Promoting Solar Power as a Water Saving Crop in India

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Abstract: Agricultural power subsidies have for long driven groundwater depletion and strained government finances in India. Yet, governments are loath to rationalize subsidies due to farmer resistance. As a workaround, researchers have experimented with paying irrigators for pumping less. In 2018, in a bold such experiment, government of Gujarat state in India offered to solarize and net-meter irrigation pumps and pay farmers for energy saved in irrigation for 25 years. We analyse four years' metered energy consumption data to show that, despite much enhanced ration of subsidised daytime grid power, 3244 adopters consumed 33.5 percent less energy in pumping groundwater compared to 1115 non-adopters on those feeders. This Gujarat experiment points to a possible way out of sticky power subsidies and uncontrolled groundwater abstraction.

Subsidies on unmetered electricity supply to farmers remains a complex and unresolved policy issue in India (1-5) and several other countries (7,8). During the 1960's, when India faced severe food shortages, subsidies on electricity, pumps and tubewells in the fertile north-western India were thought essential to accelerate groundwater irrigation for food security (3,9). This policy proved justified then since by the mid-1970's, India did become food secure, and in time, even a food exporter. Induced by subsidies, farmers invested in millions of irrigation wells and pumps. Explosive growth in private irrigation intensified land use, improved livelihoods and farm incomes, made irrigation ubiquitous and equitable, moderated regional inequality between canal commands and rainfed areas, made famines history and, in general, helped India feed its rapidly growing population (2,5,9).

Energy Subsidies and Groundwater Depletion

However, electricity subsidies, once started, could not be withdrawn nor could farm power supply get metered. In the 1990's and later, their myriad adverse effects became evident. Subsidies or free power supply caused uncontrolled increase in the number and size of electric pumps, in energy consumption per hectare and in aggregate groundwater draft (2,9,10). These in turn led to widespread decline in groundwater levels and water quality, reduced low flows in rivers and streams, and caused desiccation of wetlands (5,9,11,12,13)). Subsidies increased the carbon footprint of irrigation both because of its growing energy intensity as well as rapid replacement of diesel by carbon-intensive coal-based electricity (14, 15). They also indirectly contributed to the neglect of canal systems and irrigation tanks since free power made farmers dependent on private wells (5). Additionally, unmetered and free power for irrigation bred farmer indiscipline on rural power grid, causing deterioration in power supply and quality of rural life for all (9,16). Serious fiscal impact of electricity subsidies became manifest in their growing share in government budget deficits (4,17).

Farmer resistance to metering pumps and rationalising tariffs has been so strong that farmer lobbies played a part in voting out politicians in some states for threatening to meter tubewells in election campaigns (10;17). Therefore, a 2003 Electricity Act of Government of India mandated state governments to compulsorily meter irrigation pumps and charge farmers a token metered tariff of just INR 500/MWh (US$ 5.95 for MWh or 1000 units) (US $=INR 84). Yet no state government has since managed to meter pumps or collect metered tariff except West Bengal and Gujarat. Several states continue unmetered free power to farmers; and few others levy a token flat charge. All this while, controlling the subsidy bill and groundwater depletion became ever more pressing.

Workarounds

As a workaround, in a 2003-6 campaign, Gujarat, India's western-most state rewired the rural power grid and connected all irrigation pumps on segregated feeders (18-20). This done, farmers began getting power ration of 8 hours daily in day-and-night weekly roster. Moreover, Gujarat ensured universal metering of all new pump connections by charging farmers a subsidized tariff of INR 600/MWh (US $ 7.14/1000 units). These measures did limit energy use in groundwater draft and reduced subsidy bill (19,20) while improving rural power supply and quality of life.

However, farm-power rationing also hardened village water markets, making it costlier for tenants and small farmers to purchase irrigation service from private pump owners (20). In response, the government issued over 450,000 new power connections to poor farmers (21). This policy did help the poor but partially nullified the energy-water conservation impacts of feeder segregation and metering. More recently, solar irrigation pumps (SIPs) have emerged as a new threat for groundwater conservation (22,23). With attractive capital cost subsidy of up to 95 percent, SIP numbers in India have soared from less than 10,000 in 2015 to over 450,000 by 2023 (25). Thanks to their free, year-round daytime power supply, SIPs are expected to increase groundwater stress (22,23). Needed now was a workaround for meeting the twin threats to groundwater sustainability from grid power subsidy as well as the rapidly growing stock of off-grid solar pumps.

Gujarat's Solar Powered Farmer Scheme (SPFS)

It was to find such a workaround that, in 2018, Gujarat government launched *Suryashakti Kisan Yojana* or Solar Powered Farmer Scheme (SPFS) as a state-wide pilot project. Based on the recognition that the utility's cost of power exceeds the farmer income generated by power (24), SPFS aimed to unlock value for all stakeholders. SPFS did this by promoting among groundwater irrigators solar power as a remunerative energy-water saving crop. SPFS invited all 6814 pump owners on 95 selected agricultural feeders to join. Under its terms:

[a] each adopter would get 2 kWp solar panels per kW of pump load.

[b] pumps would continue operating on grid power; all solar energy would be evacuated to the grid.

[c] SPFS feeders would be kept live during daytime daily to ensure all solar evacuation.

[d] SPFS would meter for every pump solar energy generation, evacuation and grid power consumption. It would upload meter readings to a government-managed Solar Energy Data Management (SEDM) portal. Adopters would be trained to access SEDM portal through a mobile app for real time monitoring of their energy export.

[e] energy losses above 5 percent would be allocated pro-rata among adopters.

[f] for 25 years, the government would pay adopters feed-in-tariff (FiT) of INR 3500/MWh(US $ 41.7/1000 units) for net energy export on annual basis; net import would be charged at prevailing subsidised grid-power tariff.

[g] once joined, adopters cannot opt out.

The financing plan for SPFS was complicated. 35 percent of SPFS capital investment was to be financed by a 30 percent federal subsidy and 5 percent farmer contribution upfront. The balance 65 percent would be financed by a 7-year low-cost loan that Gujarat government took on farmers' behalf. The government would repay the loan by booking, for each of 7 years, an evacuation-based incentive

(EBI) of INR 3500/MWh (US $ 41.7/1000 units) in each adopter's account. Adopters were to evacuate approximately half their solar generation to collect enough EBI to cover the loan instalment. Evacuating significantly less would entail paying up the shortfall at year-end. This financial model was not clear to most adopters at the start and caused avoidable frustration to some as the scheme unfolded. Some heavy irrigators and water sellers found themselves paying much or all the loan for 65 percent capital investment in annual instalments. A few defaulted.

The expected benefits to government from SPFS were: [1] saving of grid power subsidy; [2] voluntary, tamper-proof metering of pumps and resulting improvement in energy audit; [3] reduced financial burden of energy losses in distribution; [4] accrual of federally mandated Renewable Energy Credits (RECs) free of cost; and [5] solar energy purchase at lower than weighted average cost from year 8-25. Expected benefits to farmers on SPFS feeders included: [6] year-round day-time power supply of 8 hours instead of day-and-night weekly roster hitherto; [7] saving of grid-power tariff; [8] income from energy export. Expected socio-ecological benefits to society included: [9] reduced GHG emissions from pump irrigation; [10] potential reduction in groundwater stress. First 9 of these 10 benefits would result merely from SPFS adoption by farmers. Benefit [10] however, would depend on whether or not adopters reduce pumping significantly in response to payment for surplus energy evacuated.

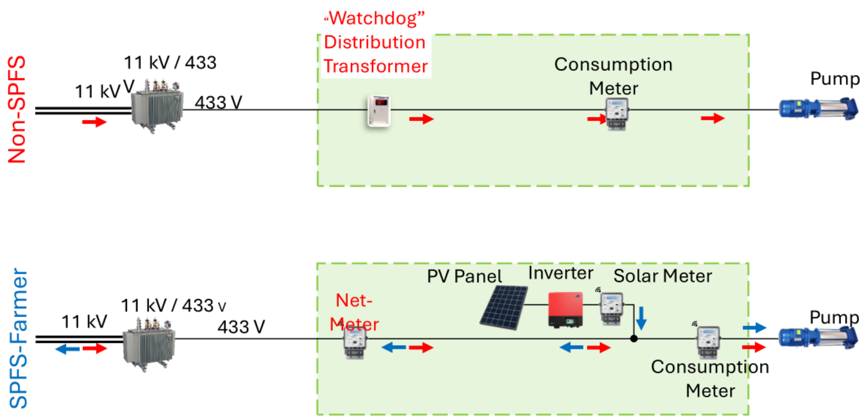

Fig. 1 Schematic diagram showing SPFS and non-SPFS pump owner after implementation

Government planners hoped that all pump owners on selected feeders would adopt SPFS. But farmers were reluctant to permanently give up existing subsidy on grid power since SPFS offered no exit option (26). Eventually, to induce greater participation, government: [a] allowed interested adopters to increase their authorised pump load; [b] guaranteed SPFS adopters 12 hours of daytime grid power supply daily instead of 8 available to non-adopters. Both these concessions proved decisive in finally attracting 4590 pump owners on SPFS feeders to join the scheme. 2224 pump owners opted out, for various reasons including capital scarcity and indecisiveness (27). Their pumps were fitted with meters and specially designed Watchdog Devices (WDDs) to restrict their grid power use to 8 hours/day. Figure 1 presents technical modifications made on SPFS adopter and non-SPFS pumps on each SPFS feeder.

These concessions, much valued by farmers (27,28), became confounders. Else, SPFS would have been a good 'natural experiment' to examine if paying for saving energy itself made adopters pump less water compared to non-adopters on SPFS feeders (29). After SPFS, Gujarat has three types of power ration for irrigation: [a] 8 hours of daily supply in day-and-night weekly roster on non-SPFS feeders; [b] 8 hours of daytime power daily for non-SPFS farmers on SPFS feeders; and [c]12 hours daytime power daily for SPFS farmers. The null hypothesis is that there is no significant difference in energy use in irrigation among farmers under these three types of ration. Our alternative hypotheses are that *ceteris paribus*:

H1: All farmers on SPFS feeders would use more energy in pumping groundwater than those on non-SPFS feeders.

H2: non-SPFS farmers would increase energy use in pumping after SPFS starts.

H3: SPFS-adopters would increase energy use in pumping even more than non-SPFS farmers unless the incentive to save energy has stronger conservation impact than enhanced daytime power ration.

Our empirical strategy permits us to test H2 and H3 but not H1.

Results

Gujarat's electricity business is managed by a cluster of specialised quasi-government companies. Electricity distribution is the responsibility of four regional distribution companies with Gujarati names, but referred to in this paper as Southern, Central, Northern and Western utilities. Figure 2 earmarks the service areas of the four utilities and shows the location of 95 SKY feeders spread across the state. Gujarat has a diverse hydrogeology; and we use pre-monsoon depth to water level as its most farmer-relevant marker since it determines well-depth and pump-size. Figure 3 shows pre-monsoon water levels for 2020-21, 2021-22, 2022-23 and 2023-24 in the service areas of the four utilities during the four years of our analysis.

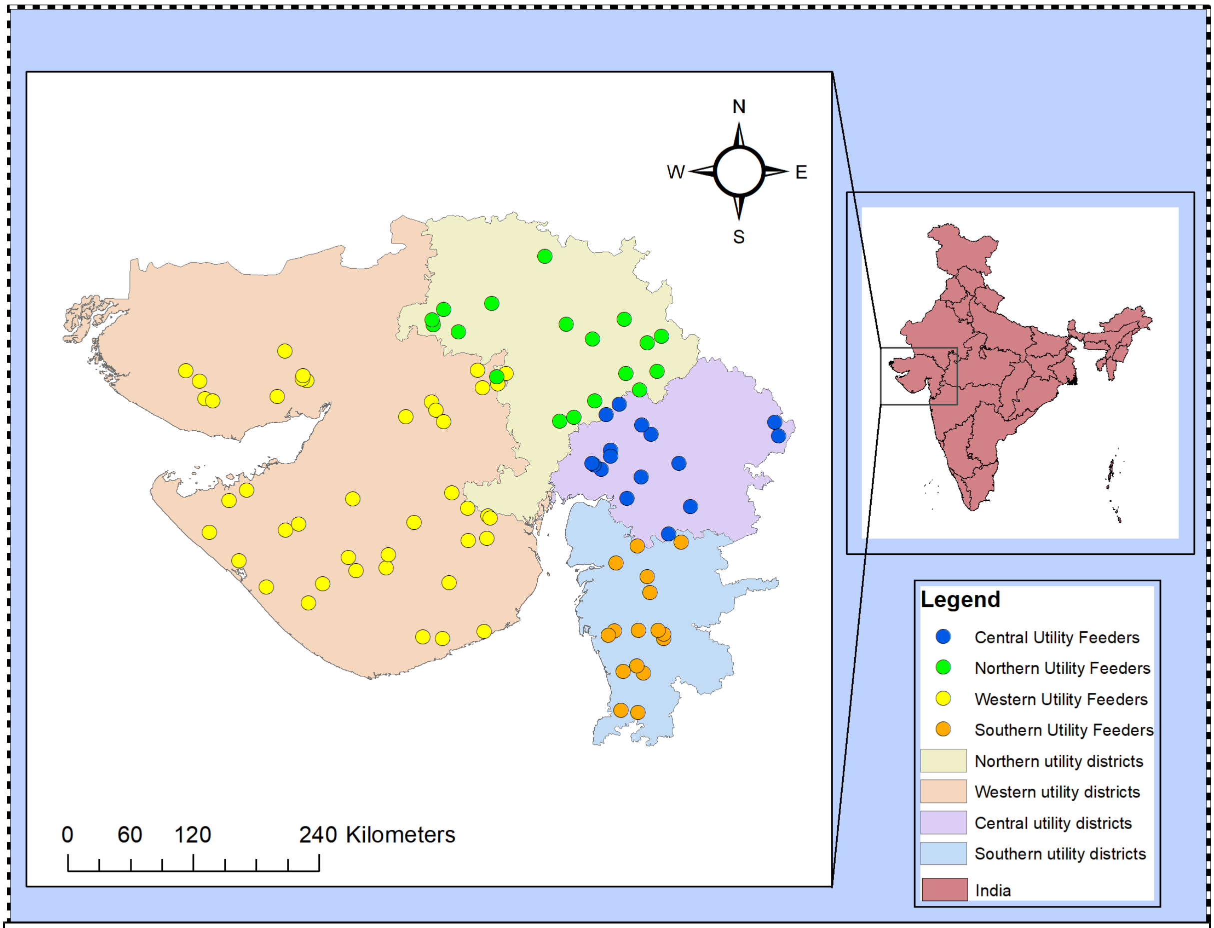

Fig. 2 Map showing: [a] Gujarat state in India, [b] service areas of Gujarat's four electricity utilities and [c] location of 95 agricultural feeders selected for SPFS implementation.

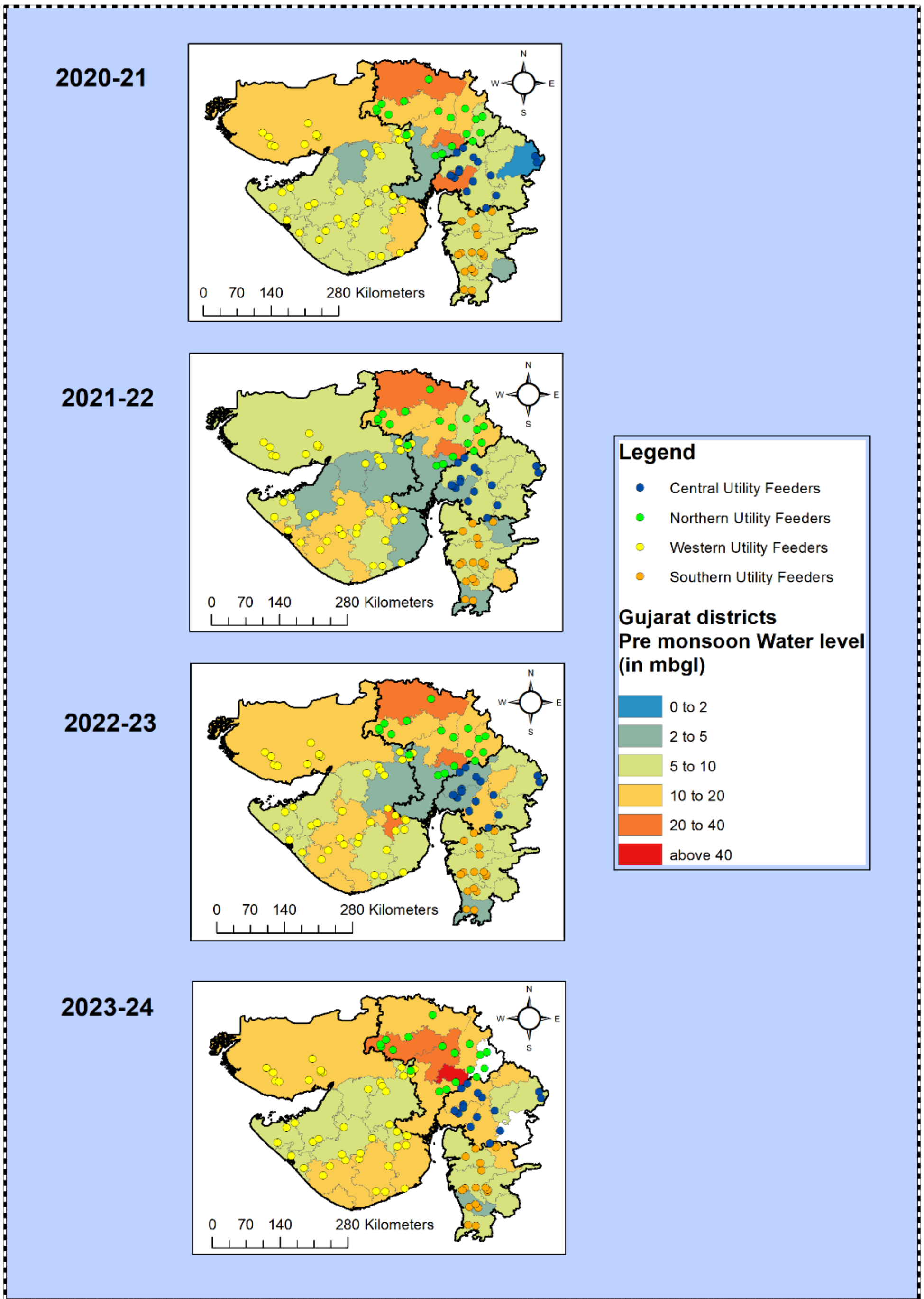

Fig. 3 Maps showing depth to pre-monsoon groundwater level in meters below ground level (mbgl) in the districts of Gujarat.

Our empirical strategy, which permits testing H2 and H3 but not H1, is to use metered consumption data for SPFS and non-SPFS farmers on SPFS feeders from the SEDM portal for financial years 2020-21 to 2023-24. SPFS implementation began in late 2018. But solarization of all SPFS farmers and WDD installation on non-SPFS farmers was completed only by the end of 2019-20. Annual energy sale and payment accounts for all SPFS adopters were settled for the first time only in May 2021when SFPS farmers were faced with financial impacts of their decisions.

We therefore surmise that behaviour change in terms of energy use in pumping would begin only from 2021-22 and continue to 2023-24 and beyond. We postulated the following simple model for each utility and for data pooled from all four utilities:

$$\text{PUMP-CONS}_{i,2022\text{-}24} = \alpha + \beta\ \text{PUMP-CONS}_{i,2020\text{-}21} + \gamma\ \text{SPFSD}_i + \delta\ \text{PUMP-HP}_i + \varepsilon_i \qquad \text{------- eq.[1]}$$

where $PUMP\text{-}CONS_{i,2022\text{-}24}$ is the simple mean for 2021-22, 2022-23 and 2023-24 of energy consumption by ith pump owner on SPFS feeder; $PUMP\text{-}CONS_{i,2020\text{-}21}$ is energy consumption of ith pump owner in 2020-21and $PUMP\text{-}HP_i$ represents pump-size of the ith farmer's pump. $SPFSD_i$ is a dummy variable representing SPFS adopters in Gujarat.

Figure 4 shows that total energy consumption by SPFS farmers averaged over 2021-22, 2022-23 and 2023-24 was lower than 2020-21 in majority of the feeders. In contrast, non-SPFS pump owners on many more feeders increased their consumption compared to 2020-21.

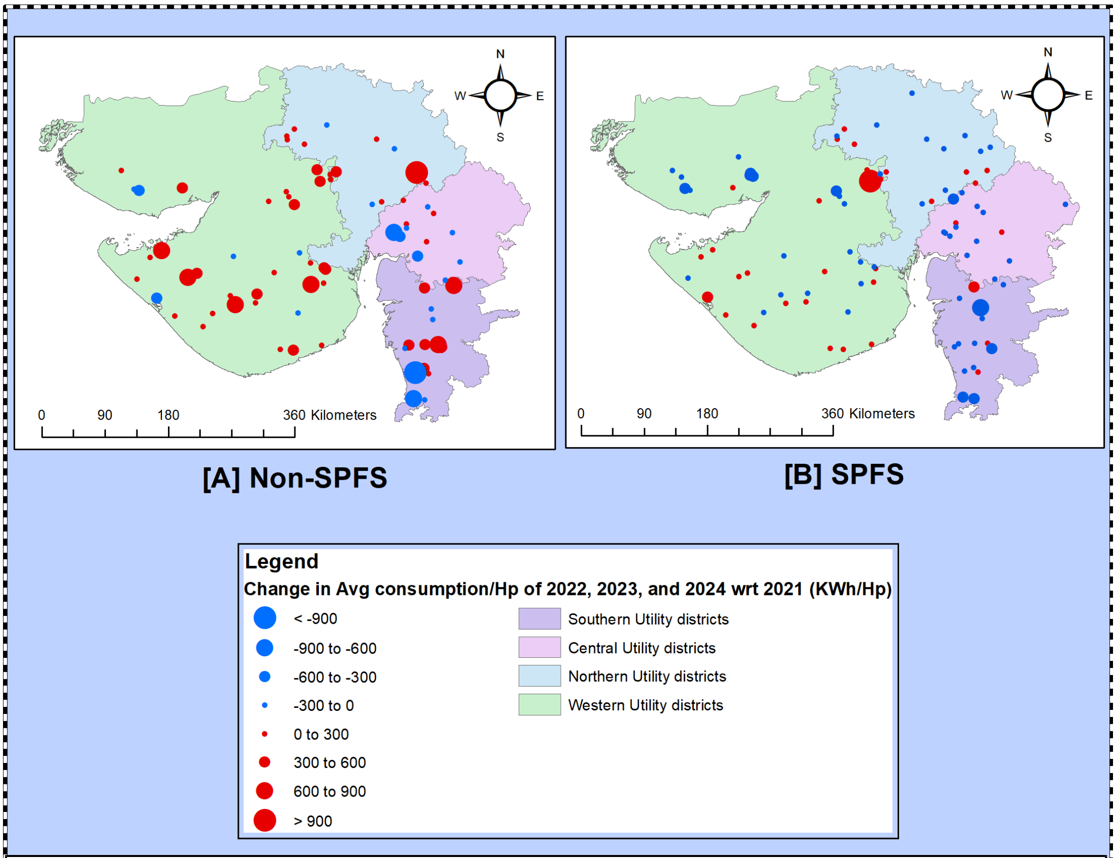

Fig.4 Change in average energy consumption/HP in pumping groundwater during the three year 2021-24 period over 2020 by SPFS adopters and non-SPFS pump owners

Of 4590 SPFS adopters and 2224 non-SPFS farmers on 95 SPFS feeders, we are able to use 4 years' metered data for 3244 treatment farmers and 1115 control farmers for estimating eq. [1] (see table S1). Table S2 presents year-to-year changes in energy consumption per HP. Table S3-5 analyse if there are significant differences between treatment and control group in average pump size, proportion of farmers who were unmetered before SPFS and of farmers with multiple grid power connections. Table 1 presents multiple linear regression results for eq. [1] in cols. 1-4 for each of the four regional utilities and col.5 for all of Gujarat's SPFS feeders together. We have reported coefficients from the 1st iteration to include all variables in eq. [1]. Large t-ratios, low p values and large F statistics are indicative of high goodness of fit, suggesting that SPFS did produce significant behaviour change among adopters. For 14 out of 17 slope coefficients, p <.001 suggesting high explanatory power of the predictors included. Especially for pooled data for all utilities (col. 5), the intercept and all slope coefficients are large and highly significant.

In col. 5, SPFSD, the dummy variable for SPFS adopters represents the combined impact of enhanced daytime power and the incentive to sell surplus energy. For Northern and Western utilities (col. 3 and 4), the coefficients of SPFSD are negative, large and highly significant, suggesting that, *ceteris paribus,* SPFS adopters significantly reduced pumping despite having 1.5 times larger daytime power allowance compared to non-adopters. In contrast, for Southern utility (col.1), the SPFSD coefficient is negative but small, with smaller t-ratio. At 0.33, R^2 and adj.R^2 indicating the overall goodness of fit of eq.[1] for Southern utility is low, too. For the Central utility (col.2), the SPFSD coefficient is positive and highly significant, suggesting that SPFS adopters here are driven more by larger daytime power allowance than earnings from energy sale. Arguably, the explanation lies in Figure 2 which shows that Northern and Eastern utilities are relatively more water-stressed compared to Southern and Central utilities. In water-abundant areas served by these latter utilities, water markets are ubiquitous and hyperactive (20, 21,28). Here, many SPFS farmers found it more remunerative to use enhanced power allowance to sell water to neighbouring farmers than selling energy to the government.

Table 1 Dependent variable ($PUMP\text{-}CONS_{i,2022\text{-}24}$) Average pump consumption of electricity during 2021-22/2023-24 (kWh/pump/year) by SPFS adopters and non-SPFS pump owners						
1		[1] SOUTHERN	[2] CENTRAL	[3] NORTHERN	[4] EASTERN	[5] ALL SPFS
2	N	807	701	593	2258	4359
3	Intercept term	1051.9*** (t=3.6) (*p*<.001)	-1075.3** (t=-2.13) (*p*=.033)	6021.5*** (t=6.69) (*p*<.001)	5118.8*** (t=15.22) (*p*<.001)	3999.1*** (t=16.54) (*p*<.001)
4	$PUMP\text{-}HP_i$	477.0*** (t=18.9) (*p*<.001)	36.01* (t=1.82) (*p*=.069)	111.2*** (t=6.99) (*p*<.001)	-15.4* (t=-1.42) (*p*=.154)	55.54*** (t=7.56) (*p*<.001)
5	$SPFSD_i$ (Dummy variable SPFS adopters)	-556.5 (t=-1.76) (*p*=.078)	1537.2** (t=3.26) (*p*=.001)	--5912*** (t=6.83) (*p*<.001)	-4064.4*** (t= -10.36) (*p*<.001)	-3452.4*** (t=-13.00) (*p*<.001)
6	$PUMP\text{-}CONS_{i,2020\text{-}21}$	0.092*** (t=3.68) (*p*<.001)	0.77*** (t=52.0) (*p*=<.001)	0.70*** (t=34.2) (*p*<.001)	0.64*** (t=48.6) (*p*<.001)	0.645*** (69.3) (*p*<.001)
7	R^2	0.33	0.85	0.79	0.61	0.66
8	$R^2_{adj.}$	0.33	0.85	0.79	0.61	0.66
9	*F*	F(2,804)= 200.4 (*p*<.001)	F(2,698)= 1935.0 (*p*<.001)	F(3,589)= 737.3 (*p*<.001)	*F*(2, 2255) = 1798 (*p*<.001)	*F*(3, 4355) = 2813.9 (p < .001)
10	Mean PUMP-HP	6.5	13.45	29.7	16.93	16.18
11	Mean consumption/ pump in 2020-21 (kWh/year)	4604	9669	14752	8436	8388
12	Mean consumption/ pump 2022-24 (kWh/year)	4172	8202	14941	7469	7993
13	Predicted consumption/ Non-SPFS pump 2022-24 (kWh/year)	4585.4	6978	19197	9833	10308
14	Predicted consumption of SPFS pump 2022-24 (kWh/year)	4014.2 (-12.3%)	8420 (+20.7)	13400 (-30.2)	6072 (-39.3)	6855.6 (-33.5)

In table 1, rows [13-14] show the predicted results of eq. [1] in cols 1-4 for the four utilities and col. 5 for all SPFS feeders together. According to this analysis, SPFS adopters in the Central utility used enhanced daytime power ration to increase pumping. In the remaining three, SPFS adopters reduced energy use in pumping by 20.7-39.3 percent. For all utilities combined, SPFS adopters used 33.5 percent less energy in pumping groundwater compared to SPFS non-adopters despite adopters enjoying 1.5 times the day-time power ration. This reduction would arguably have been even larger had they been restricted to 8 hours' daytime power ration as non-SPFS farmers were. The model shows that the conservation impact was larger in water-stressed Northern and Western Utilities than in water-abundant Eastern and Southern utilities.

Discussion

SPFS is the latest in a series of four Indian experiments in recent years to pay farmers for pumping less groundwater (see table S6 for a comparison of their assessments). All these contribute to the growing global debate on Payment for Ecosystem Services (PES), although Indian governments and utilities show greater urgency in reducing the subsidy burden. Unlike SPFS, other three experiments involved paying farmers for grid energy savings relative to a pre-determined benchmark. The first experiment [a] in north Gujarat failed to show significant reduction in self-reported but not metered pumping hours arguably because the incentive offered (of US $ 29.76/MWh) was too low (30). But another recent experiment [b] in Western utility service area of Gujarat, which offered INR 6100/MWh (US $ 72.6/1000 units), showed significant reduction (24 percent) in metered pumping hours compared to that by the control group, and that reduction increased over time (31). A 2019 World Bank funded pilot in Punjab [c] called *Pani Bachao, Paisa Kamao* ('Save Water, Earn Money') too metered tubewells of adopters (but not of non-adopters) and paid US $ 47.62/MWh for energy saved over benchmark reflecting pre-pilot consumption. An evaluation study found reduction in self-reported "electricity consumption and irrigation hours by at least 7.5 percent and up to 30 percent without impacting paddy yields." (32). A large 2022 survey also reported reduced self-reported pumping by treatment versus control farmers (27).

SEDM data did not allow propensity score matching between SPFS adopters and non-adopters. However, in Supplementary Material, we compare the two groups in terms of pump size (table S3), ownership of multiple connections (table S4) and of unmetered connections prior to SPFS (table S5). We find it unlikely these could vitiate our analysis.

SPFS mirrors a policy intervention better than earlier experiments. As a 25 year long intervention, SPFS offered a stronger reason for behaviour change compared to [a], [b] and [c] all of which, farmers knew, were to last 1 year or less. Unlike earlier experiments, SPFS also required farmers to invest and barred exit. It provides metered consumption data for treated and controlled farmers a larger sample than offered to earlier studies. Therefore, SPFS, and our analysis of its impact arguably provide stronger evidence than earlier studies that paying farmers for energy saved does change their pumping behaviour in significant manner. The $1/3^{rd}$ lower pumping by SPFS adopters relative to control group is larger than reported by all other studies.

Our results have significant policy implications. In 2020-21, Gujarat launched *Kisan Suryodaya Yojana* (Farmer Sunrise Scheme) under which, by 2024 end, all farmers were to get 8 hours' daytime power ration throughout the year instead of the current day-and-night roster (33). Moreover, before every assembly election, Gujarat's farmers' unions have been demanding removal of meters on pumps and return to unmetered power supply (34). Either or both of these eventualities would squander previous gains in energy-water conservation. A policy drawing upon the lessons of SPFS of promoting grid-connected solar irrigation pumps could not only preserve the gains but expand them with voluntary participation of farmers who would otherwise resist metering pumps and rationalisation of subsidies. Equally, in Gujarat and other regions, where financially viable, connecting

SIPs to the grid can address the twin limitations of off-grid SIPs, namely, the threat of groundwater overdraft (22) and the waste of unutilised solar energy (35).

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