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Original Article

Transition to a solarized, energy efficient irrigation system; Empirical evidence from India

Jeevan Kumar Jethani[1, 2*], Bikash Kumar Sahu[3], Atul Kumar[4],
Ashvini Kumar[5], and Gopal K. Sarangi[1]

[1] *TERI School of Advanced Studies, New Delhi, 110070, India*

[2] *Ministry of New and Renewable Energy, New Delhi, 110003 India*

[3] *Carbon Market Association of India, New Delhi, 110001 India*

[4] *School of International Studies, Jawaharlal Nehru University, New Delhi, 110067 India*

[5] *Solar Energy Corporation of India Limited, New Delhi, 110023 India*

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Abstract

Agriculture sector being the backbone of the Indian economy always receives prioritized attention by the policy makers and planners. The age old debate between energy-water nexus has received a renewed thrust due to emergence of solarized irrigation systems for the agriculture sector in the country. The present study, develops a model innovatively by combining a bottom-up approach with top-down data to understand the future water and energy requirements for agriculture sector under three scenarios till 2030 for five major agrarian states, namely Haryana, Punjab, Maharashtra, Rajasthan and Tamil Nadu. Estimates are made to understand the benefits accrued due to solarlization of existing pumps as well as by use of energy efficient pumps. Results indicate that around INR 76 billion could be saved by all the five states together due to reduction of electricity subsidy alone if such transitions are realized. Other benefits are viewed in terms of reduction in energy costs, reduction in CO_2 emissions, and efficient use of water for irrigation.

Keywords: solarized irrigation pumps, groundwater demand, electricity subsidy, energy efficient pumps

1. Introduction

Groundwater is an important source of irrigation for agricultural production in the country, with a 60% share of the total irrigation water in India (Devineni, Parveen, & Lall, 2022). A cursory look at the irrigated area in the country reveals that the share of net irrigated area accounts close to 50% of the total net sown area in the country, and about 40% of the net irrigated area gets water through canal systems while 60% uses groundwater irrigation system (Economic Survey, 2021-2022). This clearly establishes the importance of groundwater irrigation in the country, with consequent pressure on groundwater use and emerging groundwater depletion.

Increase in demand for food and other agricultural commodities over time has led to an increase in the use of groundwater (Devineni, Parveen, & Lall, 2022). In fact, India is the largest user of groundwater in the world and uses approximately 230 cubic kilometers of groundwater annually. The overuse of groundwater has led to depletion of groundwater, and nearly two thirds of the districts in the country face groundwater stress.

*Corresponding author
Email address: jethani.jk@nic.in

Increased use of groundwater is leading to increased use of energy and a consequent rise in energy demand by the agriculture sector. In India, around 221 GWh of electricity was consumed by the agriculture sector in 2020-21 for irrigation alone (CEA, 2022a). Latest statistics reveal that as of 31st of March 2021, the total number of electric pumps installed in the country was around 22.09 million. The actual consumption of electricity in the agriculture sector is largely underestimated as most of the agricultural connections are unmetered. Metering is the easiest technical solution but difficult to implement due to technical, social and political considerations. Recent initiatives such as feeder segregation have shown better results in addressing accounting problems in the agricultural electricity consumption (Mukherji, Shah, & Giordano, 2012).

In India, groundwater irrigation has been traditionally dependent on the use of diesel pumps, which are gradually getting replaced with electric pumps (Smith & Urpelainen, 2016). Electric pumps have become affordable for farmers due to provisions of subsidized electricity for the agricultural consumers in the country. However, increasing subsidies due to political and economy considerations has been a matter of concern for the State Governments to maintain the financial health of the distribution utilities (Mehta & Sarangi, 2022). Studies have shown that agriculture subsidies constitute around 75% of the total subsidies allotted for electricity sector in the country, which is quite significant (Aggarwal, Viswamohanan, Narayanaswamy, & Sharma, 2020). It may be worthwhile to note that the total fund requirement estimated for meeting the cost of subsidized tariff and the fixed charges in the year 2018-19 was INR 160 billion for Maharashtra State alone. For Haryana and Rajasthan states, the subsidy requirements were INR 67.93 billion for the year 2017-18 and INR 171 billion for the year 2019-20 respectively, as estimated against an average cost of electricity supply of INR 7.35/kWh for Haryana and INR 8.0/kWh for Rajasthan.

While there exist multiple options to reduce this humongous subsidy bills, solarized pump sets for irrigation appears one of the possible options. Solar energy has emerged as a suitable alternative to electricity and diesel due to rapid development of technology leading to sharp cost reduction. Studies indicate that the life cycle cost of operating a solar pump is lower than of an electric or diesel pump, even though the capital expenditure of a solar pump is higher (Chandel, Naik, & Chandel, 2015; Harinarayana & Vasavi, 2014). Solarization of pumps is being supported by the Government of India through its flagship PM-KUSUM scheme, which provides subsidy on the capital cost for solarization of diesel and electric pumps. Institute of Energy Economics and Financial Analysis (IEEFA) in 2018 has estimated that there will be a savings of INR 528 billion every year on account of electricity subsidy and cross subsidy being provided by State Governments, if all electric agriculture pumps are converted into solar pumps (Garg, 2018).

Furthermore, studies have pointed out that the optimal utilization of electricity and water for irrigation can bridge the gap between demand and supply (Murthy & Raju, 2009). In Haryana State, the use of efficient electrical pumps with micro irrigation systems was promoted to conserve water and mitigate high subsidy costs of solar pumps. The Direct Benefit Transfer (DBT) in Punjab state has been effective in bringing a behavioral change among farmers to save water and electricity (Gill, 2019).

Over-extraction of groundwater through tube-wells is leading to depletion of the water table, and some areas under sharp decline of groundwater level have already been classified as Dark Zones. It's appreciated that Punjab and Haryana states will have higher penetration of electric pumps to exhaust groundwater for irrigation by 2025 (Central Ground Water Board, 2017). The other concern associated with excessive water usage is that of environmental degradation, which has been reported widely in the literature (Challinor, Wheeler, Craufurd, Ferro, & Stephenson, 2007; Kang, Khan, & Ma, 2009; Krishnan, Swain, Bhaskar, Nayak, & Dash, 2007; Singh, Dam, & Feddes, 2006).

There have been studies carried out analyzing and predicting the electricity consumption for the agriculture sector in the country. For instance, the 20th Electric Power Survey of India has estimated electricity consumption of agriculture sector through Partial End Use Method for the period from 2021-22 through 2031-32, and it has been estimated that the electricity consumption by agriculture will increase to 363.2 TWh by the year 2029-30 (CEA, 2022b). Similarly, TERI (2017) has applied econometric and statistical analytical tools for understanding factors influencing electricity consumption. A number of factors such as total & sectoral GDP, irrigation pumps energized, and agricultural area, are taken into consideration to analyze their impacts on electricity consumption in the agriculture sector. Findings from the study reveal that there is a strong correlation between the above parameters and the electricity demand in the agriculture sector.

Spencer and Awasthy (2019) in a similar manner forecast the electricity demand of agriculture in India using three approaches, viz. i) econometric analysis based on historic trends, ii) cross-country historical analysis relating India's current development phase with countries which underwent a similar trajectory, and iii) partial end use analysis to study the effects of energy efficiency interventions. Under the scenarios of baseline, strong growth and high growth, it was assumed that the Gross Value Added (GVA) economic activity would grow year-on-year basis at a rate of 6.8%, 7.5%, or 8%, and the share of agriculture in GVA would remain the same in all scenarios at 9%. Results of their study suggested that the energy demand in TWh for the year 2030 would be 274.1, 240.43 or 221.3 under the different scenarios with nil, moderate (10%), and high efficiency (20%) improvements, respectively.

Given the above backdrop, it can be observed that while independent research exercises have been carried out to analyze the effects of energy efficiency interventions as well as of solarization of pump sets on energy demand and water extraction, along with consequent impacts on costs and subsidy reductions, still only scant literature exists analyzing the conjugated impacts of solarization and energy efficiency interventions together on the above-mentioned factors. In this context, the present study makes a novel attempt to understand such impacts through an integrated bottom-up modelling exercise to assess the said impacts in five major agrarian states of India for the year 2030. The study stands unique in its approach and design in analyzing such impacts in the dynamic context.

2. Methodological Approach

2.1 Materials and methods

As a methodological tool, the study develops a bottom-up integrated model of energy and then combines it with historical top-down data on water, energy, agriculture and socio-economic indicators. By using the modelling framework, it analyzes interrelationship and sensitivities between groundwater, energy and agriculture and their consequent impacts on a variety of factors such as energy demand, energy costs, subsidies, and emissions, projecting the same for 2030. Year 2010 is chosen as a reference base for the projection exercise. A variety of methodological tools such as partial end use method, econometric method, and bottom-up and end use are used for the analysis. Partial end use method is used to estimate different parameters considered for different scenarios. A block diagram offering an overview on how irrigation depends on several factors and their interrelations is presented in Figure 1.

Technological interventions such as solar pumps and efficient electric pumps are included in the alternative scenarios constructed as part of the methodological framework. Net improvement in water use efficiency is also estimated. Selection of the states was based on three key factors, the first being whether agricultural contribution accounts for a major share in the state's and the country's economy. The issues around water availability were the second factor. Thirdly, states from different geographic regions of India are intended to capture regional variations. Accordingly, the five major agrarian Indian states selected for the study are Haryana, Punjab, Maharashtra, Rajasthan and Tamil Nadu, and these states are presented on the map of India in Figure 2.

The following were the assumptions made for estimating the parameters for projections:

a) ARIMA model is used to project the agriculture sector GDP growth rate for the study states. This model has been used based on its history of relatively accurate forecasts. Forecast package (Hyndman & Khandakar, 2008) has been utilized for the estimation process.
b) Net sown area (NSA) is assumed to be constant till 2030 considering population growth and per capita income elasticity under different scenarios, which suggest the area under food crops to be the same (NITI Aayog, 2018).
c) For calculating increase in gross sown area (GSA), growth in cropping intensity (CI) from 2015 to 2030 is estimated using linear regression with cropping intensity and state agriculture GDP as the dependent and independent variables respectively.
d) The forecasted net irrigated area is used to estimate future gross irrigated area.
e) The annual groundwater irrigated area (GwIA) is expressed as the sum of net areas of tube-wells (NA_{tw}), other wells (NA_{ow}) and of other sources (A_{os}).
f) Cropping intensity of surface water irrigated area remains constant.

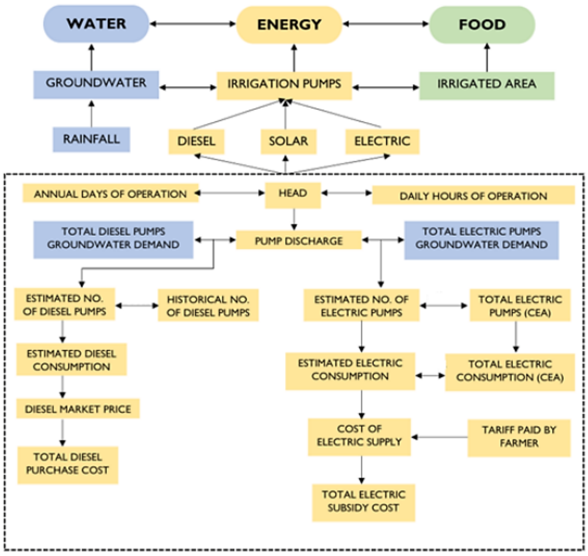

Figure 1. Overview of the model to estimate energy demand in groundwater irrigation

Figure 2. The five major agrarian states selected for study

g) For calculating the water requirement, the national average of crop water level required by different crops has been used.
h) Forecast of water demand was made using linear regression with water demand as the dependent variable and gross irrigated area as the independent variable.
i) For Rabi crops, rainfall is not accounted in reducing the crop water level required. Cotton and sugarcane which are longer duration crops require more water and time to grow. The crop water level assumed for them is 1000 and 2000 mm respectively (Singh, 2010).
j) Diesel pumps are replaced by standalone solar water pumping systems of IS 17018 (Part 1) 2022 specifications.
k) It is assumed that from year 2020 onwards, the new electric pumps being added are 20% more efficient (Bureau of Energy Efficiency, 2020).

l) Carbon emission factor for diesel has been taken as 74.10 t/TJ (Ananthakumar, Murali, Rachel, Lakshmi, & Malik, 2017). Weighted carbon emission factor 0.79 t CO_2/MWh has been used for grid electricity (CEA, 2021).

Table 1 presents the data sources and data descriptions for variables used for carrying out the model. Standard equations have been used for evaluating various economic parameters related to sown area, irrigated area, effective rainfall, crop water requirement, and forecast numbers of diesel and electric agricultural pumps.

2.2 Scenario development

As an analytical tool, various scenarios are constructed considering the above set of assumptions. Energy Scenarios provide a framework for exploring future energy perspectives, considering various combinations of technology options and their implications. Three alternative development scenarios namely Business-As -Usual (BAU), Alternative 1 (ALT1), and Alternative 2 (ALT2) are created and presented in this paper. These scenarios consider various levels of technology penetration across different time horizons in the modelling framework.

Business as Usual (BAU) scenario: The BAU scenario is characterized by most-likely- path of development in the absence of any major interventions. However, this scenario incorporates existing Government plans and policies. It is assumed that electric pumps being added from 2020 onwards are five-star rated energy efficient electric pumps. These pumps have performance factor 1.2 times fold that of the three-star less efficient pumps (Bureau of Energy Efficiency, 2020).

Alternative 1 (ALT 1) Scenario: In this scenario, improvements in energy efficiency and water usage have been considered based on the following assumptions:

- Based on the historic data and future plans for replacement of inefficient electric pumps with energy efficient pumps a total of 20% of the electric pumps would be energy efficient by the year 2030.
- By the end of the year 2030 around 22% of the diesel pumps are estimated to be solarized considering PM-KUSUM Scheme targets and future trends on similar lines.
- Improvement in water use efficiency leads to 10% lesser groundwater extraction as compared to BAU, which can be possible with improved hydraulic efficiency of pumps and pipes, and the use of micro irrigation systems.

Alternative 2 (ALT 2) Scenario: In addition to energy and water improvements suggested in ALT 1, additional improvement levels have been considered by solarizing existing inefficient electric pumps in ALT 2. It is estimated that by the end of the year 2030 around 5.45% of the inefficient electric pumps are solarized considering PM-KUSUM Scheme targets and future trends on similar lines.
The assumptions across the three scenarios are summarized in in the Table 2.

Table 1. Input parameters used to estimate groundwater and energy demand for irrigation

Variable	Description	Years	Source
Agri GDP	Annual time series (Base FY 2004)	1993 to 2014	(RBI 2019b)
Sown and irrigated area	Annual time series	1990 to 2014	(RBI 2019a)
Crop wise irrigated area	Annual time series	1984 to 2014	(IASRI 2019)
Seasonal crop wise area	Five-year normal area	2011 to 2016	(DoAC&FW 2017a; DoAC&FW 2017b).
Net irrigated area by water source	Annual time series	1984 to 2014	(Indiastat 2019)
Crop water demand	Per season assumed to be same throughout India for this study	NA	(Singh 2010)
State wise annual rainfall	Six-year mean	2012 to 2017	(Kaur and Purohit 2013, 2014, 2015, 2016, 2017)
Electric pumps	Annual time series	1990 to 2016	CEA (2019), Grundfos
Diesel pumps	Annual time series	Varying	State Government
Solar pumps	Annual time series	2011 to 2018	MNRE (2018-19)
Electricity tariff	State wise average cost of electricity supply and the tariff paid by the farmer.	2019-20	SERC Tariff Orders of Haryana, Punjab, Rajasthan, Maharashtra and Tamil Nadu
Diesel retail price	Annual average of daily retail price in Delhi, Mumbai and Chennai	01 April 2019 to 31 March 2020	PPAC
State wise groundwater level	Annual time series	1995 to 2016	CGWB 2017

Table 2. Summary of assumptions across the three scenarios by 2030

Parameter	Haryana	Maharashtra	Punjab	Rajasthan	Tamil Nadu
BAU: Share of solar pumps to total pump	5%	9%	5%	10%	3%
ALT 1 & ALT 2: Share of BEE 5 star rated electric pumps in electric pumps	20%	20%	20%	20%	20%
ALT 1 & ALT 2: Share of solarization of diesel pumps	22%	22%	22%	22%	22%
ALT 1 & ALT 2: Water saving due to improvement in irrigation efficiency	10%	10%	10%	10%	10%
ALT 2: Additional share of solarization of inefficient electric pumps (Targets as per PM-KUSUM considered)	5.45%	5.45%	5.45%	5.45%	5.45%

3. Results and Discussion

Based on the assumptions made and projections carried out under the three scenarios, the results obtained are presented in the following sub-sections.

3.1 Irrigation groundwater demand under different scenarios

It has been observed that under BAU scenario the Compound Annual Growth Rate (CAGR) for irrigation water demand from 2010 to 2030 would be highest in Tamil Nadu at 3.39% followed by Rajasthan, Maharashtra, Haryana, and Punjab with the least 0.38%. It is observed that technological innovation and water conservation measures would be successful in reducing the water demand by almost 1 BCM in each state. The groundwater demand for irrigation is presented in Figure 3 by state.

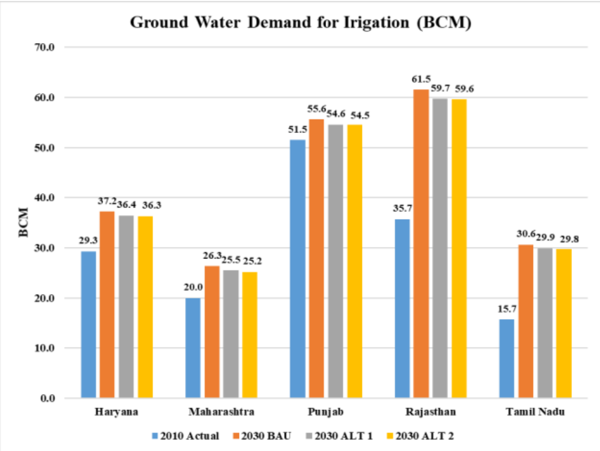

Figure 3. Groundwater demand for irrigation

3.2 Number of irrigation pumps under different scenarios

Figure 4 presents the numbers of groundwater irrigation pumps in the five states. The total number of irrigation pumps in the five study states increases to 14.99 million in 2030 from 9.95 million in 2010 with CAGR of 2.07%, while the total number of pumps in 2030 will be the highest in Maharashtra, and the highest CAGR of 3.32% is observed for the state of Rajasthan. With the adoption of standalone solar pumps, the number of diesel pumps is estimated to decline in all the states in both ALT 1 and ALT 2 scenarios.

The next sections explain the benefits to be accrued in terms of energy demand reduction, energy cost reduction and emissions reduction due to the reduction in number of pumps and the replacement of existing pumps by more energy efficient ones, as well as by solar based pumps.

3.3 Energy demand reduction possibilities under different scenarios

Electricity consumed by grid connected pumps and diesel consumed by diesel pumps have been considered on calculating the total energy demand under different scenarios. It is observed that under the BAU scenario, around 89% of total energy demand by irrigation pumps in the five states together will be from electricity in 2030. The total energy demand under BAU will increase from 281.81 PJ in 2010 to 492.91 PJ in 2030 with CAGR of 2.83%. However, under ALT2 scenario a reduction of 17% in the CAGR has been observed on account of use of energy efficient electric pumps and also of solarization of diesel and electric pumps. The overall results demonstrate reduction of energy demand against the BAU scenario through the use of energy efficiency and solarization interventions in the alternative scenarios. Figure 5 shows total energy demand for groundwater irrigation pumps under different scenarios by state. The highest growth in energy demand has been observed for the state of Rajasthan, followed by Maharashtra and Punjab.

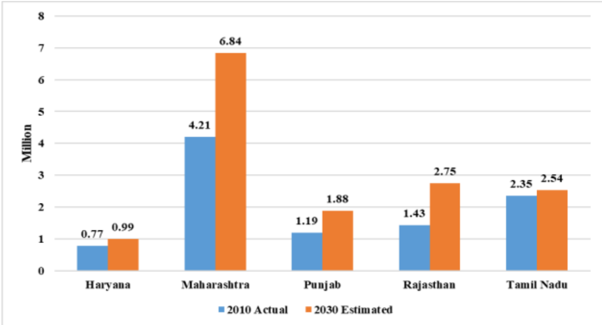

Figure 4. Number of groundwater irrigation pumps

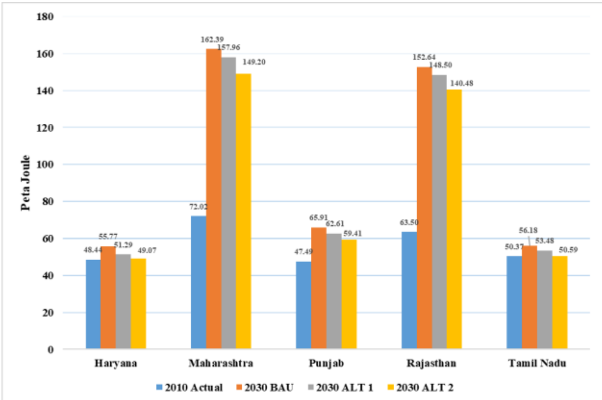

Figure 5. Energy demand for irrigation pumps under different scenarios

3.4 Energy cost reduction possibilities under different scenarios

As presented in the previous section, projections reveal that reduction in energy demand in both the alternative scenarios due to solarization of pump sets and use of energy efficient pump sets will have significant positive implications to energy cost reduction, i.e. costs incurred from electricity and from diesel: the cost reductions will be accrued primarily due to reduction in consumption of electricity and diesel. Projections for the five states show that the amount of savings in energy costs ranges from 19.44 to 43.50 billion INR, with the highest saving potential in the state of Maharashtra due to its higher number of grid connected irrigation pumps solarized by 2030. The total energy cost savings potential under ALT2 scenario in 2030 is 148.65 billion INR against the total energy cost under BAU. The reduction in electricity consumption under ALT2 scenario is expected to result in reduction of electricity subsidy to the tune of 75.62 billion INR in these five states. The energy costs in the five states are presented in Figure 6.

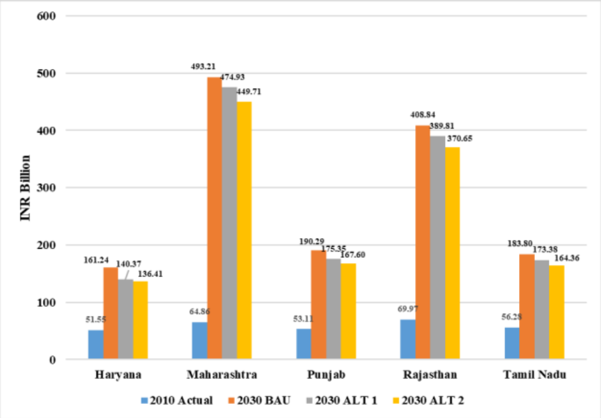

Figure 6. Energy costs for irrigation pumps under different scenarios

3.5 CO_2 emissions

Reduction in electricity and diesel consumption under alternative scenarios will lead to reduction in carbon emissions. It has been estimated that in total around 7.3 Mt CO_2 emissions can be reduced under ALT2 by 2030 in the five states under consideration. This can contribute to the larger policy climate goals of the country by contributing to attaining the national level emission reduction targets.

4. Conclusions

The analysis carried out in this study offers several key conclusions. It can be inferred from the analysis that the use of efficient electric pumps and solarization of diesel and electric pumps combined with improvement in water use efficiency can lead to significant reduction in electricity consumption and in turn in electricity subsidies for the agriculture sector. Besides the subsidy benefits, mobilizing additional finance through carbon credits by using clean energy technologies and reducing groundwater extraction for irrigation could be pursued. Another important conclusion drawn from this study is that, though Haryana and Punjab are the states having maximum area under irrigation among the five states studied in this paper, Rajasthan is found to experience the highest growth rate of groundwater irrigated area, which is an important factor to consider as it can have consequences in groundwater depletion. This will have significant implications to groundwater management in that state.

The modelling exercise carried out in this study shows that by 2030, only one fifth of total electric pumps will be energy efficient, and around 22% of diesel pumps and 5.45% of total electric pumps are projected to be solarized by the year 2030. In case the Government decides to decarbonize the agriculture sector by replacing all diesel pumps with standalone solar pumps and to solarize the electric pumps, which is very likely while considering the **"***Panch-Amrit***"** announced in COP26 at Glasgow, the model developed under this study can be used to work out corresponding energy demand, energy costs, and CO_2 emission reductions.

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