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Power tariffs for groundwater irrigation in India: A comparative analysis of the environmental, equity, and economic tradeoffs

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ABSTRACT

Groundwater irrigation using electric pumps plays a key role in India's agricultural water supply. Power utilities across different states use two common tariff modes to charge groundwater consumers: flat tariffs, where payments are fixed according to a pump's power rating, and metered tariffs based on units of power actually consumed. In this review, we use empirical evidence from past studies across multiple jurisdictions in India to compare the two tariff structures in terms of three key features: administrative burden on utilities; equity of groundwater access between high-income and low-income farmers; and influence on farmers' pumping behavior. Our analysis shows that flat tariffs have low administrative costs and more equitable distributional outcomes, but provide no incentive to farmers for water conservation. Conversely, metered tariffs have the potential to encourage judicious consumption, but are expensive to manage and disadvantageous to low-income farmers who often buy water from wealthier groundwater well owners. Flawed tariff policies, in conjunction with large subsidies for agricultural power, have caused rapid groundwater depletion in many regions as well as massive financial losses to power utilities and governments – both state and central. Since there is considerable heterogeneity in agricultural practices and groundwater availability across India, we propose location-specific strategies for rationalizing agricultural power tariffs in different regions. While the groundwater-abundant eastern regions can benefit from a hybrid flat-cum-metered tariff that encourages farmer-to-farmer water sales, western states facing unsustainable groundwater exploitation should develop tariff policies that ration power, prioritize its supply during the most critical seasons, and reward farmers who reduce their groundwater consumption. Not only will such tariff policies help conserve groundwater, but also augment government financial resources for social welfare programs such as education, health, energy access etc. Thus, improved power policies can provide substantial assistance in India's progress towards multiple UN Sustainable Development Goals.

1. Introduction

The 1960s witnessed the birth of the Green Revolution in India, a massive government-sponsored program that successfully increased national crop output through the use of high yielding crop varieties, agrochemicals (fertilizers and pesticides), and improved irrigation (Frankel, 2015). The country transformed into a net exporter of food crops due to rapid growths in crop yields; for instance, yields of wheat and rice increased 3.8-fold and 2.5-fold between 1961 and 2017 (FAOSTAT, 2018). A combination of subsidized inputs and government-assured procurement prices has made rice-wheat rotation the most prevalent cropping pattern in India (Scott & Sharma, 2009). This double cropping practice requires year-round access to water but most regions of India receive rain primarily during the Monsoon season. The success of India's Green Revolution, thus, is deeply intertwined with a rapid and widespread development of groundwater irrigation services across the country over the last few decades.

Currently, there are 20 million operational groundwater wells[1] in India; of these, more than 70% rely on electricity, 26% are diesel-powered, and the remainder depend on wind, solar, animal power and other energy sources (Prayas (Energy Group), 2018a). However, since pumps on the deepest tube wells (which require higher energy per unit water) are predominantly electric, 85% of the groundwater pumping energy is provided by electricity (Prayas (Energy Group),

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[1] Groundwater wells can be primarily divided into two categories: dug wells (an open hole excavated to a level below the groundwater table), and tube wells (a pipe driven into the earth to extract groundwater using a pump attached to the upper end). Unless otherwise specified, the term "wells" is used to collectively refer to dug wells and tube wells.

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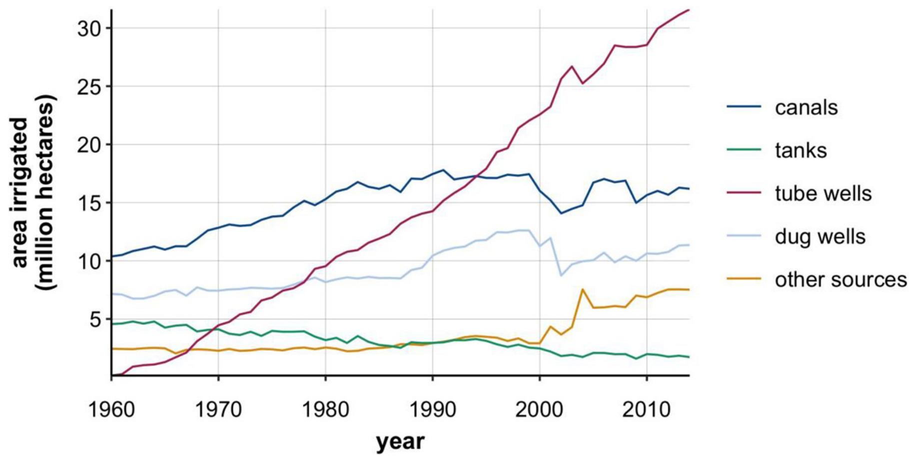

Fig. 1. Net irrigated area in India by source of water (1960–2014). Groundwater irrigation includes both tube wells and dug wells. Data acquired from Ministry of Agriculture & Farmers' Welfare (2018). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2018a). Hence, electricity pricing policies have serious consequences for India's agriculture sector.[2]

Agricultural power tariff policies in India are formulated by individual state governments, and can be broadly divided into two main categories: (a) flat tariffs, fixed according to the power rating of a farmer's groundwater pump, and (b) metered tariffs, based on the amount of electricity consumed. There have been numerous studies conducted across various jurisdictions of India that compare these tariff structures: they include studies based on empirical evidence from states that have shifted from one tariff structure to another in the past (Mukherji & Das, 2014), as well as studies contrasting behavior of flat-tariffed and metered farmers in states where both tariff structures co-exist (Kishore & Verma, 2004; Shah & Chowdhury, 2017). However, the results and findings from these studies are context-dependent and their inferences are not directly transferable to other states. In addition, most studies focus on a single aspect of the relationship between power tariffs and groundwater irrigation, such as cost of supplying power, ease of groundwater access, or the impact on groundwater overexploitation. However, the overall relationship between tariffs and groundwater irrigation is multilayered and has not been fully explored in the literature. This is the gap that we aim to address. In this work, we conduct a review of past studies of flat and metered tariffs across multiple jurisdictions (to account for variation across jurisdictions and natural resource regimes) in order to examine the administrative burden of flat and metered systems on electricity utilities, equity between high-income and low-income farmers in both systems, and the capacity of tariffs to promote groundwater conservation by influencing farmers' pumping behavior.

In terms of the structure, this paper begins with a description of the historical evolution of groundwater irrigation and agricultural electricity pricing trends. We then compare flat and metered tariff structures in terms of their administrative, social, and environmental impacts. This comparison is complemented by a discussion of the large subsidies for agricultural power in India that affect the functioning of these tariff structures. This is followed by an evidence-based assessment on the design of the most appropriate tariff structures for achieving a balance between economic feasibility, farmer welfare, and groundwater sustainability. We end with a discussion on the role of improved agricultural power tariffs in helping India meet multiple Sustainable Development Goals.

2. Historical evolution of groundwater irrigation and the associated electricity demand

In early years following independence in 1947, irrigation in India predominantly comprised of canal irrigation from rivers and large dam reservoirs (Shankar, Kulkarni, & Krishnan, 2011). However, these could only service agricultural land in the command area of the water sources. Groundwater offered an edge because it could be tapped where needed, was not dependent on the slow bureaucratic machinery for infrastructure development, and was more reliable during droughts when surface water reservoirs dried up (Smilovic, Gleeson, & Siebert, 2015). To make groundwater irrigation affordable and lucrative for farmers, the government initially established public tube wells which brought piped groundwater to fields (Shah, Burke, & Villholth, 2007). Although these services were highly subsidized, they failed to produce the desired increase in groundwater irrigated area (Shah, Giordano, & Mukherji, 2012). As installation costs dropped, farmers began digging private tube wells in their own fields. Governments, both at the central and state levels, subsidized the cost of establishing power supply networks to provide electricity to these tube wells. Public sector banks provided farmers with easy credit for covering the initial cost of drilling tube wells and buying equipment (Chakravarti, 1973). The World Bank funded rural electrification projects to stimulate agricultural growth, and power subsidies were provided to encourage groundwater irrigation. In states like Punjab and Uttar Pradesh, governments set steep targets for district-level officials to sell electricity to farmers. Some researchers attribute the success of the country's Green Revolution to these policies and the groundwater use they encouraged; indeed, the Green Revolution lagged a tube well revolution by 3–5 years (Shah, Scott, Kishore, & Sharma, 2004).

Pro-groundwater policies resulted in a marked and widespread transition from public surface irrigation facilities to privately-owned groundwater extraction systems (Fig. 1). India is the largest user of groundwater in the world today, accounting for 37% of the global consumptive use of groundwater in agriculture (Siebert et al., 2010). The importance of groundwater for national food self-sufficiency is underscored by the fact that groundwater irrigation produces 49% of rice and 72% of wheat in the country (Smilovic et al., 2015).

[2] Multiple studies have stated that groundwater irrigation accounts for almost all electricity consumption designated as "agricultural" by the Ministry of Power or Ministry of Agriculture and Farmers' Welfare (Barik et al., 2017; Birner et al., 2011; Scott & Shah, 2004). Hence, we use the terms "agricultural electricity/power consumption" and "electricity/power for pumping groundwater" synonymously.

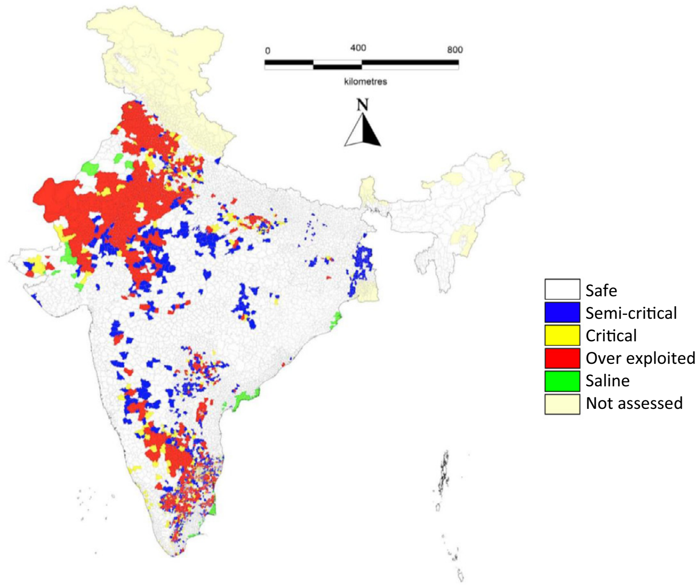

Fig. 2. Categories of groundwater assessment units in India according to the level of exploitation (as on March 31, 2013). Categories are based on Central Ground Water Board of India's specifications shown in Table S1. Figure reproduced from Central Ground Water Board (2017). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The benefits of groundwater are not limited to well owners alone; many regions in India are home to active water markets: localized institutions involving transactions between individual groundwater well owners and multiple water buyers. The high initial cost of groundwater extraction equipment is a deterrent for small-scale farmers to setup their own tube wells, and water markets are an effective way for them to access groundwater irrigation (Manjunatha, Speelman, Chandrakanth, & Van Huylenbroeck, 2011). These markets have been instrumental in rapidly spreading irrigation to more farmed areas than the public surface irrigation systems could ever reach (Shah & Chowdhury, 2017; Smilovic et al., 2015). Groundwater irrigation has thus brought economic prosperity to millions of financially disadvantaged households of India, especially in regions with insufficient surface irrigation facilities. From their analysis covering 14 major states in India, Narayanamoorthy (2007) observed a significant inverse relationship between groundwater irrigation and rural poverty.

The excessive dependence on groundwater, however, comes at a high environmental cost. Currently, 839 out of 5723 blocks (groundwater observation units) in India are overexploited, i.e. annual groundwater extraction exceeds natural recharge (Central Ground Water Board, 2017). While this translates to just over 14% blocks in the overexploited category, most of these areas are concentrated in two regions (Fig. 2). In the northwestern states of Punjab and Haryana, an epicenter of the Green Revolution, groundwater use exceeds natural recharge by 49% and 35%, respectively (Central Ground Water Board, 2017). Multiple studies, using both satellite (Barik, Ghosh, Sahana, Pathak, & Sekhar, 2017; Rodell, Velicogna, & Famiglietti, 2009; Tiwari, Wahr, & Swenson, 2009) and local groundwater well observation data (Asoka, Gleeson, Wada, & Mishra, 2017), have reported this agricultural region to be a global hotspot of groundwater depletion.

The proliferation of groundwater extraction devices has played havoc with the country's electricity supply. Estimates suggest that there are currently 14–15 million electricity-operated wells in India (Fishman, Lall, Modi, & Parekh, 2016; Ministry of Water Resources, 2017). Starting from just 6% in 1960, Indian agriculture today accounts for 18% of national electricity consumption (down from a peak of 31% in 1998[3]); this is depicted in the pie charts in Fig. 3. The equivalent figure is less than three percent in other major agricultural countries such as the USA, China, Russia, and Germany (Central Electricity Authority, 2017). Even in absolute terms of net agricultural electricity consumption, India consistently outranks the next two countries (China and USA) combined (Central Electricity Authority, 2017). Nearly all of India's agricultural electricity use can be attributed to groundwater pumping (Barik et al., 2017; Birner, Gupta, & Sharma, 2011; Scott & Shah, 2004). It increased by 235 times (0.8 to 195.5 tera watthour (TWh)) over the 1960–2016 period, compared to a 77-fold increase (13.8–1066.3 TWh) in total electricity use (Indian Council of Agricultural Research, 2018). This trend is shown in Fig. 3.

The excessive and unsustainable groundwater use and electricity consumption has further implications for rural livelihood and food security as India braces for the predicted impacts of climate change on its food systems in the near future. The repercussions are expected to be more drastic for farmers who have no access to irrigation: The Economic Survey of India 2018 (Ministry of Finance, 2018) predicts future declines in crop yields due to extreme temperature and drought events to be more severe in rainfed areas (7.3 and 11.7 percent, respectively) compared to irrigated areas (2.9 and 5.2 percent, respectively). The Government of India continues to encourage and invest in the expansion of irrigation facilities to currently rainfed regions, most recently as a part of its flagship irrigation scheme called *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) which has set an ambitious target of increasing net irrigated crop area from the current level of 45% to 100% (Ministry of Water Resources, 2017). Groundwater irrigation will play a key role in this endeavor, leading to an increased burden on the already strained groundwater and electricity systems. In other words,

[3] The decrease in agriculture's share of total electricity consumption in the last two decades has been driven primarily by a rapid rise in industrial demand, as shown in Figure 3. Meanwhile, the actual agricultural electricity demand continues to rise.

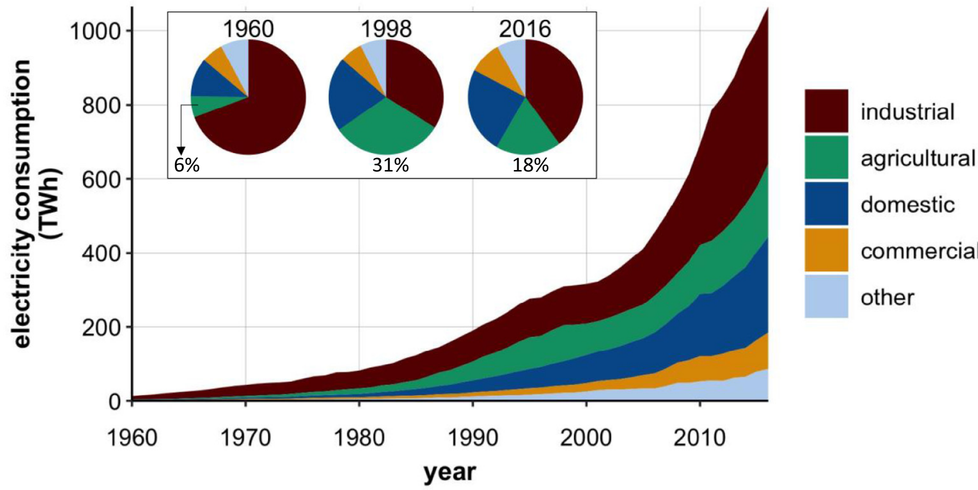

Fig. 3. Sector-wise annual electricity consumption (in tera watthour (TWh)) in India (1960–2016). Pie charts depict the proportional share of agriculture in three separate years: 1960 (before the Green Revolution), 1998 (when agriculture's share peaked), 2016 (most recent data). Data acquired from Indian Council of Agricultural Research (2018). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

climate change adaptation adds another layer of stress on the already limited groundwater resources.

Apart from the direct environmental impact of groundwater depletion, India's groundwater consumption has an indirect impact in the form of greenhouse gas and air pollutant emissions from electricity production too, since electricity accounts for 85% of the groundwater pumping energy in India (Prayas (Energy Group), 2018a). Mishra, Asoka, Vatta, and Lall (2018) found that generation of electricity used for groundwater irrigation contributes 2–7% (variable due to uncertainty in electricity production emission factors) of the total CO_2 emissions from India. Exposure to fine particulate matter from coal-fired power plants, which produce over half of India's electricity (Central Electricity Authority, 2019), is responsible for roughly 85,000 deaths nationally every year (GBD MAPS Working Group, 2018). Groundwater irrigation accounts for 18% of the national electricity consumption (Central Electricity Authority, 2017), which translates to approximately 15,000 deaths per year, making groundwater extraction an important cause of air pollution related mortality in India.

3. Historical evolution of agricultural power tariffs

When groundwater irrigation first started expanding in the early 1960s, the largely state-run electricity utilities charged farmers based on their metered consumption. However, as the number of tube wells increased rapidly, utilities found it hard to monitor individual consumption (Mukherji et al., 2009). In other major groundwater consuming countries, like the USA or Mexico, monitoring individual connections is possible because the tube wells are larger but fewer: these countries have 200,000 and 100,000 wells respectively (Scott & Shah, 2004), compared to the 14–15 million electricity-operated wells in India (Fishman et al., 2016; Ministry of Water Resources, 2017). This, combined with the fact that irrigation pumps in India are distributed over a wide area in remote villages, means that manual meter reading of groundwater wells is a costly activity for utilities. For example, in the 1980s, more than 30% of the cost of supplying power to farmers in the states of Uttar Pradesh and Maharashtra consisted of metering and monitoring costs alone (Shah, 1993). There were also issues of meter tampering, farmers colluding with meter readers to underreport consumption, and power theft through illegal connections which bypassed meters (Shah et al., 2004). Power utilities saw a solution in the form of flat tariffs wherein farmers were charged fixed monthly fees based on the power rating of their pumps. In the late 1970s, the first states to adopt flat rates were Tamil Nadu, Andhra Pradesh, and Maharashtra, and others soon followed (Shah et al., 2004); by the mid-1990s most states had shifted to flat tariffs (Scott & Sharma, 2009).

Initially seen as a solution to the difficulties of collecting revenues, flat tariffs have been consistently held responsible for India's groundwater depletion problem. The national government is under constant pressure from international agencies such as the World Bank and Asian Development Bank to shift to a metered power supply for groundwater irrigation (Mukherjee, Dhingra, & Sengupta, 2017). The Indian Electricity Act, passed in 2003, calls for a nationwide return to metering all electricity consumers (Birner et al., 2011). The act remains largely unenforced as most attempts at metering wells have been unsuccessful because of strong opposition from farmers' unions: this has been witnessed repeatedly in Punjab (Birner et al., 2011), and in Karnataka in 2003 when farmers burnt electricity meters to express their displeasure at metering schemes (Mukherji & Das, 2014). In 2013, the states of Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Punjab, Rajasthan, Tamil Nadu, and Uttar Pradesh (together accounting for 97% of the national agricultural electricity consumption) had meters installed on only 27% of the agricultural electricity connections (Prayas (Energy Group), 2018a). Currently, West Bengal in eastern India is the only state supplying metered electricity to all groundwater consumers (Chatterjee, 2018; Mukherji & Das, 2014).

The other prominent feature of agricultural power tariffs in India is the prevalence of large subsidies. States in India have the autonomy to formulate groundwater policy, which aligns well with the incentives of state legislators who often indulge in politics of appeasement (Palit & Bandyopadhyay, 2017) and heap subsidies on electricity supplied to farmers. Some states like Karnataka, Punjab, Tamil Nadu, and Andhra Pradesh have gone a step further by providing free power to agricultural consumers (Prayas (Energy Group), 2018a). Agricultural electricity subsidies have certainly achieved their intended objectives of improving crop yields through irrigation and supporting millions of farmers (not least through buyer-friendly water markets), but they have also caused substantial societal losses by incentivizing farmers to invest heavily in deeper wells (Sayre & Taraz, 2018). Annual subsidies for agricultural power have increased rapidly over the past years, from 156 billion INR (4.4 billion nominal USD) in 1996 (Planning Commission, 2001) to 670 billion INR (11.4 billion nominal USD) in 2013 (Planning Commission, 2014). These subsidies are among the biggest financial drains on the exchequer in India (Tongia, 2003), and the revenue lost from the electricity sector amounts to a quarter of the national fiscal deficit (Bassi, 2014). In 2002, agricultural power subsidies were more than double the national expenditure on health or rural development (Badiani & Jessoe, 2013).

The burden of these subsidies is borne collectively by the state governments, the power utilities (which are mostly state-run), and other consumer sectors[4] (Prayas (Energy Group), 2018a). Unfortunately, payments from state governments to the utilities are often delayed, and at times not paid in full; simultaneously, the portion of the subsidies borne by the power utilities too counts as a substantial loss on their balance sheets. For example, power utilities in the state of Tamil Nadu absorbed almost 50% of the state's agricultural subsidy (66 billion INR, or 1.1 billion nominal USD) in 2013 (Prayas (Energy Group), 2018a). Most states' power departments operate under losses and depend on multiple financial bailouts from the governments: they received 400 billion INR (8.5 billion nominal USD) in 2001, and 1.9 trillion INR (35.6 billion nominal USD) in 2012 (Khurana & Banerjee, 2015). By 2015, the utilities had again accumulated a debt of 4.3 trillion INR (67 billion nominal USD) and the national government was forced to intervene with the *Ujjwal DISCOM Assurance Yojana* (UDAY) financial scheme which allowed state governments to take over a part of the utility debts and pay back lenders by selling bonds (Keeley & Keeley, 2016). Shah et al. (2004) described the perverse nature of agricultural power subsidies as a situation where "the region's groundwater economy has boomed by bleeding the energy economy" (p. v).

The perilous financial state of the utilities has led to a deterioration in their investment capabilities to maintain infrastructure and to add power generation capacity (Shah et al., 2012). Consequently, the quality of power, both in terms of the number of hours and the stability of supply, has deteriorated over time. In major agricultural states like Punjab, Haryana, Tamil Nadu, Gujarat, and Andhra Pradesh, farmers received 18–20 h of daily power supply in the 1980s; now they have to sustain their crops with 6–10 h of power per day (Mukherji et al., 2009). Their pumps are also frequently damaged due to power interruptions, fluctuating voltage, and phase imbalances (Gulati & Pahuja, 2015). Some leave their land fallow when the power supply is not adequate to meet their crops' minimum irrigation requirements (Mukherji & Das, 2014). Willingness-to-pay studies conducted in Haryana and Andhra Pradesh show that some farmers, if provided with uninterrupted and good quality power supply, are ready to forego subsidies and pay higher tariffs at par with other commercial users (Shah et al., 2012).

The other important characteristic of power subsidies is that they are seldom targeted to a specific economic class, making the subsidy distribution system prone to inequity: wealthy farmers with comparatively larger tracts of land are usually the biggest beneficiaries (Jain, 2006). To start with, the high initial technology cost is a big deterrent for low-income farmers to setup their own tube wells and access subsidy benefits. For instance, Howes and Murgai (2003) found that in the state of Karnataka, farmers owning more than two hectares (comprising just 11 percent of the rural population) accrue 80 percent of the subsidy benefits. This distortion in pump ownership can even increase the wealth gap, as witnessed by Sarkar (2012) in a water-scarce village in Punjab; tube well owners there had negligible operating cost (farmers receive free power in Punjab) while the water buyers had to contend with 50% of their input cost going towards water purchase alone. Even among the pump owners, irrigation cost is not immune to economies of scale and Srivastava et al. (2017) found that for marginal farmers (owning less than one hectare), the cost of irrigation per unit of land can be three times higher than that for large farmers (owning more than 10 ha). In the state of Andhra Pradesh, almost 75% of all subsidy is appropriated by large farmers, while the marginal and small (owning 1–2 ha) farmers' share is 5% (Kumar, Scott, & Singh, 2013).

4. Comparative analysis of flat and metered tariffs

Electricity provides 85 percent of agricultural groundwater pumping energy in India (Prayas (Energy Group), 2018a), hence power tariff structures have important consequences for the groundwater irrigation sector. In this section, we compare flat and metered tariffs in terms of their administrative characteristics, equity between high-income and low-income groundwater consumers, and influence on farmers' pumping behavior to promote groundwater conservation. Our findings are summarized in Table 1.

4.1. Influence on electricity administration

The nationwide shift to flat tariffs in the 1980s and 1990s was carried out to overcome drawbacks of the metered systems: high cost of monitoring individual consumers, meter tampering, collusion between farmers and meter readers, and rampant power theft through illegal connections (Shah et al., 2004). Flat tariffs, since they require no regular monitoring and provide little incentive for pilferage, are more attractive for power utilities than metered tariffs. Although farmers can underreport pump capacity, such instances are easier to manage than power theft from metered consumers (Shah et al., 2004).

However, the more serious administrative complexities in flat tariff setups originate on the supply side. In India, flat tariffs operate with little to no energy accounting. There is a scarcity of dependable data for the number of electric pumps (Prayas (Energy Group), 2018b), and flat-rate systems have no reliable accounting mechanism for accurately quantifying agricultural power consumption. In such a scenario, some power utilities overreport the amount of electricity provided to farmers, both to appear efficient by hiding their transmission & distribution losses under the garb of agricultural power supply (Sant & Dixit, 1996), and to collect higher subsidy compensations from the state governments. Manipulation of data by utilities is often blatant; for instance, in 2002 Karnataka state's Electricity Regulatory Commission observed discrepancies in the number of electric pumps reported by different departments of the same electricity utility (Rawat & Mukherji, 2014). Shah (2001) notes that agricultural power use in the state of Uttar Pradesh was 35% lower than reported during their period of analysis. Similarly, Shah et al. (2004) report that the technical and pilferage losses in Haryana were 10% higher than the official claim of 37% which might have been made to appear more efficient in the official reports. There

[4] Power utilities are allowed to recover a part of the losses incurred from supplying subsidized agricultural power by charging other consumers (domestic and industrial) higher tariffs than the cost of supply (Prayas (Energy Group), 2018b).

Table 1
Summary of the comparative analysis between flat and metered tariffs in terms of their impact on electricity administration, livelihood of small and marginal farmers, and farmers' pumping behavior. Bold, regular, and italicized text denotes positive, mixed, and negative influence, respectively.

Influence on	Flat tariffs	Metered tariffs
Electricity administration	**No metering or regular monitoring cost since farmers operate unmetered pumps and pay fixed tariffs (Shah et al., 2004).**	*High cost of metering and regular monitoring of millions of electric pumps distributed over a wide area (Shah et al., 2004).*
	No incentive to farmers for pilferage or underreporting of consumption (Shah et al., 2004)	*Prone to power theft, and erroneous reporting through collusion between farmers and meter readers (Shah et al., 2004)*
	Utilities can overreport agricultural power consumption to hide transmission losses and collect higher subsidy compensations from the government (Prayas (Energy Group), 2018a; Sant & Dixit, 1996).	**Regular collection of comparatively reliable power consumption data, although it is still vulnerable to inaccuracies arising from pilferage and erroneous reporting by meter readers (Prayas (Energy Group), 2018b).**
Livelihood of small and marginal farmers	**Due to a fixed monthly cost, tube well owners try to sell water to as many customers as possible. This competition creates buyers' water markets where poor farmers benefit from low-priced groundwater (Shah et al., 2017a).**	*As tube well owners are under no obligation of a fixed cost to be covered through water sales, water markets operate as sellers' markets and the price of water is higher (Mukherji et al., 2009; Shah & Chowdhury, 2017; Shah & Verma, 2008).*
Farmers' pumping behavior	*Farmers have no incentive to consume groundwater judiciously (Scott & Shah, 2004). When supply is irregular or discontinuous, they sometimes keep their pumps running continuously (Sarkar, 2012).*	Capacity to promote groundwater conservation depends on a region's social, agricultural, and economic conditions. For example, metered farmers in Gujarat consume less groundwater than their flat-rated peers in some areas (Kumar et al., 2011), while no significant difference observed in other regions (Kishore & Verma, 2004).

are also cases of negative distribution losses reported by power utilities in Punjab and Maharashtra, wherein utilities' claims about power consumed by end users were found to be higher than the power input into the grid at the central distribution nodes (Prayas (Energy Group), 2018a). Consequently, from a policymakers' perspective, unmetered connections translate to lack of reliable power consumption data for establishing subsidies, allocating funds in annual budgets, and policing the utilities to improve their transmission efficiency (Sarkar & Das, 2014).

4.2. Influence on the livelihood of small and marginal farmers

The primary benefit of pump irrigation economy in India is in supporting the livelihood of millions of financially disadvantaged farmers (Shah et al., 2004). The 19–20 million wells in India (Ministry of Water Resources, 2017; Scott & Shah, 2004) are a source of irrigation for 90 million rural households (Zaveri et al., 2016). This has been made possible through the widespread proliferation of informal groundwater markets throughout the country. Twenty million hectares are currently irrigated through these water sales from groundwater well owners to farmers with no wells of their own (Mukherji, 2008). The transaction has symbiotic benefits: a buyer who might otherwise not be able to access groundwater, receives irrigation facilities, while a seller is able to offset their expenditure on electricity and sometimes make a profit. Water markets are especially important for the livelihood of socially marginalized sections in India, as was illustrated by Anderson (2011). They found that lower caste water buyers in villages where the majority of the land belongs to lower caste households have better access to irrigation, and consequentially 45 percent higher yields, compared to lower caste buyers residing in villages where landholders are predominantly upper caste and therefore less likely to sell water to the lower caste farmers.

States like Gujarat and West Bengal have historically had well-functioning water markets, and as local energy policies have evolved over the past couple of decades, the link between tariffs and water markets has been extensively studied. Till 2003, well owners in Gujarat had unrestricted access to long hours of power supply, which encouraged them to aggressively sell water (Shah & Verma, 2008). Competition among sellers created a buyers' market which greatly benefitted the low-income farmers. However, excessive agricultural demand adversely affected rural households which shared power lines with the farmers[5]. The state government responded in 2003 with a program called the *Jyotigram Yojana* (JGY) which put all groundwater wells on separate feeders with rationed supply while rural residents got a dedicated 24-hour power line (Shah, Bhatt, Shah, & Talati, 2008). For farmers, JGY mandated a daily supply of eight hours for existing flat-rate pumps, and metering of all new connections (Shah & Verma, 2008). As flat-tariff well owners had their pumping hours reduced, and metered farmers were under no obligation of a fixed cost to be covered through water sales, there was an immediate rise in water prices for marginal and tenant farmers. Literature-reported increases in water rates post-JGY vary from 30 to 85% across the state (Shah & Chowdhury, 2017; Shah & Verma, 2008). Overall, the average area of buyers' land served by groundwater decreased by 40%, while there was no significant effect on well owners (Shah & Chowdhury, 2017). The authors also reported instances of former water buyers leasing out their land to well owners due to increased water prices. Hence, the brunt of the economic impact of rationed power supply and metering of new connections is being borne by marginal and small farmers who depend primarily on water markets for irrigation.

West Bengal presents a similar relationship between agricultural tariffs and water markets. Until 2008, the state charged its farmers commercial-level flat rates for electricity (Mukherji, 2007). Unlike their counterparts in all other major agricultural states of India, West Bengal's farmers received no subsidy on their power consumption (Chatterjee, 2018), and fixed monthly fees constituted a major expense for well owners. To cover high fixed monthly charges, water sellers engaged in a strong competition to transact with as many buyers as possible (Shah, Chowdhury, & Shah, 2017a). This led to the development of a buyers' water market, wherein low-income farmers benefited from cheap and reliable irrigation services. High flat tariffs were thus a blessing for them as they were able to negotiate and bargain with water sellers.

[5] Pre-2003, Gujarat's agricultural and domestic consumers shared the same power lines, and power utilities relied on a system of virtual segregation: they supplied three-phase power (required to operate groundwater pumps) for a limited number of hours per day, and single-phase power for the remainder which only ran domestic appliances (T. Shah & Chowdhury, 2017). As farmers' electricity demand rose over time, utilities were forced to reduce agricultural supply hours. Farmers circumvented this rationing by using illegal splitting capacitors which ran irrigation pumps off the 24-hour single-phase domestic supply. Tube wells now operated continuously while households suffered from outages and voltage drops. Physical feeder separation was thus a cornerstone of the Jyotigram Yojana.

Water markets were so pervasive in West Bengal that a survey of 17 districts found that 92% of rural households engaged in water markets as either a buyer, a seller, or both (Mukherji, 2007). Water buyers accounted for 77% of the groundwater used and 69% of area irrigated using wells (Shah et al., 2017a). Unlike in western and northwestern India, widespread use of groundwater was not an environmental concern since West Bengal annually taps less than 40% of its naturally replenished groundwater resources (Shah et al., 2017a). Hence, flat tariffs in West Bengal, in combination with active water markets, resulted in significant benefits trickling down to the marginal and landless farmers (Mukherji, 2008).

Groundwater well owners believed that flat tariffs were too high and successfully lobbied the government to shift to metered tariffs in 2008 (Shah & Chowdhury, 2017). Pump owners were now under no obligation to maximize groundwater extraction because they paid for only the amount of power they consumed. The market transformed into a sellers' market, and water prices increased by 30–50% in just one year (Mukherji et al., 2009). The sellers also set stricter conditions on transactions such as payment in advance or delivery during irregular hours. This resulted in a decrease in area under summer rice cultivation within a year of the shift in tariffs (Mukherji et al., 2009). Shah and Chowdhury (2017) report an even more alarming trend, that of pump owners forcefully leasing land from buyers during the summer season in exchange for providing water during the other, less profitable, seasons. Pump owners could now realize up to seven times higher profits by cultivating the water buyer's land during the summer months, than by selling them water in that season (Shah et al., 2017a). Metered tariffs have effectively made ownership of electricity-powered wells a more important wealth creator than land ownership in West Bengal (Shah & Chowdhury, 2017).

To summarize, access to groundwater from water markets is most equitable under a flat tariff scheme with minimum rationing of power, in water-abundant regions where there are functioning markets unhindered by caste and other social barriers. A shift towards stricter rationing and metered tariffs increases the burden on under-served households more heavily compared to high-income households. First, when flat-rated power is rationed, the reduction in hours of supply hurts the small farmers disproportionately because pump owners only sell water once their own demand is met. This has been observed both in Punjab (Sarkar, 2012) and Gujarat (Shah et al., 2008). Second, when states shift from flat to metered supply, evidence from West Bengal suggests that it hurts the marginal water buyers the most who are forced to pay higher water prices, or lease out their land during a part of the year, or even exit agriculture.

While flat tariffs are preferable from a water buyer's point of view, the economic implications of flat and metered tariffs for tube well owning farmers are more complex. Since different states have different subsidy structures for their farmers, comparison of flat and metered tariffs in terms of their economic equity is contingent on the actual price that farmers pay for subsidized power. For example, the state of Punjab shifted from metered to flat tariffs at highly subsidized rates in 1996 (Scott & Sharma, 2009), and started providing free power to farmers a year later (Singh, 2012). Hence, flat tariffs (with 100% subsidy) have obvious economic advantages over metered consumption for well owners in this state. Similarly, after the implementation of the JGY program in Gujarat, all new connections are metered and pay INR 0.77 per kilowatt hour (kWh), which is higher than the INR 0.66 per kWh tariff paid by flat-rated tube well owners (Shah & Chowdhury, 2017). However, in the state of West Bengal, where tube well owners have historically paid commercial rates for power with very low subsidies from the government, a shift from flat to metered tariffs led to an immediate reduction of up to 45% in their electricity bills (Mukherji & Das, 2014). Thus, the economic ramifications of flat versus metered tariffs on tube well owners are dependent on the level of subsidies provided by the state governments to both types of consumers.

4.3. Influence on farmers' pumping behavior

Groundwater irrigation, as discussed earlier, has caused unsustainable depletion of aquifers in many regions of India. The electricity tariff policies, by influencing farmer behavior, can be used as an effective tool for groundwater conservation and sustainable consumption. Here we present empirical evidence for the influence of flat and metered tariffs on efficiency and trends of agricultural groundwater consumption in different parts of the country.

Farmers paying flat charges face no marginal cost of pumping groundwater (Scott & Shah, 2004). As a result, flat-tariffed regions have witnessed rapid groundwater depletion and wasteful power consumption in agriculture. For example, Sarkar and Das (2014) report that while electricity consumption per unit of land area has increased in Punjab[6] (where farmers receive free power), food production per unit of electricity consumed has fallen over time. Rice crop needs to be irrigated approximately 20 times over a season, so some farmers err on the side of caution and keep their pumps running continuously during the sowing days to keep fields inundated (Sarkar, 2012). This tendency to overirrigate is reinforced when power supply is discontinuous (rationed number of hours per day) and fraught with unannounced interruptions; since farmers are unsure of when power will be available next, they tend to pump as much water as possible, leading to lower water productivity (Kumar, Scott, & Singh, 2011). Flat tariffs thus lead to wasteful consumption of finite groundwater and electricity resources.

The impact of metered tariffs on farmers' groundwater pumping behavior is more complex. Their capacity to promote groundwater conservation depends on the social, agricultural, and economic circumstances of the region. Opinions are divided on this issue, so we present arguments and accompanying evidence from both positions. Irrigation generally constitutes a small portion of the cost of cultivation, while considerably reducing the risk of crop failure (Narayanamoorthy, 1997; Scott & Shah, 2004). This behavior is amplified among farmers that receive power at highly subsidized rates, and therefore, transfer a major portion of the cost to the exchequer. Hence, farmers do not always respond to change in tariff structures. De Fraiture and Perry (2002) argue that the energy costs at which demand becomes elastic to pricing are too high to be socioeconomically and politically feasible, so metered tariffs at the currently subsidized levels do not incentivize water conservation. Evidence for this was reported by Kishore and Verma (2004) who compared the pumping behavior of 51 metered and 32 unmetered pump owners in Anand (Gujarat) and found no statistically significant difference. The authors believe this was due to the presence of well-established water markets in which the cost of power charged under the metered system was more than compensated by the high price received from water buyers. Saleth (1997) posits that as long as the marginal profits from pumping water are greater than its cost for the farmer, the latter will continue to consume groundwater. In other words, for metered tariffs to be successful in controlling groundwater draft, the price has to be set at such a level that the marginal cost becomes higher than the marginal return. Some researchers also believe that current metered power prices (with the subsidies) are far below that threshold and so, the demand displays little to no response to price variation (Scott & Shah, 2004). Hence, subsidies can reduce the capacity of

[6] The state provided extensive power subsidies in the form of low flat power tariffs till 1997, and free electricity to all farmers thereafter (Singh, 2012). Punjab currently leads all states in terms of proportion of groundwater blocks in the overexploited category (Central Ground Water Board, 2017).

metering to encourage groundwater conservation among farmers who historically paid flat rates. A shift to metered supply has to occur with a simultaneous withdrawal of subsidies in such cases.

On the other hand, some studies have observed evidence of farmers reacting to changes in tariff structure. Studying farmer behavior in Gujarat, Kumar et al. (2011) found that farmers with metered connections not only irrigate to a lower depth but also extract higher economic value per unit water, compared to farmers who pay flat rates. Metering encouraged farmers to optimize costly inputs, thereby operating their pumps for fewer hours (30% less than their flat-priced counterparts). However, the authors also report a reduction in net return per unit land, which begs the question of whether farmers would have voluntarily chosen metered over flat tariffs. Farmers' response to metered tariffs is also heavily dependent on the net utility of groundwater, which can vary between seasons, as was observed by Meenakshi, Banerji, Mukherji, and Gupta (2013) in West Bengal. They found that a shift from flat to metered tariff reduced water use in monsoon season but did not affect farmers' pumping behavior in the drier summer season. Additionally, there is evidence that marginal pricing of water increases the impact of water-conserving technologies on farmers' pumping behavior: Chakravorty, Dar, & Emerick (2019) observed that paddy farmers in Bangladesh paying volumetric price for groundwater reduced their water use when they started using a water conservation methodology called "Alternate Wetting and Drying" (AWD) while farmers paying fixed per acre water prices exhibited no change in water consumption after they started using AWD. Although this study was conducted in Bangladesh, the results are relevant for India because of significant similarities in the climate, agricultural practices, and groundwater availability in Bangladesh and neighboring regions of India.

There are thus several contextual nuances to the utility of metered tariffs for effecting groundwater conservation. The argument that increasing the price of metered power is an effective tool to control groundwater use breaks down when power prices are stretched beyond a certain point (Saleth, 1997). For instance, when tariffs (metered at that time) were raised in the state of Uttar Pradesh in 1975, many farmers replaced their electric motors with diesel engines. Later, as the cost of power came down with the introduction of flat tariffs in 1982, most farmers switched back to electric motors. To summarize, the effect of metered tariffs on farmer behavior is dependent on multiple factors like the prevalence of water markets and power subsidies, overall utility of groundwater to the farmer, and other options available to the farmer for accessing the aquifers.

5. Potential tariff strategies to make groundwater irrigation more efficient, equitable, and sustainable

Redesigning or improving tariff policies is a complicated process that needs to balance the divergent objectives of reducing financial losses to the exchequer, providing cheap and reliable irrigation to financially disadvantaged rural households, and conserving groundwater resources. There is considerable variation across India in terms of agricultural practices and groundwater availability. Additionally, the situation is made more complex by considerable geographical variation in the properties and levels of exploitation of aquifers. In regions like central and southern India, farmers dependent on the hard rock aquifers face reduced groundwater availability due to historical overexploitation (Shah, 2012). Similarly, the alluvial aquifers in northwestern India exhibit rapidly receding groundwater levels because consumption far exceeds natural recharge. In contrast, eastern alluvial regions with ample rainfall and snowmelt have extensive renewable groundwater reserves that, if used judiciously, can lead to prosperity and improve food security. Hence, there is no one-size-fits-all tariff framework that can operate successfully in all Indian states. Rather, tariff policy has to be formulated at the regional level while considering the local drivers and outcomes of agricultural groundwater consumption.

Here we present certain strategies discussed in the literature that can potentially solve the problems plaguing the existing power tariff structures discussed above. The first three tariff restructuring schemes are pertinent for regions currently facing excessive groundwater exploitation, and are followed by a strategy that is more relevant for eastern states like West Bengal with sufficient groundwater for increased adoption in agriculture (Shah, Chowdhury, & Shah, 2017b). Table 2 summarizes the impact of these strategies on the three criteria used for comparing flat and metered tariffs in the previous section.

5.1. Intelligent rationing of flat tariffs

Shah et al. (2004) believe that while metered power supply can be the long-term goal of governments currently providing power at flat rates, metering is not socially and politically viable in the short term. A more feasible option is to transform the perverse flat tariff structure to a more intelligently scheduled (albeit unmetered) power supply. The authors posit that the electricity supply to farmers, if synchronized with their demand, can lead to a more efficient consumption of electricity and water without harming their livelihood. For example, in Gujarat, farmers currently receive around eight hours of power per day throughout the year (Prayas (Energy Group), 2018a). Shah et al. (2004) suggest that if utilities were to supply 18–20 h of power for 40–50 crucial days[7] and restrict supply to two–three hours during the remaining days, 80–90% of the farmers will manage to meet their irrigation needs. The authors very aptly call this scheme a shift from "degenerate flat tariff to a rational flat tariff". Our back of the envelope calculation[8] shows that this synchronized supply would in fact need 33% fewer hours of pumping compared to eight hours every day throughout the year.

Shah et al. (2008) conducted a survey in rural Gujarat to understand the seasonal variation in farmers' demand for electricity. They asked respondents to distribute an aggregate of 3000 h (at an average rate of 8.3 h per day) over the year and found a consistent trend of more hours being allocated to November-March (Fig. 4). This is also correlated (R^2 = 0.82) to the mean monthly precipitation received by the state: understandably, farmers' demand for power is maximum during the drier seasons. Hence, an intelligent rationing scheme has potential benefits for all stakeholders, from farmers, power utilities, to bookkeepers of national food production and groundwater reserves. Additionally, restricting power supply during the non-essential time of the year will not only encourage farmers to adopt water-efficient irrigation technologies (Shah et al., 2004), but also reduce wasteful use of free power. Given farmers' tendency to over-pump water in the face of unpredictable and sporadic power availability (Sarkar, 2012), a strictly scheduled supply at preannounced hours is expected to discourage wasteful behavior.

Variation in demand patterns across different regions of the state will ease the pressure on power utilities by distributing demand over a wider time period. Nonetheless, this system will still need extensive planning on the part of power utilities because meeting a varying demand is more difficult than supplying uniform power throughout the year (Shah et al., 2004). To further

[7] Crops in Gujarat are most susceptible to damage from moisture-deficit for usually two and five weeks during the kharif (Jul-Oct) and rabi (Nov-Mar) season, respectively (Shah et al., 2004).

[8] Existing supply = 8*365 = 2920 h/year. Proposed supply = 20*50 + 3*315 = 1945 h/year. Saving = (2920–1945)/2920 = 33%.

Table 2
Impact of proposed tariff rationalization strategies on the three criteria of comparison between flat and metered tariffs. Bold, regular, and italicized text denotes positive, mixed, and negative outcomes, respectively.

Strategy	Regional suitability	Outcome		
		Electricity administration	Livelihood of small and marginal farmers	Farmers' pumping behavior
Intelligent rationing of flat tariffs	Western and northwestern regions with rapidly depleting aquifers due to overexploitation	**Does not require metering, so it is easily implementable in flat-tariffed systems. Utilities can cater to varying demand by splitting consumers into zones and supplying power cyclically (Shah et al., 2004).**	*Reducing supply hours will penalize water buyers disproportionately as pump owners usually sell water only after their own demand is met (Sarkar, 2012; Shah & Verma, 2008).*	**Prioritizing power supply during periods of peak demand and rationing power at other times will discourage wasteful groundwater extraction (Shah et al., 2004).**
Payment for groundwater conservation	"	All three schemes require metering of individual consumers which can be costly (Shah, 1993). Potential solution exists in the form of tamper-proof smart meters that do not require manual meter reading (Mukherji et al., 2009; Zekri et al., 2017). Metering will lead to the collection of reliable consumption data which can assist in future policy decisions.	*Compensating pump owners for forsaking profit from water sales is expected to increase water prices, thereby affecting water buyers adversely.*	**Monetary compensation for reducing groundwater consumption is expected to discourage its overexploitation (Fishman et al., 2016; Gulati & Pahuja, 2015).**
Restructuring subsidies as a minimum quantity of electricity supply	"	"	Distributing subsidized power according to farm size will lead to greater equity between large and small pump owners (Gulati & Pahuja, 2015). Water buyers may face higher water prices as pump owners reduce their groundwater extraction.	"
Combination of flat and metered tariffs	Eastern regions with abundant groundwater	"	**Flat portion of the tariff will encourage water sales (Shah et al., 2017a).**	**Metered portion of the charges will discourage wasteful consumption (Shah et al., 2017a).**

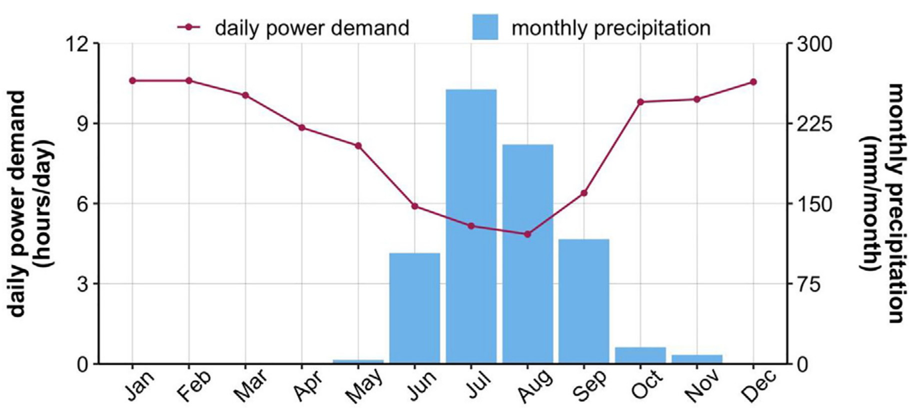

Fig. 4. Farmers' preference for seasonally varying hours of daily power supply in Gujarat, juxtaposed against monthly precipitation. Power demand data extracted from Fig. 4 in Shah and Verma (2008); precipitation data acquired from the Indian Meteorological Department (Rajeevan, Bhate, Kale, & Lal, 2006).

reduce the variability in overall power demand, the authors of this study suggest dividing up regions into geographic zones and supplying power cyclically to different zones on different days, while still meeting the seasonally varying demand as closely as possible.

A potential drawback of this strategy is that rationing agricultural power will adversely impact rural households sharing electricity lines with groundwater well operators. Hence, the implementation of this scheme requires a separation of electricity feeder lines supplying agricultural and domestic power. The government of India launched the *Deen Dayal Upadhyaya Gram Jyoti Yojana* (DDUGJY) scheme in 2014 to accomplish this at the national scale (Palit & Bandyopadhyay, 2017). The aim was to supply uninterrupted and reliable electricity, without outages or voltage drops, to all rural households by 2019. As a part of this scheme, feeder segregation has been completed or is underway in most states of India (Prayas (Energy Group), 2018a).

5.2. Payment for groundwater conservation

This intervention aims to create flat-tariffed systems that promote water-efficient agricultural practices. Fishman et al. (2016) tested a scheme in Gujarat wherein farmers were compensated for reducing their power consumption. The researchers calculated baseline power consumption for farmers who volunteered to be a part of this study, installed meters to monitor their power consumption, and offered monetary compensation per unit reduction of electricity use below the baseline. To avoid backlash from consumers who had gotten accustomed to an unlimited supply of subsidized power, participants who ended up consuming more than the baseline were not penalized in any form. Farmers continued to pay the regular flat charges to the utilities throughout the study.

The farmers displayed great interest in this study, with 75% who received an offer to participate signing up for it. However, at the end of one year, no significant reduction was observed in the electricity demand of study subjects. The authors hypothesize that complications may have risen because of difficulty in calculating baseline entitlement. There is no accurate way to measure (and subsequently model) a farmer's energy consumption; even if that were possible, usage may fluctuate between years thereby leading to inaccurate compensation. If the entitlement is set too high, farmers might receive compensation without taking active steps to reduce their consumption; on the other hand, if the baseline is set too low, users who make genuine efforts to reduce consumption may be refused compensation, thereby discouraging their future efforts to conserve water. The authors suggest bigger randomized control trials to test the utility of this compensation scheme.

A similar scheme called "*paani bachao, paise kamao*" ("save water, earn money") has been launched recently in the state of Punjab (Punjab State Power Corporation Limited, 2018). The state government has partnered with the Abdul Latif Jameel Poverty Action Lab (J-PAL) to study the impact of monetary compensation to farmers who reduce their agricultural power consumption. The Punjab State Power Corporation Limited (PSPCL) first calculated average electricity consumed by all pumps connected to the distribution feeders chosen for this pilot. Farmers who volunteer to get a meter installed on their pumps will receive monetary compensation for the difference between their power consumption and this baseline. Similar to the pilot in Gujarat discussed earlier (Fishman et al., 2016), there is no penalty for exceeding the baseline. To encourage farmer participation, if more than 80 per cent of consumers connected to a single distribution feeder join this scheme, consumers on that feeder are promised two extra hours of electricity per day, in addition to the regular time-rationed power currently being supplied to all agricultural consumers in the state. This pilot project started in June 2018 and further results are awaited to ascertain its efficacy in promoting judicious use of groundwater.

5.3. Restructuring subsidies as a minimum quantity of electricity supply

Groundwater suffers from the "tragedy of the commons": like all other common pool resources, it is highly susceptible to overexploitation in the absence of an effective mechanism to regulate individual consumers (Meinzen-Dick et al., 2018). In the current structure of unrestrained subsidized power for flat-rate consumers, large farmers accrue disproportionately greater benefits than small farmers (Mukherji et al., 2009; Sarkar, 2012). Landholders who have the capital to install bigger pumps and dig deeper tube wells are able to consume more power and pump more groundwater – even after normalization by landholding size – than their financially disadvantaged neighbors (Singh, Singh, & Singh, 2014).

To minimize, and possibly eradicate, this "to whomsoever they reach" quality of power subsidies, there is a need to restructure the distribution of subsidized power in a manner that is not only more equitable - both socially and economically – but also prevents wasteful consumption of groundwater in flat-tariffed regions. Gulati and Pahuja (2015) suggest a subsidized electricity distribution system based on the size of landholding. Specifically, their "Minimum Energy Support" (MES) scheme would annually provide each pump owner with a prespecified electricity amount (proportionate to their landholding size) at a subsidized rate, and all consumption beyond that will be at commercial rates. Farmers will be allowed to transfer any unused subsidy quota to the next year, or sell it back to the power utility. The authors believe such a setup could encourage the adoption of water-efficient agricultural practices and reduce groundwater depletion in critical regions.

Implementing this scheme might be tricky because of the current subsidy setup across India. When farmers receive heavily subsidized (even free) power at flat rates, there is little incentive for them to let governments restrict their power supply by switching over to this MES scheme. They will not easily relinquish that access unless presented with a more attractive proposition. Gulati and Pahuja (2015) believe that the stimulus should come in the form of extended hours of higher quality power than what the tube well owners currently receive. Essentially, the MES is a switch from an unlimited supply of low-quality power to an amount-rationed supply of high-quality power. Although the scheme has not yet been tested at pilot-scale to the best of our knowledge, the authors report that some farmers in Punjab and Karnataka have expressed a willingness to test this MES program.

An apparent impediment to implementing the last three strategies is the large number of electricity consumers in agriculture, and the subsequent cost associated with manually monitoring their individual consumption. The high cost of metering was a catalyst for the shift to flat tariffs in the 1970s, and the number of tube wells has only risen since then (Ministry of Water Resources, 2017). However, a potential solution exists in the form of smart meters with a central information management system (Zekri, Madani, Bazargan-Lari, Kotagama, & Kalbus, 2017) that do not require manual reading by utility employees. West Bengal has installed tamper-proof meters that use cellphone networks for data transmission, thereby reducing both pilferage and meter reading cost (Mukherji et al., 2009). Automated systems such as these can be beneficial to programs that require monitoring of individual consumption.

5.4. Combination of flat and metered tariff

Shah et al. (2017a) proposed this strategy for water-rich states like West Bengal where increasing groundwater use has been recommended as a viable option for supporting marginal farmers. The strategy has the dual purpose of ensuring equitable access to cheap and dependable irrigation services for water buyers while preventing wasteful water pumping. The authors believe that the objectives can be met by charging groundwater well owners a fixed flat rate based on pump size (lower than the flat tariffs farmers paid in the past) in conjunction with per unit pricing (again, lower than that currently being charged in exclusively metered tariff systems). The proportions of the flat and metered rates can be tweaked to encourage competitive rates for water buyers (through the flat component) while simultaneously discouraging excessive exploitation of groundwater resources (by adjusting the metered component).

Shah, Chowdhury, and Shah (2018) conducted a study in partnership with 23 well owners in a village in West Bengal. They calculated the average of the 23 farmers' bills for corresponding months from the last year, set that as monthly benchmarks, and proposed to pay each farmer 70% of their monthly bill in excess of the corresponding benchmark. The benchmarks acted as the month's flat tariffs (identical amount that all pump owners paid), while 30% of the remainder served as a low per unit tariff to discourage frivolous pumping. This one-year pilot concluded recently and contrary to the authors' expectations, there was no decrease in water prices compared to the base year (the year previous to the pilot). The authors speculate from their interactions with the farmers that there might be multiple reasons behind this: pump owners tend to stick together and decide water prices collectively; they do not encroach on each other's customers; pump owners were also wary that water prices once reduced would be hard to increase once the pilot ended (Shah et al., 2018). The researchers did observe an increase in the competitiveness of the water markets in terms of the Herfindahl Index (a measure of the relative market shares of the well owners) along with an improvement in the quality of irrigation services as rated by the water buyers.

The strategies we have discussed in this section are targeted to specific geographical regions because of the considerable variation across the country in terms of agricultural practices and groundwater availability. Before being implemented at full-scale, there is a need of extensive pilot tests to tailor them to meet the particular requirements of different regions. The importance of these tests is underscored by the unexpected results discussed earlier from some preliminary pilot tests of these schemes. If implemented correctly, these strategies can improve India's agricultural power tariffs and assist in the country's development towards a more sustainable future. We discuss this in more detail in the next section.

6. Restructuring power tariffs as a pathway to meeting sustainable developments goals

India was among the 193 nations that adopted the United Nations' 2030 Agenda for Sustainable Development in 2015. To achieve the Sustainable Development Goals (SDGs) put forth in the agenda, India has set ambitious targets for itself in multiple areas of economic and social progress. Given the crucial role groundwater-irrigated agriculture plays in India, we propose that rethinking agricultural power tariffs and subsidy structures can help target multiple SDGs related to poverty reduction, food security, water and energy access, inclusive economic growth, inequality reduction, and overall sustainable consumption. Although this list is not exhaustive, we provide a few examples to illustrate our argument:

- SDG 1 pertains to poverty reduction. Restructuring power tariffs to ensure equitable access to groundwater for agriculture can assist India in achieving multiple sub-targets related to poverty reduction and eradication, as well as ensuring equal rights to natural resources for all.
- Under SDG 2 (zero hunger), improved tariffs that ensure groundwater access to low-income farmers through groundwater markets will go a long way toward achieving sub-target 2.3 which aims to double the agricultural productivity and incomes of small-scale food producers.
- SDGs 6 and 7 relate to ensuring sufficient access to and sustainable management of water and energy resources, respectively. Given the highly intertwined relationship between energy and water, improved tariffs can also be instrumental in achieving these goals.
- SDG 10 aims to reduce inequality within countries. This too shall benefit from rational tariff policies that are designed with the objective of equitable access to groundwater for both large and small farmers.

Simultaneously, rationalized tariffs and reduced subsidies can help India achieve SDGs indirectly by freeing funds that can then be diverted towards other projects. In India, the proportion of GDP spent on social welfare programs such as education and health is very low, especially compared to other developing economies like Brazil, Nepal or Kenya (Research and Information System, 2016). The current study is relevant from this aspect because the financial drain from subsidizing agricultural electricity has significant negative spillover effects on other public welfare programs (Badiani & Jessoe, 2017). The fiscal savings from rationalizing tariffs and reducing the overall amount of subsidized power provided to farmers can boost government expenditure in other sectors such as education, public health and sanitation, clean energy, rural electrification, infrastructure development, women and child welfare, to name a few. Thus, we believe that restructuring and improving the agricultural power tariffs can assist India's progress towards achieving many, if not all, UN Sustainable Development Goals.

7. Conclusion

This paper is a review, based on empirical evidence from past case studies, of two widely used power tariff modes - flat and metered - for charging groundwater consumers in India's agricultural sector. Flat-rated systems do not require metering and regular monitoring of individual consumption, and are therefore economical and less labor-intensive for utilities compared to metered systems. Since groundwater well owners paying flat charges face zero marginal cost of power, they compete aggressively to maximize water sales and create favorable water markets for the financially disadvantaged farmers; metered consumers, on the contrary, have a lower proclivity to engage in water sales and buyers are forced to pay higher prices. However, flat tariffs are disadvantageous from the groundwater conservation point of view because consumers have no incentive to use water judiciously. Conversely, metering elicits a mixed response from the farmers: their tendency to reduce groundwater consumption is heavily dependent on the region's agricultural, climatological, and economic conditions, as well as the prevalence of local water markets.

Building on our findings that flat and metered tariffs have their specific benefits and drawbacks, we present four strategies from our literature review that can assist policymakers create tariff structures which ensure sufficient irrigation to millions of farmers without jeopardizing the country's limited groundwater reserves. For regions where groundwater overexploitation is already causing rapid aquifer depletion (particularly in western and northwestern India), primary focus should be on tariff policies that promote groundwater conservation through power rationing and financial incentives. Eastern states like West Bengal, which have relative groundwater abundance, could benefit more from schemes like a hybrid flat-cum-metered tariff that can stimulate water markets by encouraging groundwater consumption and improve the livelihood of low-income farmers who depend solely on water bought from well owners. However, such policies have to be designed and implemented while being cognizant of the fact that unbridled overconsumption of groundwater in currently water-rich regions may cause unsustainable exploitation as witnessed in the western regions over the past few decades. We believe that improved power tariffs have the potential to help India attain multiple Sustainable Development Goals, both directly through water and electricity conservation, and indirectly through fiscal savings for other social development programs.

While this paper focused primarily on types of agricultural power tariffs, any analysis of the latter is incomplete without a discussion of power subsidies for farmers. Although tariffs and electricity subsidies are two distinct policy instruments, the results of our tariff comparison should be interpreted within the context of subsidized electricity supply for both flat and metered consumers. Researchers have proposed that a reduction in subsidies on agricultural power should be among the primary goals of policymakers (Gulati & Pahuja, 2015). The strategies we have discussed for regions with excessive groundwater consumption (which are usually the ones with highest subsidies (Prayas (Energy Group), 2018a)) can be used by policymakers in this endeavor. However, past experience in Gujarat and West Bengal has shown that subsidy reductions hurt the water buyers the most (Shah & Chowdhury, 2017), so withdrawals have to be complemented by efforts to simultaneously allocate groundwater more equitably.

For formulating future tariff policies, India needs a holistic approach that is not based solely on power availability and demand, but also incorporates diverse aspects such as groundwater availability, farmers' irrigation demand, and opportunity cost of subsidized electricity. Simultaneously, long-term judicious groundwater use is also contingent on a broader overhaul of agricultural policy. The cost of agricultural production in terms of groundwater depletion, which has hitherto been externalized to the environment, needs to be internalized into the cost of production, while adjusting farmers' compensations to mitigate any potential adverse impacts on their livelihood. Although a detailed discussion is beyond the scope of this study, this may necessitate significant steps like financial incentives for encouraging a shift to less water-intensive crops in groundwater-scarce regions. The ramifications on food prices and food security can also not be ignored in these decisions. In conclusion, decisions need to be taken on the basis of in-situ constraints, and farmers should be involved in the decision-making process so that the new policies adopted are actually successful in achieving their goals with minimum impact on farmers' financial wellbeing and national food security.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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