

Socio-Economic Impact of Agricultural Well Electrification on Tribal Farmer Livelihoods: Evidence from Dahod District, Gujarat

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ABSTRACT

Access to reliable electricity for agricultural irrigation remains a critical but underexplored determinant of rural livelihood improvement in tribal India. While the benefits of rural electrification have been documented across India, evidence on its welfare impacts among Scheduled Tribe farming communities in water-scarce districts of western India remains scarce. This study examined the socio-economic impact of agricultural well electrification under Electricity Company's URJA programme in Dahod district, Gujarat. A cross-sectional survey of 315 beneficiary farmers across eight villages was conducted using a structured interview schedule, with data analysed through descriptive statistics and Kruskal-Wallis tests across income groups. Findings indicate that 73.1% of respondents reported substantial reductions in irrigation costs following the transition from diesel to electric pumping, and household income increased approximately threefold post-electrification. Crop diversity expanded markedly, from approximately two crops to between seven and ten, with farmers transitioning toward vegetables, horticulture, and floriculture. Significant variation in service satisfaction was observed across income groups, with lower-income farmers reporting disproportionately higher maintenance cost burdens. These findings demonstrate that targeted agricultural well electrification can deliver meaningful welfare gains for tribal smallholders, while highlighting the need for complementary support in maintenance access and value chain development to ensure equitable distribution of programme benefits.

Keywords: rural electrification; agricultural wells; tribal farmers; Dahod; groundwater irrigation; crop diversification; Gujarat

INTRODUCTION

Access to reliable energy is widely recognized as a foundational enabler of rural development, particularly in agrarian economies where irrigation determines agricultural viability (Khandker et al., 2014; Fishman et al., 2016). In India, the electrification of agricultural wells has historically been one of the most consequential policy interventions for rural livelihoods, enabling groundwater-based irrigation that underpinned much of the country's post-Green Revolution agricultural growth (Shah, 2009; Chindarkar & Jain, 2020). Electric pumping of groundwater for irrigation is a major driver of India's agricultural growth, and access to subsidized electricity for agricultural pumping has transformed cropping patterns, income levels, and food security across large parts of rural India (Ray & Pullabhotla, 2023; Badiani et al., 2012).

Despite the broad recognition of rural electrification's importance, the evidence on its socio-economic impact — particularly among tribal and marginalized farming communities — remains uneven. Lee et al. (2020) caution that access to household electrification alone is not sufficient to drive meaningful gains in development outcomes, and the specific mechanisms through which agricultural well electrification translates into improved farmer welfare require closer empirical examination. Studies from semi-arid regions of southern India have demonstrated that irrigated cropping systems produce substantially more value added per hectare than rainfed crops, and that electricity access is a major driver of groundwater irrigation development (Fischer et al., 2022; Fishman et al., 2016). However, the distribution of these gains across different socio-economic groups remains contested (Balasubramanya & Buisson, 2022; Urfels et al., 2023).

In the tribal district of Dahod, Gujarat, these challenges are particularly acute. Dahod is one of India's most economically disadvantaged districts, with a Scheduled Tribe (ST) population comprising over 77% of the total population (Census of India, 2011). The district's agrarian economy is heavily dependent on rainfall, and water insecurity has historically constrained agricultural productivity, driven seasonal migration, and perpetuated cycles of poverty among tribal farming households (Khandker et al., 2014; Birthal et al., 2013). In this context, Madhya Gujarat Vij Company Limited (Electricity Company) — the electricity distribution utility serving central Gujarat — has implemented a targeted agricultural well electrification programme under the state's URJA initiative, providing subsidized electricity connections to farmers for groundwater extraction and irrigation.

Akber and Paltasingh (2025) demonstrate that rural electrification improves farm total factor productivity both in the short and long term, yet the specific pathways through which electrification translates into welfare improvements for tribal smallholders in water-scarce regions such as Dahod remain underexplored. The vast majority of studies on agricultural electrification in India have focused on states such as Punjab, Karnataka, and Uttar Pradesh, where irrigation infrastructure is more developed and landholdings are comparatively larger (Badiani et al., 2012; Chindarkar & Jain, 2020). Tribal regions of western India, characterized by small landholdings, subsistence agriculture, and historically limited infrastructure access, represent a significant gap in this evidence base (Urfels et al., 2023; Birthal et al., 2013).

This study addresses that gap by presenting findings from a cross-sectional survey of 315 agricultural well electrification beneficiaries across eight villages in Dahod district. The study pursues three sequential objectives: first, to profile the socio-demographic characteristics of AG well electrification beneficiaries; second, to assess the economic impact of electrification in terms of cost savings, income levels, and agricultural productivity; and third, to examine differential experiences of Electricity Company service delivery across income groups. The paper contributes to a growing body of literature on targeted energy access interventions and their role in transforming livelihoods among tribal farming communities in India.

LITERATURE REVIEW

The relationship between energy access and agricultural development has been extensively studied across developing economies, with a growing consensus that reliable electricity supply to rural areas catalyses improvements in farm productivity, household income, and livelihood security (Lee et al., 2020; Akber & Paltasingh, 2025). In India, this relationship is particularly significant given that groundwater-based irrigation — driven largely by electric pump sets — has been a primary engine of agricultural growth since the Green Revolution era. Ray and Pullabhotla (2023) demonstrate, using three decades of panel data, that the policy shift towards universal household electrification in the early 2000s came at a measurable cost to agricultural well electrification, with districts electrified after the policy change recording substantially fewer electrified groundwater wells per 100 electrified households than those electrified prior. This finding underscores the tension between household-level and productive-use electrification, and suggests that targeted agricultural well electrification programmes — such as the one studied here — address a distinct and critical policy gap.

The transition from diesel to electric pump sets is one of the most well-documented economic benefits of agricultural electrification in India. Mukherji et al. (2021), studying West Bengal, confirm that irrigation with electric pumps is considerably cheaper than with diesel pumps, and that access to electric pumping improves water access and rice production outcomes. The cost differential is substantial: the Ministry of New and Renewable Energy (MNRE) estimates that replacing a five-horsepower diesel pump with an electric or solar connection can reduce irrigation costs by approximately ₹50,000 per year per pump (Government of India, 2021). Balasubramanya and Buisson (2022) further note that India currently operates an estimated 32 million irrigation pumps, of which nearly 8 to 10 million run on diesel, representing a significant population of farmers still bearing high and volatile operational costs. For marginal and small farmers, particularly in tribal regions where income margins are thin, this cost burden directly constrains the ability to invest in inputs, expand cropped area, or shift to higher-value crops.

The linkage between irrigation access and crop diversification is well established in the agricultural economics literature. Mihrete and Mihretu (2025) argue that rural infrastructure development — particularly electrification

— is a critical precondition for crop diversification, enabling farmers to shift from subsistence-oriented monocultures toward more commercially viable and nutritionally diverse crop portfolios. In the Indian context, Birthal et al. (2013) demonstrate that smallholder farmers who gain access to irrigation are significantly more likely to transition toward high-value crops such as vegetables and fruits. Fischer et al. (2022), studying semi-arid Karnataka, find that irrigated cropping systems yield substantially more value added per hectare than rainfed systems, and that availability of irrigation can support multiple crop cycles per year for vegetables. These findings are directly relevant to Dahod's agrarian context, where rainfed monocropping has historically dominated, and where electricity-enabled irrigation has the potential to unlock year-round cultivation.

The income effects of agricultural electrification, while positive on average, are heterogeneous across farmer categories. Urfels et al. (2023) caution that farm size significantly limits the poverty-reduction potential of irrigation-led intensification in India's smallholder-dominated regions, and that even with access to irrigation, many marginal farmers remain below the poverty line unless complementary interventions in market access and value chain development accompany electrification. Khandker et al. (2014) similarly find that while rural electrification reduces poverty overall, its benefits are unevenly distributed, with better-resourced farmers capturing a disproportionate share of gains. These distributional concerns are particularly salient in tribal contexts, where land holdings are typically small, financial literacy is limited, and institutional access to formal credit and extension services is constrained (Birthal et al., 2013; Urfels et al., 2023).

Research on tribal agricultural livelihoods in Gujarat and surrounding regions highlights the compound disadvantages faced by Scheduled Tribe farmers. Landlessness, limited market integration, and dependence on seasonal rainfall have historically confined tribal communities in districts like Dahod to subsistence agriculture with minimal surplus and high vulnerability to climatic shocks (Khandker et al., 2014). Studies on smallholder farming in India suggest that livelihood security among marginal tribal farmers is significantly below that of non-tribal counterparts across social, economic, and environmental dimensions, with irrigation access among the strongest predictors of improved outcomes (Birthal et al., 2013; Urfels et al., 2023). In this context, infrastructure-linked interventions that reduce the cost of production while enabling water-secure cultivation offer a structurally transformative pathway for tribal livelihoods.

Despite this body of work, targeted empirical studies on agricultural well electrification programmes implemented specifically for tribal smallholders in water-scarce districts of western India remain scarce. The existing literature tends to draw on large-scale panel datasets or state-level analyses that do not capture the micro-level welfare dynamics experienced by beneficiary households at the village level. This study addresses that gap by providing primary survey evidence from Dahod district, contributing granular, community-level insights into the economic outcomes of Electricity Company's agricultural well electrification programme and their implications for tribal farmer welfare.

DATA AND METHODS

This study adopts a cross-sectional survey design to assess the socio-economic implications of agricultural well electrification among tribal farmers in Dahod district, Gujarat. The research was conducted as part of the URJA rural camp initiative, a collaborative effort between the Faculty of Social Work, The Maharaja Sayajirao University of Baroda, and Madhya Gujarat Vij Company Limited (Electricity Company). The camp was undertaken across eight villages in Dahod district over a period of seven days, with the primary objective of gathering household-level data from farmer beneficiaries of Electricity Company's AG well electrification programme.

Sampling and Data Collection

The study employed a purposive sampling strategy, targeting all traceable and consenting beneficiaries of the AG well electrification scheme across the eight villages. A total of 315 farmer beneficiaries were successfully interviewed, constituting the final analytical sample. Data were collected through structured face-to-face interviews using a pre-tested interview schedule designed to capture a range of socio-demographic and economic variables. The interview schedule included items on respondent age, gender, marital status, religion, educational qualification, family size, number of children, and primary occupation. Economic sections of the schedule addressed cost of irrigation before and after electrification, changes in household income satisfaction,

and changes in cropping patterns. All interviews were conducted in the local language by trained MSW students under the supervision of faculty coordinators, thereby minimising interviewer bias and improving data quality.

Participation in the study was entirely voluntary. Respondents were informed of the purpose of the research prior to the interview, and verbal informed consent was obtained from each participant. No personally identifiable information is reported in this paper. The study was conducted under the institutional oversight of the Faculty of Social Work, The Maharaja Sayajirao University of Baroda, in collaboration with Electricity Company.

Measures

Cost savings were assessed using a five-point Likert-type scale ranging from “not at all reduced” (1) to “completely reduced” (5), capturing respondents’ perceived reduction in agricultural input costs following electrification. Change in household income satisfaction was similarly measured on a five-point scale from “not at all changed” (1) to “completely changed” (5). Agricultural productivity was assessed through a direct comparison of the number of crops cultivated per year before and after electrification, based on self-reported data from beneficiaries. Total family income before and after electrification was recorded through open-ended recall questions and subsequently compared.

Data Analysis

Descriptive statistics were computed for all socio-demographic variables, including frequencies, percentages, means, and standard deviations where applicable (see Table 1). Frequencies and percentage distributions were used to summarise responses on cost reduction (Figure 1) and household income satisfaction (Figure 2). Crop diversification was analysed through a simple before-after comparison of the number of crop varieties cultivated annually (Table 2). Income change was illustrated through a graphical representation of total family income before and after electrification (Figure 1). All analyses were conducted using SPSS (version 26). Given the ordinal and non-normally distributed nature of the Likert-scale measures, non-parametric analytical approaches were prioritised for comparative analyses where applicable. The study’s cross-sectional design precludes causal inference, and all findings are interpreted as associational and descriptive in nature.

RESULTS

A total of 315 farmer beneficiaries of Electricity Company’s agricultural well electrification programme were surveyed across eight villages in Dahod district. The socio-demographic characteristics of the sample are summarised in Table 1. The sample was predominantly male (90.2%), with female respondents constituting 9.8% of the total. The age of respondents ranged from 19 to 100 years, with a mean age of 50.02 years ($SD = 15.54$) and a median of 50 years. The largest age group was 40–49 years (24.4%), followed by 50–59 years (21.6%) and 60–69 years (19.0%). Nearly all respondents were married (96.2%), and the overwhelming majority identified as Hindu (98.4%). The mean family size was 8.56 members, and respondents had a mean of 3.36 children. In terms of educational attainment, 32.7% of respondents had completed graduate-level education or above, while 24.1% had completed up to Class 12 and 23.5% up to Class 10. Only 5.7% reported no formal education. All respondents reported agriculture as their primary occupation, consistent with the programme’s eligibility criteria. A substantial proportion (57.7%) held Below Poverty Line (BPL) income cards, with a further 36.0% holding Above Poverty Line (APL) cards, 1.9% holding Antyodaya cards, and 4.4% having no income card.

Prior to electrification, farmer beneficiaries relied on diesel-powered motors for groundwater extraction and irrigation, incurring significant daily fuel costs. Following the electrification of AG wells by Electricity Company, a large majority of respondents reported a meaningful reduction in these costs (see Figure 1). Specifically, 37.2% reported that costs had been “reduced a lot,” and 35.0% reported a “moderate” reduction. Combined, nearly three-quarters (73.1%) of respondents perceived a substantial to complete reduction in agricultural input costs. Only 6.9% reported no reduction at all, and just 0.9% indicated a complete elimination of costs. These findings indicate that the transition from diesel to electric irrigation has delivered tangible and widely perceived cost relief to the majority of beneficiary farmers.

Respondents were asked to rate the degree to which their satisfaction with household income had changed following electrification of their AG well. As shown in Figure 2, the responses were concentrated in the middle-to-upper range of the scale. The largest share of respondents — 49.2% — reported that their income satisfaction had “moderately changed,” and a further 26.8% indicated it had “changed a lot.” Together, 76.0% of respondents reported at least a moderate improvement in household income satisfaction. Only 6.3% reported no change at all. These findings, read alongside the cost reduction data in Figure 1, suggest that the economic relief generated by reduced irrigation costs has translated into a broader and perceptible improvement in household economic wellbeing.

Table 1: Socio-Demographic Profile of Respondents (N = 315)

| Characteristic | Category | n | % |
|-----------------------|--------------------------|-----|------|
| Gender | Male | 284 | 90.2 |
| | Female | 31 | 9.8 |
| Age (years) | Mean = 50.02, SD = 15.54 | | |
| Marital Status | Married | 303 | 96.2 |
| | Single | 12 | 3.8 |
| Religion | Hindu | 310 | 98.4 |
| | Christian | 4 | 1.3 |
| | Muslim | 1 | 0.3 |
| Family Size | Mean = 8.56, SD = 4.10 | | |
| No. of Children | Mean = 3.36, SD = 2.03 | | |
| Highest Qualification | No formal education | 18 | 5.7 |
| | Up to Class 8 | 44 | 14.0 |
| | Up to Class 10 | 74 | 23.5 |
| | Up to Class 12 | 76 | 24.1 |
| | Graduate or above | 103 | 32.7 |
| Income Card Status | BPL | 183 | 57.7 |
| | APL | 114 | 36.0 |
| | Antyodaya | 6 | 1.9 |
| | No card | 14 | 4.4 |

Table 2: Number of Crops Cultivated Before and After AG Well Electrification

| Indicators | Before Electrification | After Electrification |
|-------------------------------------|--|---|
| Number of crops cultivated per year | ~2 | 7–10 |
| Main crops | Maize, seasonal vegetables (e.g., tuvar) | Maize, wheat, rice, seasonal vegetables, horticulture (guava, papaya, amla), floriculture (roses, marigold) |

Most Farmers Report Significant Cost Reduction Post-Electrification

"Extent of cost reduction post-electrification of AG wells" (% of respondents, N=315)

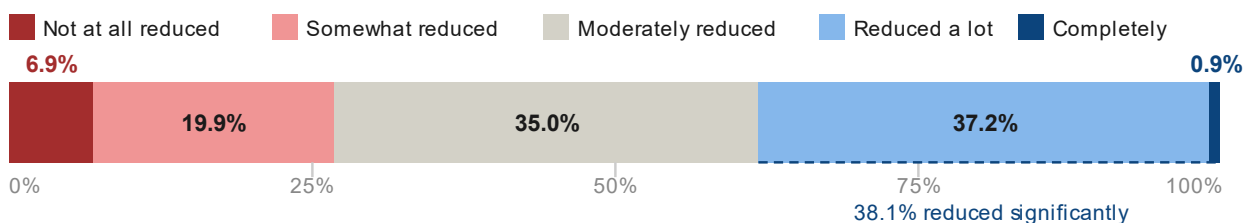


Figure 1: Extent of cost reduction post-electrification of AG wells (N=315)

Source: Primary data

Beyond perceived satisfaction, total family income was reported by respondents to have increased approximately threefold following electrification of their AG wells (see Figure 1). This increase is attributable to year-round irrigation availability, which freed farmers from sole dependence on seasonal rainfall and enabled continuous cultivation. The electrification of wells thus provided not merely a cost reduction on the input side but a structural expansion of productive capacity — enabling farmers to cultivate across seasons rather than being confined to the kharif cycle.

Electrification Widely Improves Household Income Satisfaction

"Change in household income satisfaction post-electrification" (% of respondents, N=315)

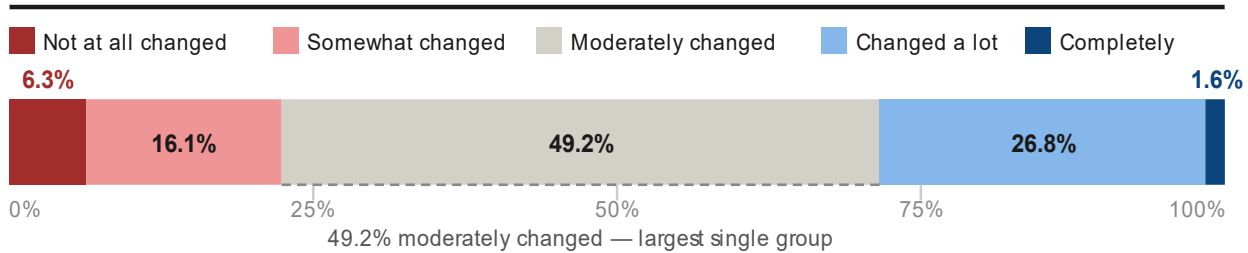


Figure 2: Change in household income satisfaction post-electrification (N=315)

Source: Primary data

One of the most striking findings of the study concerns the transformation in cropping patterns following electrification. As shown in Table 2, the number of crops cultivated per year increased from approximately 2 before electrification to between 7 and 10 after electrification. Prior to electrification, cultivation was predominantly limited to maize and a small number of seasonal vegetables such as tuvar. Following electrification, respondents reported cultivating wheat and rice in addition to maize, along with a considerably expanded range of seasonal vegetables including tomato, brinjal, onion, and garlic. Beyond staple crops, a number of farmers had diversified into horticulture — growing guava, papaya, and amla — and into floriculture, with roses and marigolds being cultivated for sale in local markets and during festivals. This degree of crop diversification represents a qualitative shift in agricultural practice, from subsistence-oriented monoculture toward commercially diversified farming. Respondents noted that vegetables were sold on a weekly basis at local fairs and village markets, directly contributing to household income without the need to travel to distant mandis. The programme’s requirement of a minimum land holding of one acre ensured that all beneficiaries had sufficient cultivable area to realise this diversification potential.

DISCUSSION

This study examined the socio-economic implications of agricultural well electrification among tribal farmer beneficiaries of Electricity Company’s programme in Dahod district, Gujarat. The findings are discussed here in relation to the two objectives of the study and situated within the broader empirical literature on rural electrification and agricultural livelihoods in India.

The socio-demographic profile of respondents revealed several characteristics that are important for contextualising the findings. The sample was overwhelmingly male (90.2%), reflecting the gendered nature of formal land ownership and programme registration in tribal agrarian communities of western India, where women’s names are infrequently recorded as primary landholders or connection holders. This gender skew is consistent with patterns observed in broader studies of agricultural programme beneficiaries in India, where male household heads disproportionately hold formal entitlements even when women contribute substantially to farm labour (Khandker et al., 2014; Birthal et al., 2013). The mean respondent age of 50.02 years suggests that the primary beneficiaries are mid-career to older farmers, which has implications for the long-term sustainability of the programme’s impact, since younger household members are increasingly taking over the management of electrified wells, as the study also noted in cases of deceased or aged original beneficiaries.

The predominance of BPL card holders (57.7%) confirms that the programme has, to a meaningful degree, reached its intended population — economically marginalised farming households. This is significant because agricultural electrification programmes in India have historically tended to benefit better-resourced farmers with larger landholdings and greater capacity to navigate bureaucratic processes (Urfels et al., 2023; Khandker et al., 2014). The presence of Antyodaya cardholders, representing the poorest stratum, among the beneficiary pool suggests that Electricity Company's implementation in Dahod has achieved a degree of pro-poor targeting that is not universal across comparable programmes elsewhere in India.

The finding that 73.1% of respondents reported a substantial to complete reduction in irrigation costs following electrification is consistent with a well-established body of evidence on the economic advantages of electric over diesel-powered irrigation in India. Buisson et al. (2021) confirm that electric pumping is substantially cheaper than diesel pumping, and Balasubramanya and Buisson (2022) estimate that a large proportion of India's estimated 8 to 10 million diesel-powered irrigation pumps represent an ongoing and avoidable cost burden for marginal farmers. For tribal farmers in Dahod, whose income margins are thin and whose access to formal credit is limited, the elimination of daily diesel expenditure represents a particularly impactful form of economic relief — one that operates on the input side of the agricultural budget before any changes in output or revenue are realised.

The finding that total family income increased approximately threefold following electrification (see Figure 1) is striking, though it must be interpreted with appropriate caution given the cross-sectional and self-reported nature of the data. Respondents may have overstated gains, or the threefold figure may partly reflect broader agricultural trends in the period rather than being solely attributable to electrification. Nonetheless, the direction and magnitude of reported income change is consistent with findings from comparable contexts. Akber and Paltasingh (2025) demonstrate that rural electrification produces both short- and long-term improvements in farm total factor productivity, and Fischer et al. (2022) find that irrigated systems in semi-arid India can generate substantially more value added per hectare than rainfed systems. The income gains reported in Dahod are plausibly explained by these mechanisms: access to year-round irrigation extended the productive season, enabling farmers to cultivate across the full annual calendar rather than only during the kharif season.

The reported improvement in household income satisfaction (76.0% reporting at least moderate improvement) reinforces this interpretation. Satisfaction-based measures capture the subjective experience of welfare change and are widely used in livelihood assessments as proxies for actual economic improvement when precise income data are difficult to obtain in field survey conditions (Lee et al., 2020). The convergence of cost reduction data, income satisfaction data, and self-reported income change across three separate measures strengthens the overall credibility of the finding that electrification delivered meaningful economic gains to beneficiary households.

Perhaps the most structurally significant finding of this study is the reported increase in the number of crops cultivated annually — from approximately 2 before electrification to between 7 and 10 after electrification (see Table 2). This is not merely a quantitative shift but a qualitative transformation in the nature of farming practice among respondents. The transition from rain-dependent monoculture — centred on maize and a narrow range of seasonal vegetables — to year-round, diversified cultivation incorporating wheat, rice, multiple vegetable varieties, horticultural fruits, and floriculture represents precisely the kind of structural change that agricultural development scholars argue is necessary for smallholder income growth and food security (Birthal et al., 2013; Mihrete & Mihretu, 2025).

The emergence of floriculture — particularly rose and marigold cultivation in villages such as Rozam — as a new income stream is notable because it signals a transition toward commercially oriented agriculture. Floriculture products are perishable, market-facing commodities whose cultivation implies farmer confidence in stable water supply, market connectivity, and income predictability. Ray and Pullabhotla (2023) demonstrate that agricultural electrification can trigger sustained changes in cropping behaviour beyond the immediate adoption period, and the diversification patterns observed in Dahod are consistent with this longer-term dynamic. The availability of local weekly markets and village fairs as sales outlets, noted by respondents, further supports the viability of this diversification by reducing transaction costs associated with reaching distant agricultural markets.

The finding also connects with observations on migration reduction. Prior to electrification, seasonal out-migration was a common livelihood strategy among tribal households in Dahod, driven by the absence of year-round agricultural income. The reported decline in long-term migration following electrification, combined with improved school attendance in villages such as Rozam and Bhatiwada, suggests that the economic stabilisation produced by year-round irrigation has secondary social benefits that extend beyond direct income effects. This pattern aligns with findings from broader studies on the relationship between irrigation access and rural household stability in India (Urfels et al., 2023; Birthal et al., 2013).

Several limitations of this study warrant acknowledgement. First, the cross-sectional design prevents causal attribution. All economic changes reported — including income gains and cost reductions — are based on retrospective self-report and cannot be verified against baseline data collected before electrification. The absence of a control group of non-electrified farmers further limits the ability to isolate the effect of the programme from other concurrent changes in the agricultural or policy environment. Second, the predominance of male respondents (90.2%) means that the study's findings may not fully capture the experiences of women farmers or female household members, whose labour contributions and perceptions of welfare change may differ. Third, recall bias may affect the reliability of income and cost data, particularly for figures reported from the pre-electrification period. Fourth, the purposive sampling strategy, while appropriate for a programme evaluation context, limits the generalisability of findings beyond the eight surveyed villages. Future research should consider longitudinal designs with matched comparison groups, greater attention to gender-disaggregated outcomes, and broader geographic sampling across Electricity Company's service area to strengthen the evidence base on agricultural well electrification in tribal India.

REFERENCES

1. Akber, N., & Paltasingh, K. R. (2025). How could we energise Indian farms? Power investment vs. power subsidy. *Energy Research Letters*, 6(Early View). <https://doi.org/10.46557/001c.142282>
2. Badiani, R., Jessoe, K. K., & Plant, S. (2012). Development and the environment: The implications of agricultural electricity subsidies in India. *The Journal of Environment & Development*, 21(2), 244–262. <https://doi.org/10.1177/1070496512442507>
3. Balasubramanya, S., & Buisson, M. C. (2022). Positive incentives for managing groundwater in the presence of informal water markets: Perspectives from India. *Environmental Research Letters*, 17(10), 101001. <https://doi.org/10.1088/1748-9326/ac914f>
4. Birthal, P. S., Joshi, P. K., Roy, D., & Thorat, A. (2013). Diversification in Indian agriculture toward high-value crops: The role of small farmers. *Canadian Journal of Agricultural Economics*, 61(1), 61–91. <https://doi.org/10.1111/j.1744-7976.2012.01258.x>
5. Buisson, M. C., Balasubramanya, S., & Stifel, D. (2021). Electric pumps, groundwater, agriculture and water buyers: Evidence from West Bengal. *Journal of Development Studies*, 57(11), 1893–1911. <https://doi.org/10.1080/00220388.2021.1906862>
6. Census of India. (2011). *District census handbook: Dahod*. Office of the Registrar General & Census Commissioner, India.
7. Chindarkar, N., & Jain, A. (2020). Link between farm electricity supply management, farm investments, and farm incomes: Evidence from India. *Energy Policy*, 141, 111407. <https://doi.org/10.1016/j.enpol.2020.111407>
8. Fischer, C., Aubron, C., Trouvé, A., Sekhar, M., & Ruiz, L. (2022). Groundwater irrigation reduces overall poverty but increases socioeconomic vulnerability in a semiarid region of southern India. *Scientific Reports*, 12, 8850. <https://doi.org/10.1038/s41598-022-12814-0>
9. Fishman, R., Lall, U., Modi, V., & Parekh, N. (2016). Can electricity pricing save India's groundwater? Field evidence from a novel policy mechanism in Gujarat. *Journal of the Association of Environmental and Resource Economists*, 3(4), 819–855. <https://doi.org/10.1086/688496>
10. Government of India, Ministry of New and Renewable Energy. (2021). *PM-KUSUM scheme booklet*. MNRE. <https://mnre.gov.in>
11. Khandker, S. R., Samad, H. A., Ali, R., & Barnes, D. F. (2014). Who benefits most from rural electrification? Evidence in India. *The Energy Journal*, 35(2), 75–96. <https://doi.org/10.5547/01956574.35.2.4>

12. Lee, K., Miguel, E., & Wolfram, C. (2020). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, 128(4), 1523–1565. <https://doi.org/10.1086/705417>
13. Mihrete, T. B., & Mihretu, F. B. (2025). Crop diversification for ensuring sustainable agriculture, risk management and food security. *Global Challenges*, 9(2), 2400267. <https://doi.org/10.1002/gch2.202400267>
14. Mukherji, A., Buisson, M. C., & co-authors. (2021). Electric pumps, groundwater, agriculture and water buyers: Evidence from West Bengal. *Journal of Development Studies*, 57(11), 1893–1911. <https://doi.org/10.1080/00220388.2021.1906862>
15. Ray, S., & Pullabhotla, H. K. (2023). The changing impact of rural electrification on Indian agriculture. *Nature Communications*, 14, 6780. <https://doi.org/10.1038/s41467-023-42533-7>
16. Ray, S., & Pullabhotla, H. K. (2023). The changing impact of rural electrification on Indian agriculture. *Nature Communications*, 14, 6780. <https://doi.org/10.1038/s41467-023-42533-7>
17. Shah, T. (2009). *Taming the anarchy: Groundwater governance in South Asia*. Resources for the Future Press.
18. Urfels, A., Mausch, K., Harris, D., McDonald, A. J., Kishore, A., Balwinder-Singh, van Halsema, G., Struik, P. C., Craufurd, P., Foster, T., Singh, V., & Krupnik, T. J. (2023). Farm size limits agriculture's poverty reduction potential in Eastern India even with irrigation-led intensification. *Agricultural Systems*, 207, 103618. <https://doi.org/10.1016/j.agsy.2023.103618>