size of land holdings for both well owners and water buyers in the diesel pump commands is higher than that of their electric counterparts. The well owners in electric well irrigated farms have larger sized holdings (0.73 ha) as compared to their water buyers (0.53 ha). In diesel pump commands, the differences are larger. The average size of land holding of well owners here is 1.26 ha, whereas for water buyers it is 0.57 ha.

Hence, the average size of land holding in water rich eastern UP and south Bihar plains is much smaller when compared to water scarce north Gujarat. This is one of the important factors that determine the utilisation of available water resources. In case of water abundant region, the limited land availability should motivate farmers to maximise returns per unit of land. Against this, in water scarce region, water availability is a limiting factor for maximising returns from crop production, and hence generally, they would be motivated to maximise the returns from every unit of water (Kumar *et al.*, 2008). However, lack of resources for investing in wells and energising devices is a limiting factor for many farmers in south Bihar and eastern UP to access the water.

4.2 *Cost of Groundwater Pumping*

The cost of groundwater pumping was estimated for well owners by taking into account the following: (1) cost of well construction and pump set installation; (2) cost of obtaining power connection; (3) cost of operation and maintenance of the well and the pump set; (4) life of the well and the pump set; (5) the average hours of groundwater pumping per year; and (6) discharge of the pump set. Since the year of construction is not the same for all wells, the cost of construction of each well was adjusted to inflation to make it correspond to the prices in the base year, i.e., the year of study (2008), and then discounted for the life of the system (20 years) to get annualised costs, using discount rate. To this, the variable cost (cost of operation and maintenance) was added to obtain the annual cost of irrigation. This, when divided by the annual hours of irrigation and the pump discharge (m^3/hour), yields the cost of groundwater irrigation per m^3 of water.

In the case of electric wells with metered connections, the hourly operation cost is worked out using the energy charges per kilowatt-hour (kWh) of use. Similarly, in

the case of diesel wells, the operation cost was worked out using the price of one litre of diesel and the amount of diesel consumption per hour of running. The cost of irrigation was finally worked out per cubic metre of water using well output data. In the case of wells with flat rate electricity connection, the implicit cost per hour of irrigation is worked out using the annualised cost, and the number of hours of irrigation per annum. Based on the figures of well discharge, cost estimates were worked out for eastern UP, northern Gujarat and south Bihar and are presented in Table 2. The unit rates charged by diesel pump owners for irrigation services are much higher than those of electric pump owners.

TABLE 2. COST OF IRRIGATION WATER FOR DIFFERENT CATEGORIES OF FARMERS
FROM THE THREE STUDY LOCATIONS

Area (1)	Water source (2)	Average ($\overline{\overline{\text{₹}}}$/m^3) (3)	Range ($\overline{\overline{\text{₹}}}$/m^3) (4)
Eastern UP	Electric pump owner	0.18	0.10 – 0.30
	Electric pump buyers	0.65	0.52 – 0.84
	Diesel pump owners	1.38	0.99 – 2.04
	Diesel pump water buyers	2.81	2.07 – 3.63
North Gujarat	Metered connections	1.07	0.14 – 3.91
	Non-metered connections	1.60	0.19 – 4.27
South Bihar	Electric pump owner	0.77	0.17 – 3.39
	Electric pump water buyers	0.70	0.31 – 0.92
	Diesel pump owners	1.87	1.51 – 2.95
	Diesel pump water buyers	2.15	1.84 – 2.42

Source: Calculated from the author's primary data.

4.3 *Cropping Patterns*

The cropping pattern of well owners and water buyers under different modes of energy pricing, i.e., connected load (electric well) and unit consumption (diesel well) in eastern UP is presented in Table 3. The crops grown in the study villages are foodgrains, pulses, oilseeds, vegetables, cash crops and fodder crops. Paddy and wheat are the dominant crops. During the *kharif* season, well owners and water buyers under both energy regimes allocate larger portion their land holding under paddy.

In diesel well commands, pump owners allocate about 26 per cent of the gross cropped area to paddy cultivation, whereas in the case of water buyers, it is only 22 per cent. In electric well commands, pump owners allocate 12 per cent to paddy and water buyers allocate about 15 per cent to paddy. Electric pump owners also grow groundnut. Water buyers in both electric and diesel well commands allocate larger portion of their cropped area under green fodder and other vegetables during *kharif* season as compared to pump owners. Water buyers in diesel well commands growing lentils of the *arhar* variety. Water buyers in electric well commands grow lady's finger (okra).

TABLE 3. CROPPING PATTERNS OF WELL OWNERS AND WATER BUYERS UNDER DIFFERENT
ENERGY REGIME, EASTERN UP

Name of the crops	Electric well command				Diesel well command			
	Owner		Water buyers		Owner		Water buyers	
	Area (ha)	Per cent area	Area (ha)	Per cent area	Area (ha)	Per cent area	Area (ha)	Per cent area
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Kharif season								
1. Paddy	0.71	11.51	0.36	14.81	1.55	26.18	0.91	22.14
2. Bajra	0.32	5.15	0.14	5.85	0.23	3.85	0.13	3.25
3. Maize	0.24	3.97	0.12	4.78	0.23	3.81	-	-
4. Lady's finger	0.32	5.18	0.23	9.53	-		-	
5. Other vegetables	0.32	5.30	0.17	7.08	0.14	2.41	0.34	8.35
6. Arhar	-	-	-	-	-	-	0.30	7.42
7. Black gram	0.27	4.39	0.11	4.68	-	-	0.11	2.78
8. Green gram	0.37	6.06	-	-	-	-	0.11	2.78
9. Sesame	0.08	1.30	0.06	2.34	0.23	3.85	0.11	2.78
10. Groundnut	0.33	5.34	-	-	-	-	-	-
11. Sugarcane	0.11	1.77	0.06	2.34	0.16	2.68	-	-
12. Green fodder	0.16	2.60	0.08	3.20	0.11	1.89	0.10	2.38
Rabi season								
1. Wheat	0.67	10.94	0.29	12.00	1.27	21.48	0.83	20.29
2. Barley	0.23	3.73	0.08	3.28	-	-	0.09	2.23
3. Pea	0.23	3.80	0.13	5.47	0.34	5.73	0.17	4.08
4. Gram	0.17	2.85	0.04	1.46	0.42	7.02	0.20	4.84
5. Mustard	0.70	10.06	0.53	4.45	0.27	4.55	0.14	3.50
6. Linseed	0.06	0.93	-	-	0.34	5.78	0.10	2.50
7. Potato	0.50	8.15	0.29	11.94	0.37	6.24	0.23	5.57
8. Barseem (Green fodder)	0.07	1.14	0.05	1.89	0.06	1.05	0.07	1.64
Summer season								
1. Sunflower	0.10	1.58	-	-	-	-	-	-
2. Vegetables	0.11	1.86	-	-	0.11	1.93	-	-
3. Green Fodder	0.15	2.38	0.12	4.89	0.09	1.55	0.14	3.48
Gross cropped area (GCA)	6.13	100.00	2.44	100.00	5.92	100.00	4.10	100.00

Source: Calculated from author's primary data.

The major crops grown during winter season are wheat and barley, potato, pea, gram, mustard, linseed and barseem. The percentage area allocated for crops, viz., wheat, pea, potato and barseem is lower for well owners as compared to water buyers, whereas, the area allocated to crops, viz., mustard, gram, barley and linseed is higher for pump owners as compared to water buyers.

In diesel well commands, pump owners allocate larger share of their cropped area under winter crops as compared to water buyers. Such sharp differences are not seen in case of electric well commands. During the summer season, the major crops grown in electric well commands are green fodder, sunflower and vegetables. While all these crops are grown by the electric pump owners, water buyers grow only green fodder. In diesel well commands, crops grown during summer season are green fodder and vegetables. Both diesel well owners and water buyers are found to be growing some green fodder.

In the case of north Gujarat, the major crops grown by the tube well owners under both tariff regimes are green fodder, food grain crops, pulses, groundnut and

cash crops such as cluster bean, cotton and castor. The farmers of this region allocate small area under green fodder throughout the year.

During *kharif* season, tube well owners under pro rata tariff regime allocate slightly larger percentage of the cropped area under cotton, castor and fodder bajra. During winter, tube well owners under flat rate tariff regime are allocating more area under green fodder, wheat and mustard. The tube well owners under pro rata tariff regime allocate slightly larger area under cumin, which is a high valued cash crop. The major crops grown during summer season are green fodder and bajra. The area allocated by flat and unit tariff paying tube wells owners under the bajra crop is about 10 per cent of the gross cropped area.

In South Bihar, very high monsoon rain results in submergence of most of the cultivated land during *kharif* season. During this season, farmers grow paddy and green fodder, with larger area under paddy. Out of the gross cropped area, nearly 38 per cent is under paddy. During winter, farmers grow wheat, gram, mustard, barseem (fodder), potato, radish, carrot and coriander. During summer, farmers grow onion, maize and green fodder. There is no significant difference in *kharif* cropping pattern between well owners and water buyers in electric well commands or diesel well commands. During winter, water buyers in electric well commands cultivate gram and carrot. Diesel pump owners and water buyers in both diesel and electric well commands keep a larger area for growing potato. During summer, only diesel pump owners and water buyers in their commands cultivate green fodder. In general, electric pump owners allocate larger area under different crops as compared to electric pump water buyers. There is a similar trend in the case of diesel pump command areas.

4.4 *Irrigation and Crop Water Productivity*

In this section, the estimates of irrigation water application, physical water productivity (kg/m^3) and water productivity in economic terms (₹/m^3) of different crops grown by electric/diesel pump owners and water buyers in their commands are presented. Higher physical productivity of water use for a given crop indicates more efficient use of irrigation water through on farm water management or better farm management. Higher water productivity in economic terms means better economic viability of irrigated production, if land is available in plenty.

Comparison electric the estimates of irrigation water dosage for *kharif* and winter crops between of pump owners and water buyers counterparts shows the total amount of irrigation water applied for crop production is higher for electric pump owners as compared to water buyers for all crops. Further, comparison of estimates of irrigation water productivity of crops in both the seasons between electric well owners and their water buyer counterparts shows that for most of the crops, both physical and economic productivity of water are higher for water buyers than their water-selling counterparts. Equally important is the fact that water buyers do not grow crops during

summer when crop water requirement is generally high, whereas well owners grow water intensive vegetable crops.

As regards diesel well commands, though the well owners as well as the water buyers are confronted with marginal cost of using water, the water buyers incur higher cost for irrigation water. But, there is not much difference in the cropping pattern of pump owners and water buyers, except that water buyers do not grow sugarcane and maize. To economise on irrigation water, water buyers cultivate water efficient crops such as arhar, black gram and green gram during *kharif* season. The cropping pattern during winter is the same for diesel pump owner and water buyers. During summer season, only pump owners grow vegetables. The estimates of irrigation water dosage and water productivity in physical and economic terms for different crops show that the water buyers in diesel well commands apply less amount of water to their crops as compared to their water selling counterparts. Further, the physical productivity of water (kg/m^3) and water productivity in economic terms (₹/m^3) is higher for water buyers as compared to diesel pump owners for all the crops. This could be owing to the higher marginal cost of irrigation water affected in the case of diesel well commands.

Table 4 presents similar data for different energy pricing regimes for North Gujarat. Electric pump owners, who pay marginal cost for electricity, maintain higher water productivity in both physical and economic terms for all the crops as compared

TABLE 4. WATER USE, AND WATER PRODUCTIVITY IN PHYSICAL AND ECONOMIC TERMS UNDER FLAT AND UNIT ENERGY PRICING REGIME, NORTH GUJARAT

| Name of Crop (1) | Electric pump owner | | | Electric pump water buyer | | |
	Depth of irrigation (mm) (2)	Water productivity (kg/m^3) (3)	Water productivity (₹/m^3) (4)	Depth of irrigation (mm) (5)	Water productivity (kg/m^3) (6)	Water productivity (₹/m^3) (7)
Kharif						
1. Alfalfa	36.3	5.42	-	41.1	5.64	-
2. Cluster bean	85.2	1.02	9.09	106.2	1.11	9.37
3. Jowar	107.1	2.76	8.27	101.4	2.26	6.62
4. Bajra	98.1	1.00	5.13	89.4	1.45	6.39
5. Black gram	81.3	1.07	15.14	52.6	1.50	16.75
6. Green gram	76.2	0.91	10.85	87.3	0.98	11.20
7. Groundnut	94.7	0.58	3.58	51.4	0.56	4.68
8. Cotton	62.9	0.41	5.34	61.0	1.15	19.28
9. Castor	116.6	0.59	5.06	110.2	0.62	6.52
Rabi						
1. Alfalfa	32.7	3.65	-	28.3	5.71	-
2. Wheat	127.2	0.82	4.64	96.3	0.91	5.17
3. Barley	22.9	0.47	0.70	62.9	1.11	6.17
4. Rajgaro	91.4	0.56	4.11	72.7	0.89	8.50
5. Mustard	113.8	2.86	22.25	74.6	2.10	23.50
6. Cumin	89.5	0.82	36.71	81.4	0.99	47.71
Summer						
1. Alfalfa	38.2	2.30	-	-	-	-
2. Bajra	168.7	1.95	6.43	129.2	1.94	7.31

Source: Calculations from author's primary data.

to those who are paying for electricity on the basis of connected load (pump horsepower). Further, they do not keep highly water intensive alfalfa, which is a fodder, in their fields during summer.

A comparison of the estimates of mean values of irrigation water dosage and water productivity in physical and economic terms for both pump owners and water buyers in electric pump command area in south Bihar plains for all crops (Table 5) shows that water buyers apply less water to their crops, and maintain higher physical water productivity for many crops in comparison to electric well owners. However, they secure lower water productivity in economic terms for most of the crops, except radish and onion. This could be due to the higher cost of irrigation water, which eventually reduces net returns from crop production, the value of numerator of water productivity.

TABLE 5. WATER USE, AND WATER PRODUCTIVITY IN PHYSICAL AND ECONOMIC TERMS UNDER ELECTRIC WELL COMMAND, SOUTH BIHAR PLAIN

	Electric pump owner			Electric pump water buyer		
Name of crop	Depth of irrigation (mm)	Water productivity (kg/m^3)	Water productivity (₹/m^3)	Depth of irrigation (mm)	Water productivity (kg/m^3)	Water productivity (₹/m^3)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Kharif			
1. Paddy	75.1	2.5	6.35	46.7	2.69	8.4
2. Maize	25.0	20.5	-	12.5	27.34	-
			Rabi			
1. Wheat	48.2	1.8	5.56	35.1	1.76	5.8
2. Potato	192	13.1	43.16	20.0	11.74	41.8
3. Barseem	5.6	10.4	-	4.0	11.91	-
4. Mustard	26.7	1.8	20.16	-	-	-
5. Gram	-	-	-	9.3	0.66	9.2
6. Radish	12.7	10.0	13.92	9.6	9.59	18.5
			Summer			
1. Onion	46.0	4.4	18.48	21.8	5.40	23.2
2. Maize	20.7	5.9	21.66	17.6	6.86	19.1

Source: Calculated from author's primary data.

Comparing the water use and water productivity of crops raised by two categories of farmers in diesel well commands of south Bihar plains - both in physical and economic terms shows that the diesel pump owners and water buyers grow almost similar crops. For all crops except onion and summer green fodder, water buyers in diesel well commands secure higher physical water productivity as compared to pump owners. Again, for all crops except onion, the water buyers secure higher water productivity in economic terms as compared to pump owners.

The trends emerging from the foregoing analysis are as follows: (1) the net water productivity of water buyers from electric pumps is greater than from diesel pumps both in east UP and south Bihar; (2) net water productivity of electric pump owners under flat rate provision is comparatively less than that under pro rata tariff; (3) water productivity of electric pump owners in economic terms is less than that of diesel

pump owners; and, (4) economic water productivity of water buyers from electric pumps is less than those buying water from diesel well owners.

4.5 *Farm Level Water Productivity*

In eastern UP and south Bihar, farmers should try and economise on the use of water, though it is not a scarce resource in these regions in physical terms. The reason is that using more water means paying more for pump rental services. Farms are the units, for many investment decisions by farmers in agriculture including water allocation decisions. Hence, they try to optimise water allocation over the entire farm, rather than individual crops, to maximise their returns. Therefore, the impact of power pricing on the efficiency with which water is used by farmers should be analysed by looking at the water productivity for the entire farming system.

The study has analysed the water productivity in overall farm operations, which takes into account water productivity in dairy farming (not included in the paper) along with crops. The WP in overall farming operations is much higher for water buyers in diesel well commands in eastern UP and south Bihar (Table 6). In electric well commands also, the differences exist in favour of water buyers in spite of very low marginal cost of using water ($₹\ 0.65/m^3$). The farm level water productivity is much higher for farmers who are confronted with marginal cost of electricity in north Gujarat as compared to those who pay for electricity based on connected load. The water productivity improvement in highest in eastern UP in the diesel well commands, where the water buyers' marginal cost of using irrigation service is $₹2.81/m^3$. Difference in water productivity between farmers with flat rate connection and those with metered connections is also quite substantial in North Gujarat.

TABLE 6. FARMING SYSTEM LEVEL WATER PRODUCTIVITY IN AGRICULTURE
UNDER DIFFERENT PRICING REGIMES

Name of the regions (1)	Name of the district (2)	Electric well command		Diesel well command	
		Flat rate (3)	Unit pricing (4)	Well owner (5)	Water buyers (6)
North Gujarat	Banaskantha	6.20	7.90	N.A.	N.A.
		Well owner	Water buyer	Well owner	Water buyer
Eastern UP	Varanasi and Mirzapur	10.95	11.18	8.67	12.89
South Bihar Plains	Patna	9.28	10.13	11.97	12.43

Source: Calculated using author's primary data.

Further, comparison between electric well owners and diesel well owners in both the locations substantiates the earlier point that positive marginal cost promotes efficient use of water at the farm level.

4.6 *Groundwater Pumping and Net Farm Returns of Farmers*

Pricing would introduce efficiency, but may not ensure sustainability of resource use (Kumar, 2005). The total amount of groundwater pumpage per unit of cultivated

area is determined by the cropping pattern, the cropping intensity, and the degree to which crop water needs are met. Increased allocation of cultivable area under highly water intensive crops would increase the demand for irrigation water by a farmer. Hence, total pumpage per unit cultivated area could be a good indicator of the sustainability impacts of change in mode of pricing on groundwater. However, farmers with very small land holding size are more likely to intensify cropping, which would increase the total pumpage. This would mean longer hours of pumpage per ha of cultivable area as the value of numerator would increase and that of denominator would decrease.

But, the results from eastern UP and south Bihar show that the pumpage of groundwater per unit area of cultivated land is lower for water buyers, in spite of them having lower sized holdings (Table 7). The data for north Gujarat show that the pump owners having metered connections, in spite of having smaller sized land holdings (2.95 ha against 3.45 ha) use much less water per ha of land as compared to their flat rate counterparts (304.0 hours per year against 444.0 per year). The difference in aggregate pumping is much greater between farmers with meters and those without meters (Table 7). Such a high reduction is water usage per unit of cultivated land, which is disproportionately higher than the reduction in net return per unit of land, is made possible through high improvements in water productivity in economic terms.

TABLE 7. AVERAGE HOURS OF GROUNDWATER USE/HA OF CROP LAND BY FARMERS UNDER DIFFERENT PRICING REGIMES

Name of the regions (1)	Name of the district (2)	Groundwater pumpage by electric pump owners		Diesel pump	
		Pro rata pricing (3)	Flat rate (4)	Well owner (5)	Water buyers (6)
North Gujarat	Banaskantha	304.0	444.00	NA	NA
		Groundwater use in electric well command by		Groundwater use in diesel well command by	
		Well owner	Water buyer	Well owner	Water buyer
Eastern UP	Varanasi and Mirzapur	175.0	184.0	222.0	148.0
South Bihar	Patna	330.0	250.0	231.0	198.0

In spite of slight reduction in pumping, the net return from unit area of land is higher for water buyers in eastern UP and South Bihar plains (Table 8). This is achieved through high improvement in water productivity through selection of crops that are less water consuming and high valued. Though the net returns per unit of land were marginally lower for farmers who paid on pro rata basis in north Gujarat (Table 8), this is not a concern, as in water-scarce regions like north Gujarat farmers would not have land constraints in maximising returns. Even if the farmers attempt to expand the area to maintain the net farm return at the previous levels, the aggregate water usage would still be lower than the previous levels.

TABLE 8. NET INCOME FROM FARMING OPERATIONS IN THE THREE STUDY LOCATIONS

Region (1)	Type of well command (2)	Type of farmer (3)	Net income from crops (₹) (4)	Net income from dairying (₹/day) (5)	Total farm level income (₹) (6)	Farm level income per unit land (₹/ha) (7)
	Electric well	Well owner	124587	7152	131740	24880
Eastern UP		Water buyer	54638	6165	60803	27570
	Diesel well	Well owner	74765	7430	82194	14528
		Water buyer	62323	6261	68584	18075
North Gujarat	Electric well	Flat rate pricing	369120	30048	768287	57531
		Pro rata pricing	311807	45636	669250	56882
	Electric well	Well owner	120477	10293	130770	210345
South Bihar		Water buyer	61518	8131	76024	190031
	Diesel well	Well owner	140105	9958	150064	191387
		Water buyer	71810	12232	84043	197895

Source: Calculated from author's primary data.

V

IMPLICATIONS OF FARM-SECTOR ENERGY PRICING FOR GROUNDWATER SUSTAINABILITY,
POWER SECTOR VIABILITY AND CARBON EMISSIONS

The foregoing analysis showed that introducing marginal cost for electricity motivates farmers to use water more efficiently at the field level from physical, agronomic and economic points of view through careful use of irrigation water, use of better agronomic inputs and optimising costly inputs. This is evident from: (1) the lower irrigation dosage applied by the farmers who are either using diesel wells or buying water from well owners or paying for electricity on pro rata basis, with lowest dosage found in the case of water buyers of diesel well commands, who pay higher unit price for irrigation water; and (2) the higher physical and economic productivity of water in crop production secured by the farmers who are either using diesel wells or buying water from well owners, or paying for electricity on pro rata basis.

The analysis also showed that introducing marginal cost for electricity motivates farmers to use water more efficiently at the farm level through careful selection of low water intensive crops, and livestock composition that give higher return from every unit of water, as higher pumping leads to higher energy costs for irrigation. Further, higher cost of irrigation water affected by higher energy cost will not lead to lower net return from every unit of water used as the farmers modify farming system itself in response to increase in energy cost, as indicated by the higher water productivity obtained by farmers who purchase water from diesel wells as compared to the well-owning counterparts.

The analysis also shows that pro rata pricing has significant impact in reducing groundwater pumpage from every unit of irrigated land, which is disproportionately higher than the reduction in net return from unit of land. This means that even if farmers expand the area to maintain the net farm returns at the previous levels, the groundwater use would still be lower, implying positive impact of pro rata pricing on

sustainability of groundwater use. The empirical evidence further reinforces the inference drawn by Kumar (2005) that the arguments against pricing are flawed.

The potential impacts of introducing pro rata power tariff on reducing carbon emissions and their associated social benefits are remarkable. If we assume that the all the electricity produced for supplying to the agriculture sector comes from a thermal power (coal based or gas based) plant, the economic cost of capturing carbon emissions from generating one kilowatt hour (unit) of thermal power can be treated as the opportunity (social) cost of using one unit of thermal power in agriculture. Hence, the same can be treated as the benefit of saving one unit of power consumed in agriculture through pricing mechanism. As per estimates provided by David and Herzog (undated), the cost of capturing one kilogram of CO_2 emission from thermal power generation is US $ 0.049 or INR 0.49 (ppp adjusted), and one kilowatt hour of power generation produces 0.26 kilogram of carbon or 0.96 kilogram of CO_2. Hence, the social benefit associated with preventing carbon emission by saving one kilowatt hour of electricity would be equal to ₹ 0.47. The total electricity consumption in agriculture sector was estimated to be 107.77 billion units per annum in 2008-09. If we assume that there would be 20 per cent energy-saving obtained from water productivity improvement in irrigated farm production alone due to efficient pricing,[2] the total social benefit would be to the tune of ₹ 709 crore per annum, for a total electricity saving of 2156 crore (21.56 billion) units. Here we assumed that only 70 per cent of the total electricity consumed in the country comes from thermal power, and the rest comes from clean energy sources such as nuclear power and hydropower.

VI

TECHNOLOGY FOR INTRODUCING ELECTRICITY METERING IN FARM SECTOR

The SEBs and policy makers in government recognise the importance of metering electricity from the point of both cost recovery and improving energy efficiency. This means reducing the unaccounted for losses in electricity distribution, improving the financial working of the SEBs and reducing the overall power deficits. But, for almost two decades, they were also toiling with the idea of carrying out metering of farm-power connection in a way that makes it fool-proof as well as cost effective. The problem was the rampant tampering of meters in rural areas, and malfunctioning meters. Today, technologies exist not only for metering but also controlling energy consumption by farmers (Kumar, 2009; Zekri, 2008).

The pre- paid electronic meters, which are operated through scratch cards and can work on satellite and internet technology, are ideal for remote areas to monitor energy use and control groundwater use online from a centralized station (Zekri, 2008). It is important to note here that over the past 7-8 years, there has been a remarkable improvement in the quality of services provided by internet and mobile (satellite) phone services, especially in the rural areas, with a phenomenal increase in the number of consumers. As Zekri (2008) notes, such technologies are particularly

important when there are large numbers of agro wells, and the transaction cost of visiting wells and taking meter reading is likely to be very high. It is inevitable that they will be adopted in rural India. They prevent electricity pilferage through manipulation of pump capacity. It helps electricity company restricts the use of electricity. The company can decide on the 'energy quota' for each farmer on the basis of reported connected load and total hours of power supply, or sustainable abstraction levels per unit of irrigated land. But, for operationalising this, database for every agricultural consumer of the connected load, coordinates, and field data to assess sustainable withdrawal levels, among other data, are required. Farmers can pay and obtain activation code through mobile SMS (Zekri, 2008).

Restricting farmers' energy use for pumping groundwater is analogous to rationing water allocation volumetrically, and this will motivate them to allocate the available water to economically more efficient uses. This will have positive impact on efficiency of groundwater use by all categories of farmers. Here again, the energy quota for all the farmers tapping water from the same aquifer will have to be decided on the following considerations: sustainability of groundwater use; geo-hydrological environment prevailing in the area; the land holding size of the farmers; and equity. But, in such cases, it is important that the consumers are informed about their energy quota (in KWhr), and the approximate number of hours for which they could pump water from their wells using this quota, well in advance of the agricultural season. Such information would help them choose the crops depending on the availability of power over the entire crop year.

VII

CONCLUSION AND POLICY IMPLICATIONS

Pro rata pricing of electricity coupled with rationing of energy supply based on groundwater resource sustainability criterion is the best option for co-management of electricity and groundwater. This would address the issue of equity, efficiency and sustainability of groundwater use, while improving the energy economy. This will also have a significant impact on reducing carbon footprint in agriculture. But, implementing this requires great political will as rights of farmers to use groundwater would be regulated by this intervention. Government can offer subsidies for meters if farmers are willing to go for this on account of the positive welfare effects. For implementing this, it is necessary that SEBs set up computerised database of all agro wells, comprising their latitude and longitude, physical characteristics and land use data.

There are some initial transaction costs in introducing pre-paid meters. Also, there are processes involved in putting the systems such as fixing energy quota of individual farmers, generating database of well owners, and providing extension services to the farmers for effectively using the new technologies such as pre-paid meters. All these would take time, technical and human resources and finance. But,

the opportunity costs of not doing this will be significant. They will be in the form of low agricultural productivity, and threat to sustainability of groundwater resources and livelihoods of millions of farm households. On the other hand, there are economic and social benefits of following the new system of supplying electricity, metering and charging higher tariff such as improved productivity of use of electricity and water, greater agricultural outputs, increased revenue for the state electricity boards from farm sector, and improved financial viability of power sector, and reduced carbon emissions. All these can be done without adversely affecting the economic viability of irrigated production.

NOTES

1. This is based on the formula that producing one unit of electricity through fossil fuel burning would emit 0.26 kg of carbon or 0.96 kilogram of CO_2 (Nelson and Robertson, 2008).

2. Energy saving can also come from improvement in pump efficiencies, occurring as a result of pro rata pricing of electricity. However, we have not considered this.

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