Punjab's Energy-Water-Food Nexus: Exploration of Drivers and Practical Ways Out

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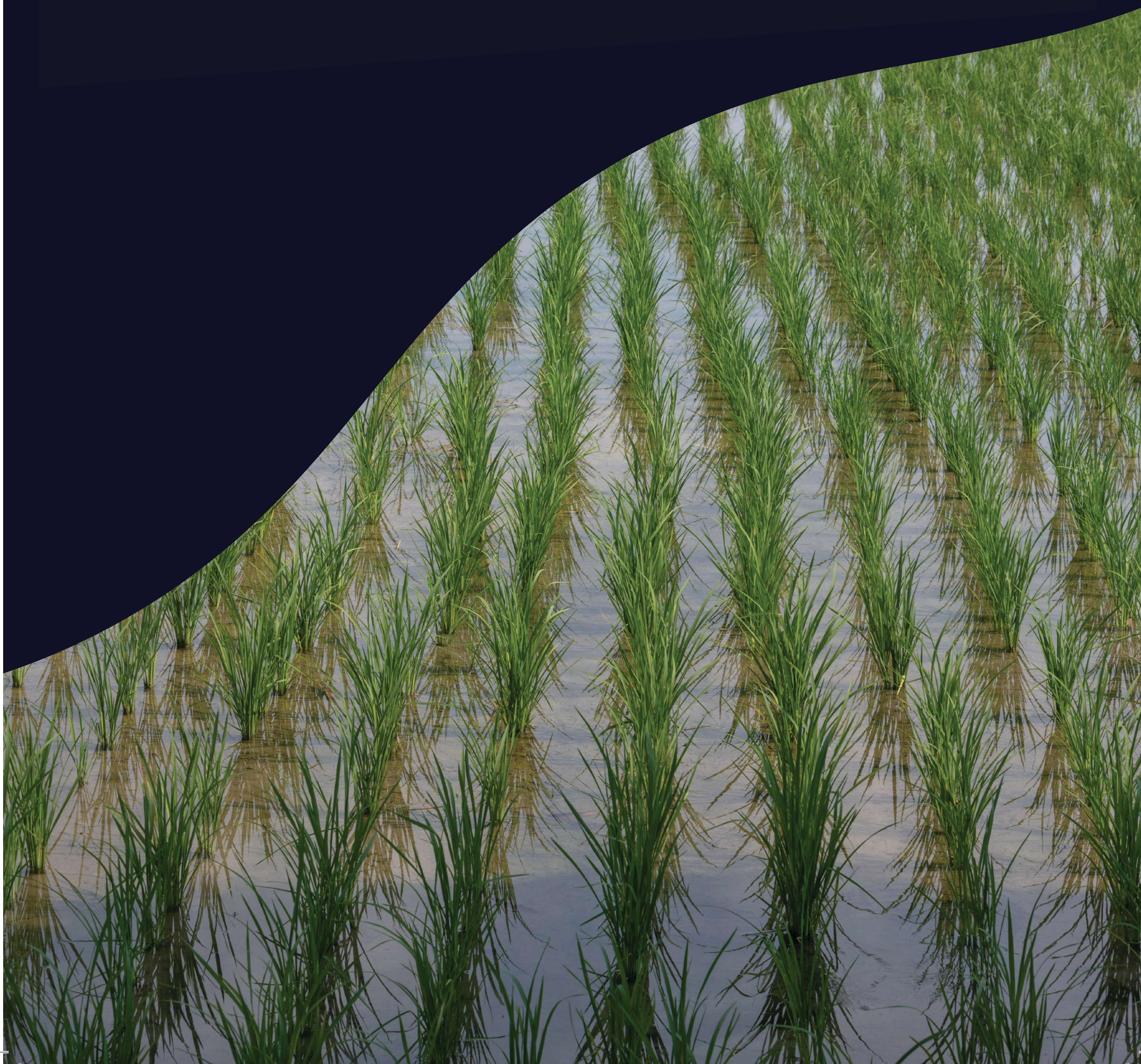

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Highlights

- The central problem of Punjab's rice socio-ecology is input over-intensification driven by: [a] guaranteed door-step procurement of rice at above-world prices; [b] free power for irrigation; and [c] fertilizer subsidy.
- Relentless groundwater depletion in Punjab can be countered by any of these four interventions: viz., consumption-linked electricity tariff; crop diversification away from rice; restoring canal irrigation and full utilization of surface water; and promoting water saving irrigation technologies like AWD and DSR. However, each of the above reinforces the other; and therefore, synchronizing all four may produce the best outcome.
- Even without rice irrigation, free power will find its way into profligate over-irrigation; so, crop diversification per se is no guarantee of sustainable groundwater management.
- The best entry point may be to rationalize farm power subsidies by imposing progressive, consumption linked tariff schedule which worked well in north China. But metering pumps and metered pricing of grid power do not seem politically feasible in Punjab as of now.
- Solarizing existing tubewells, metering them and paying farmers for surplus solar energy evacuation on telescopic feed-in tariff (FiT) may be the most practical (and politically acceptable) first step towards change. This is better also because it is pilotable on small scale unlike direct subsidy transfer schemes as suggested by many.
- Conservation impact of this can be further leveraged with effective canal rehabilitation which is already on the state government's political agenda.

1. Introduction

Sustained depletion of groundwater is a critical challenge facing the agri-food economy of north-west India, especially, Punjab. In 2022, 117 of Punjab's 153 development blocks were declared groundwater-overexploited[1], with the state withdrawing 1.5 times more groundwater every year than its long term average recharge. Based on a comprehensive assessment by India's Central Groundwater Board (2020)[2], the National Green Tribunal (NGT) warned in 2022 that Punjab will run out of groundwater by 2039[3]. The principal challenge in achieving sustainable foodscape in Punjab is two-fold: first, weaning Punjab away from excessive reliance on rice cultivation; second, getting its 1.4 million electric tubewells to use their unmetered free electricity as if it is costly. In a recent newspaper article, the Chairman of Punjab State Power Corporation Ltd (PSPCL) argued that groundwater depletion across Punjab districts is directly proportional to the density of tubewells[4]. He further posed that average power subsidy in irrigation is Rs 60,000/tubewell in Punjab. Since tubewell owners have no incentive to conserve energy or water, there is rampant over-irrigation especially of paddy fields which account for over 80 percent of Punjab's groundwater use in irrigation.

The incongruity of Punjab's rice economy is put into bold relief by table 1 which contrasts it with the

[1] https://www.news18.com/news/opinion/complex-patrolling-on-groundwater-spell-out-another-disadvantage-for-punjabs-industry-7059169.html

[2] Central Groundwater Board (2020) Groundwater Resources of Punjab State (as of 2020), New Delhi, GoI, CGWB, https://cgwb.gov.in/sites/default/files/MainLinks/Punjab_State_Resource_Report_2020.pdf

rice economy of West Bengal. West Bengal produces less rice than Punjab but uses only 45 percent of its annual renewable groundwater for rice irrigation against Punjab's 165 percent. Punjab uses 12 times more electricity/hectare to pump groundwater than West Bengal. Were rice to be sold at global prices and electricity charged at full cost, West Bengal would still carry on as usual but Punjab's rice economy would shrink significantly.

		Punjab	West Bengal
1	Rice production (mmt)[6]	18.3	14.8
2	Rice yield/ha (kg/ha)	6600	5400
3	Normal rainfall (mm/year)	780	2074
4	Renewable groundwater resource (BCM)[7]	12.74	14.31
5	Level of groundwater development (%)[8]	165	45
6	Public procurement of rice (mmt) and its Share in production (%)	12.6 (68%)	4.5 (30%)
7	# of electric tubewells ('000)	1400	350
8	Electricity consumption/net sown ha (kWh/year)	3165	254
9	Metering of electricity supply to farms	Unmetered	Fully metered
10	Price of electricity to farmer (Rs/kWh)	0	6.50
11	Farm power subsidy bill (Rs/year)	9500 crore	0

Table 1 – Two Systems of Rice Irrigation: Punjab versus West Bengal[5]

No cropping system can afford relentless pumping of groundwater. Henry Vaux (2011), an American economist had claimed that "Persistent [groundwater] overdraft is always self-terminating", since increasing pumping depth due to overdraft makes groundwater irrigation progressively unprofitable, forcing farmers to economize on water use including turning to rainfed farming. The Vaux-dictum works well in countries like the US, Australia, China, Spain where tubewells are metered and energy is charged at full cost; here, energy price doubles up as a surrogate for groundwater price. The Vaux dictum also works where diesel/petrol driven pumps are the mainstay of groundwater irrigation —as in Bangladesh, Nepal terai, much of Sub-Saharan Africa—because subsidizing diesel/petrol only for irrigation remains impractical and prone to excessive leakage. In many parts of the world, however, farmers have organized to ensure that electricity subsidies enable unrestrained groundwater irrigation far beyond the threshold of economic and financial viability —as in Iran, Saudi Arabia, Mexico, much of western India (Shah 2023). Here the Vaux dictum breaks down. In this last category, output-side incentives combine with electricity (and other input) subsidies to drive farmers towards suboptimal hyper-intensification of input use in irrigated agriculture. Output-price incentives and input subsidies together create a venomous concoction resulting in a political gridlock that has proved hard to break. Punjab is amongst the most advanced examples of this gridlock.

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[3]https://www.downtoearth.org.in/news/water/punjab-is-a-bleak-example-of-india-s-groundwater-crisis-here-is-how-88479

[4]Sood, Aman (2023) Very High Density of Tubewells Leads to Fall in Water Tables, Tribune 7 December https://epaper.tribuneindia.com/c/74055130

[5]Based on Sarkar, Anandita. 2020, Groundwater irrigation and farm power policies in Punjab and West Bengal: Challenges and opportunities, Energy Policy 140(2020) 111437, but some figures updated with data from government sources.

[6]Ministry of Agricutlture and Farmers Welfare

[7]Central Groundwater Board

[8]Central Groundwater Board

2. Policy Antecedents

Over the recent decades, Punjab has become the showcase for the most pernicious environmental and fiscal impacts of energy-water-food nexus. Four policy-induced step-changes led Punjab to its precarious state today. Until the 1960's, Punjab depended largely on canals and diesel-driven tubewells for irrigating cotton, maize, wheat and other similar crops. It had few electric tubewells but these were metered and subject to consumption-linked tariff. The food crisis of the 1960's made it imperative to incentivise increased grain production for delivery to the Public Distribution System. It also made it urgent to accelerate tubewell irrigation in north-western India. The overhang of these persisted long after the food crisis was resolved and in time paved the way to the present impasse. In 1978, Government of Punjab (GoP) decided to do away with meters on irrigation pumps and began levying a flat tariff of Rs 50/HP/month for power consumed in irrigation. In 1984, the tubewell connection charge too was reduced to a token amount. This was the first step-change which made electricity the preferred energy source compared to increasingly costly diesel. What followed was a spurt in the number of electric tubewells, but the average pump size was kept in check.

In the years that followed, rising demand for electric tubewells also brought into bold relief the power of farm electricity pricing as a plaything of politicians in the electoral vote bank politics. In the run up to the 1997 assembly elections, much against expert advice, the chief ministerial aspirant promised free power for all farmers with less than 2 ha of farm holding. The candidate lost the election; but the winner made farm power supply free for all farmers. This gave a big impetus to not only new tubewell connections but also for replacing small pumps by larger pumps, resulting in tripling of connected load/ha of net sown area from 0.8/ha in 1997 to 2.5/ha in 2021.

The third step change during 2009-12 was the separation of agricultural feeders and day-and-night rostering of rationed farm power supply which led farmers to install increasingly large pumps to avoid night irrigation. Irrigation pump sets in the state increased 57 percent between 2000–01 and 2015–16; and at 3165 kWh/hectare, energy intensity of Punjab agriculture raced way ahead of other states (Central Electricity Authority 2023)[9] . Together, these four step changes made Punjab agriculture among the most energy-intensive among Indian states, and average electricity use in Punjab irrigation more than doubled during the first 20 years of the new millennium.

The policy of rice-wheat procurement at guaranteed prices further aggravated the environmental crisis in Punjab agriculture. During the 1960's decade of acute food scarcity, central government created Food Corporation (FCI) of India to buy food grains from farmers to create a buffer stock for the Public Distribution System. FCI procurement of rice and wheat at higher than global guaranteed prices crowded out cotton, maize, millets and other crops from Punjab agriculture and condemned Punjab—indeed all of north-west India—into a rice-wheat monoculture which further deepened the perverse after-effects of the nexus.

Thanks to this double whammy—of free farm power and guaranteed grain procurement at higher than global prices—Indian Punjab emerged as a groundwater governance basket case. Groundwater levels in central and many areas of north-east Punjab have been on a secular decline. The bulk of its excessive free energy use occurs during paddy season of June-October and is directly responsible for secular groundwater decline in 80 percent of Punjab's land mass, mostly in central and northern districts (Gulati, Roy and Hussein 2021)[10], leading to the prophesy that Punjab will run out of groundwater by around 2039 (Zumbish 2023)[11] unless something drastic were done to control the current rate of abstraction.

Punjab inherited substantial canal system which was expanded during early years after Independence. Punjab's canals were managed well and wetted large tracts. However, under free power regime, canal systems have gradually fallen into disuse, especially below the distributaries where the network of minors,

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[9]Gulati, A, R Roy and S Saini Revitalising Indian Agriculture and Doubling Farmers Income, Springer https://doi.org/10.1007/978-981-15-9335-

[10]Gulati, A, R Roy and S Hussein (2021) Performance of Agriculture in Punjab, in Gulati, A, R Roy and S Saini Revitalising Indian Agriculture and Doubling Farmers Income, Springer https://doi.org/10.1007/978-981-15-9335-

sub-minors and water courses have steadily deteriorated and abandoned. Many farmers within command areas have not seen canal water on their fields in decades. In contrast, far more canal water is sloshing around poorly drained soils of south-west Punjab, causing water logging and secondary salinization. It is an irony that on the one hand, Punjab continues depleting its groundwater; on the other hand, it is unable to utilise its full supply of canal water, allowing substantial portions to run away to Pakistan when it could be fruitfully used to replace and/or recharge groundwater.

There are other environmental impacts, besides of course the massive problem of crop residue burning and deteriorating winter air quality all over northern India. The intensification of groundwater use in paddy-wheat irrigation in Punjab has increased C footprint of irrigation. Back in 2012, when groundwater draft in Punjab was much lower than today, Kaur, Agarwal and Lal (2016) had estimated C emission at 55 g per m3 of groundwater used and 78 g per kg of grain produced. Paddy farming in Punjab is also environmentally problematic with its aggregate GHG emissions of 5 tonnes CO2 eq/ha, much higher than 3.1 tonnes CO2 eq/ha at All-India level (Singh, Thangraj,Juneja and Gulati 2024)[12] . Total GHG emissions from groundwater irrigation in Punjab has been estimated at 5.64 million tons of CO2-equivalent/year, 9 to 12.5 percent of India's total emission from groundwater pumping (Rajan, Ghosh and Shah 2020)[13].

That the groundwater crisis of Indian Punjab is a direct outcome of policies is signified by the fact that Pakistan Punjab which shares similar agro-climatic and hydro-geological setting has suffered far less severe groundwater depletion. Fig 1 reproduces the map of extreme groundwater depletion in north-west India based on GRACE satellite data produced by Rodell et al (2009)[14]. Between 2002 and 2008, Rajasthan, Punjab and Haryana depleted their groundwater resource by an astounding 109 km^3. But neighbouring Pakistan Punjab shows no sign of such runaway depletion. The most likely reason is that farmers in Pakistan Punjab, who depend mostly on diesel and costly electricity, are better able to economize on groundwater use and achieve better conjunctive management of ground and canal water in irrigation. For the same reasons, Pakistan Punjab's rice economy has a much lower Carbon foot print than Indian Punjab's: 80 percent of Pakistan's pumps are diesel pumps whose emission factor is 1/4th of that of electric pumps (Rajan et al 2020)[15] ; and because of high fuel cost, they pump less than Indian Punjab's electric pumps running on free power. Note also that Pakistan Punjab is as steeped into rice-wheat monoculture as Indian Punjab; and yet, its groundwater regime has remained more sustainable. Thanks to its suboptimal hyper-intensification, Indian Punjab is able to harvest 43-45 percent higher yield/ha of rice and wheat compared to Pakistan Punjab[16] but at an unacceptably high socio-ecological cost.

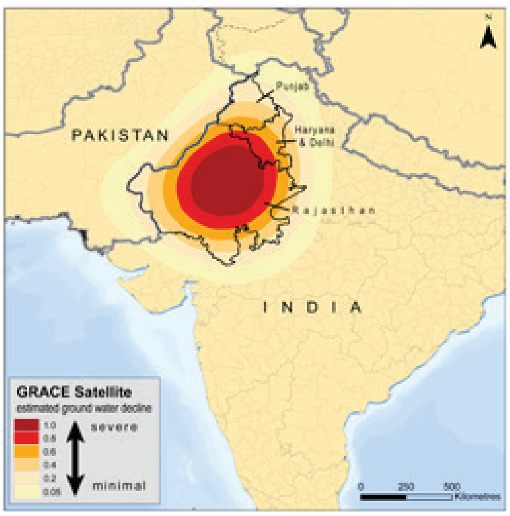


Figure 1 NASA's GRACE satellite map of groundwater depletion in north-west India

[11]Zumbish.2023. Punjab is a bleak example of India's groundwater crisis. Here is how, Down to Earth, March 7th. https://www.downtoearth.org.in/water/punjab-is-a-bleak-example-of-india-s-groundwater-crisis-here-is-how-88479#:~:text=In%20June%202022%2C%20a%20National,last%20for%20just%2017%20years.

[12]R Singh, P Thangraj, R Juneja, A Gulati 2024. Saving Punjab and Haryana from Ecological Disaster: Re-aligning Agri-Food Policies, New Delhi: ICRIER, Policy Brief 21.

[13]Rajan, A., Ghosh, K., & Shah, A. (2020). Carbon footprint of India's groundwater irrigation. Carbon Management, 11(3), 265–280. https://doi.org/10.1080/17583004.2020.1750265

[14]Matthew Rodell , Isabella Velicogna & James S. Famiglietti. 2009 Satellite-based estimates of groundwater depletion in India, Nature, Vol 460| 20 August 2009| doi:10.1038/nature08238

[115]Rajan, A., Ghosh, K., & Shah, A. (2020). Carbon footprint of India's groundwater irrigation. Carbon Management, 11(3), 265–280. https://doi.org/10.1080/17583004.2020.1750265

[16]In 2021, Indian Punjab harvested 6.3 mt/ ha of rice and 5.5 mt of wheat(Source: GoP). In comparison, Pakistan Punjab harvested 4.4 mt/ha of rice and 3.8 mt of wheat (Source: Pakistan Bureau of Statistics)

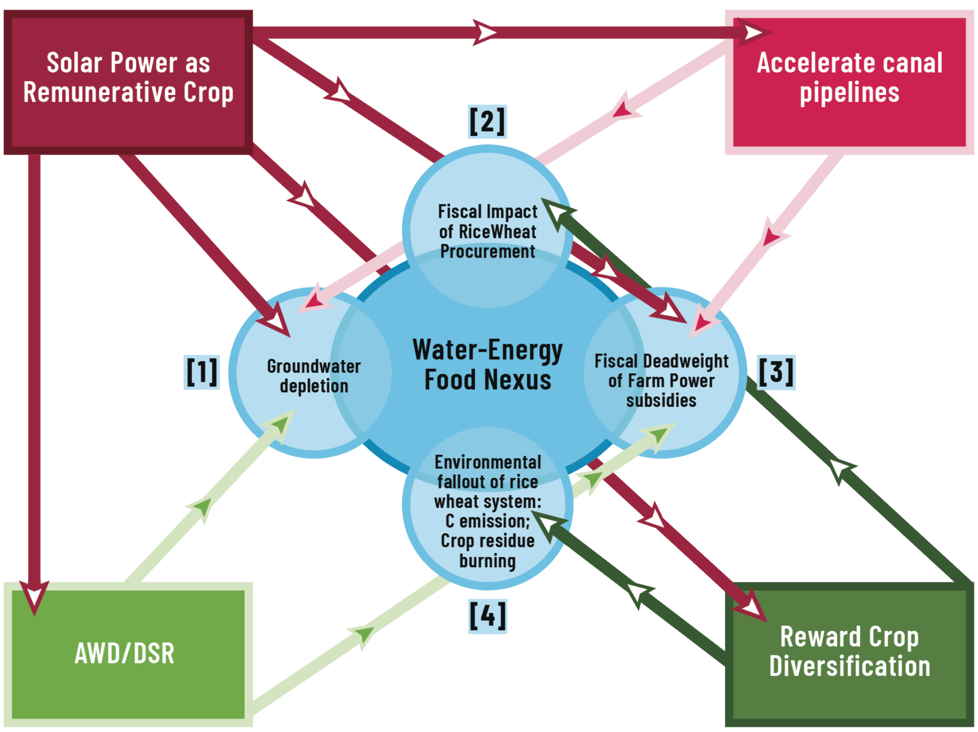
3. Practical Ways Out of the Nexus

Perverse impacts of the nexus in the context of north-west India are mainly 4 as shown in figure 2: [a] subsidy burden of guaranteed grain procurement at above global prices; [b] fiscal deadweight of farm power subsidy; [c] secular groundwater depletion; and [d] myriad environmental impacts of rice-wheat monoculture. Resolving the nexus is not so much a techno-economic or scientific but a political issue. In theory, the gridlock can be opened by reneging on policies—of free power and guaranteed grain procurement—that originally created the problem and continue to perpetuate it. However, no leader will invest political capital in a solution that farmers are unwilling to embrace. The practical challenge is then to find techno-economic and scientific solutions that pass political test. Two distinct clusters of solutions are on offer, one using the agronomy-diversification entry-point and another using water-energy-irrigation as entry-point.

AGRONOMIC/CROP DIVERSIFICATION SOLUTIONS:

Much emphasis has been placed on solutions that can wean Punjab farmers away from paddy cultivation by incentivising non-paddy crops. Haryana already has a scheme mera pani, meri virasat (my water, my heritage) under which the government pays Rs 7000/acre to farmers who grow kharif crops other than paddy[17]. Researchers believe that financial returns and freedom-from-risk of paddy cultivation would require larger payout to induce farmers to give up paddy. The Haryana scheme registered initially around 1.26 lakh acres but final physical verification showed that just around 5000 ha actually underwent crop change away from paddy[18]. A recent Indian Council for Reseach on International Economic Relations (ICRIER) policy brief (Singh, Thangraj, Juneja and Gulati 2024) recommends an "upfront Incentive of Rs. 30,000 - 40,000 per hectare for non-paddy farmers by re-purposing power

Fig 2 Practical Ways Out of the Nexus



[17]https://hwra.org.in/Gallery/pdf/Crop%20Diversification%20Programme%20%E2%80%93%20%E2%80%98Mera%20Pani%20Meri%20Virasat%E2%80%99.pdf

[18]Haryana's crop diversification drive figures are as diversified - Hindustan Times

subsidy (state) and fertilizer subsidy (centre) to alternate kharif crops." They surmise that this can shift 12-15 lakh ha away from paddy farming. However, if such a shift is achieved, it would directly reduce perverse impacts [2] and [4] in figure 2 and ameliorate [1] and [3].

Another clutch of solutions in this cluster, less hopeful about cropping shift away from paddy, propose water-saving paddy irrigation methods such a is Alternate Wetting and Drying (AWD) of rice paddies and Direct Seeding of Rice (DRS). The key premise is that large proportion of water used in paddy is a substitute for herbicides and weeding-labour both of which can be saved by adopting AWD and/or DSR without a significant yield penalty. Punjab gives farmers Rs 1500/acre for using DSR; yet, in 2023, only 1.73 lakh of Punjab's 79 lakh ha of paddy fields used DSR. Damodaran (2024)[19] has, however, argued that new rice and wheat varieties that can tolerate imazethapyr, a herbicide, can make DSR far more acceptable. These can open a revolutionary path to control weeds and grasses that compete with plants for nutrients, water and sunlight. According to Damodaran, imazethapyr-tolerant rice and wheat varieties/hybrids can revolutionise direct seeding of rice and zero-tillage wheat sowing resulting in much reduced water and fuel consumption, and much-reduced air pollution from crop residue burning. Devineni, Parveen and Lall (2022)[20] have argued that removing distortionary impacts of food procurement by changing the geography of cropping can reduce pressure on groundwater without removing electricity subsidies. However, experience of Iran and Saudi Arabia shows that removing output side incentives per se may not necessarily eliminate groundwater stress induced by free power. Both countries stopped buying wheat at higher than global prices; but there was no let-up in groundwater use as farmers replaced wheat by fruit trees which guzzled even more water as they grew (Shah 2023).

WATER-ENERGY-IRRIGATION SOLUTIONS:

These include policies that promote water-energy conservation behaviour as well as interventions that present alternatives to groundwater for irrigation. Government of India's World Bank supported Atal Bhujal Yojana operates on the premise that involving rural community in understanding, monitoring, planning groundwater resource promotes conservation behaviour. However, there is no evidence anywhere of sustainable behaviour change through such approaches (Shah 2023). Another proposal is to meter tubewells but levy a progressive electricity tariff which is low for small-scale users but increases as consumption per pump increases (Chowdhury and Torero 2009)[21]. The problem here is of practicality in overcoming farmer resistance to metering pumps. An alternative approach, arguably more practical, operates on the premise that if it is not possible to charge farmer to use energy and water responsibly, paying them to save energy and water would promote conservation behaviour. This approach has wider appeal in Payment for Ecosystem Services (PES) debate. In recent years, this approach has been tried in Punjab and elsewhere to mitigate perverse impacts of farm power subsidies. All these experiments have involved metering tubewells, prior determination of benchmark energy consumption and paying farmers for energy saving relative to the benchmark. An early experiment in north Gujarat failed to produce significant behaviour change because the incentive offered was too low (Fishman et al 2016). But a more recent and bigger one-year experiment in Saurashtra led to significant reduction (24 percent) in energy consumption among target farmers relative to a control group (Hagerty and Zucker 2024)[22]. A large, World Bank funded pilot called Pani Bachao, Paisa Kamao, faced challenges but evaluations showed that "cash incentives for unused electricity has the potential to incentivize farmers to reduce electricity consumption and irrigation hours by at least 7.5 percent and up to 30 percent without impacting paddy yields." (Mitra, Subramanyan and Brouwer 2022:861[23]).
Suryashakti Kisan Yojana (SKY), a large pilot project in Gujarat provided 4300 tubewell owners on 92

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[19]Damodaran, Harish 2024 How a new tech promises to kill weeds in rice and wheat fields, remove need for stubble-burning, New Delhi: Indian Express, August 5.

[20]Devineni, N., Perveen, S. & Lall, U. Solving groundwater depletion in India while achieving food security. Nat Commun 13, 3374 (2022). https://doi.org/10.1038/s41467-022-31122-9

[21]Chowdhury, S and Torero, M; (2009). Power and Irrigation Subsidies in Andhra Pradesh & Punjab. IFPRI, Washington.

[22]Nick Hagerty and Ariel Zucker 2024 Paying farmers for voluntary conservation can help solve the groundwater crisis, unpublished.

[23]Archisman Mitra, Soumya Balasubramanya, Roy Brouwer. 2022. Can cash incentives modify groundwater pumping behaviors?Evidence from an experiment in Punjab, Amer JAgrEcon.2023;105:861–887.

agricultural feeders grid-connected, net-metered solar panels and has been paying them Rs 3.50/unit of their net energy export since 2020. SKY thus promoted 'growing' Solar Power as Remunerative Crop (SPaRC). A recent study compared their consumption with tubewell owners on the same feeders who did not join the scheme. A confounding factor was the change in grid power hours on SKY feeders: SKY farmer are given 12 hours of daytime power year-round; but non-SKY farmers too get 8 hours of daytime power instead of a day-and-night weekly roster they were earlier subject to. The study found that non-SKY farmers used increased daytime power hours to increase their consumption/HP by 53 percent over 5 years (2020-24), while SKY farmers decreased their consumption by 13.5 percent despite 50 percent more daytime power hours. With 8 hours/day power ration, SKY farmers would have arguably reduced consumption much more (Shah, Choudhury, Rathod, Rai and Verma 2024[24]). This suggests that replacing grid powered tubewells by grid-connected solar pumps with guaranteed buy-back of unused solar power at remunerative price can promote conservation behaviour, encourage farmers to diversify to solar energy as a new crop whose financial returns are proportional to energy saved in pumping groundwater.

Another potentially powerful irrigation solution to the nexus is restoring canal irrigation to the preeminent status it enjoyed during the 1960's in Punjab. One reason Pakistan Punjab does not have as severe groundwater depletion as Indian Punjab is that the former have achieved better conjunctive management of surface and groundwater in paddy wheat irrigation at main canal, distribution system as well as farm level. Recent experience has shown that conjunctive management can get a big boost in Punjab by replacing last-mile open water courses by buried pipelines. These have many benefits: these minimise water loss during conveyance and do not need constant maintenance as earthen channels do particularly during early weeks of high weed intensity of paddy season; it releases land that is brought under cultivation; it facilitates conjunctive use of saline groundwater by mixing it with fresh water for providing lifesaving irrigation;[25] and above all it removes the head-tail inequity inherent in open channel distribution. Punjab took nearly 25 years to bring some 500,000 ha under buried canal pipelines; it needs to accelerate the pace to reduce pressure on groundwater. Replacing free-power tubewells by grid-connected solar pumps with power purchase guarantee will increase demand for and installation of buried canal pipelines.

Among the politically feasible solutions to unlock Punjab's energy-water-food nexus, the four we have explored are mutually reinforcing and are best implemented in a synchronized manner, with SPaRC taking the lead. Neutralising perverse effects of free power is the necessary conditions for all other interventions to deliver their full benefit. DSR and crop diversification may have potential to save water but under free power regime, neither DSR nor diversification are unlikely to deliver expected water savings. Likewise, under free power, farmer demand for canal pipelines and conjunctive management too will be lukewarm, especially where groundwater quality is acceptable. However, once farmers find energy-water conservation seriously profitable, getting them to adopt AWD, DSR, water saving crops and technologies, and conjunctive management of canal and groundwater would become much easier than has been the case under free grid power.

Acknowledgement

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[24] Shah, T, A. Choudhury, R Rathod, GP Rai, S Verma. 2024. "The case for grid-connected solar irrigation pumps: Evidence from Gujarat's Surya Shakti Kisan Yojana (SKY)". Economic and Political Weekly (under review).

[25] https://rkvy.nic.in/static/download/RKVY_Sucess_Story/Punjab/Sweet_Water_Ferried_by_Underground_Pipes_in_Haryanaand_Punjab.pdf

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