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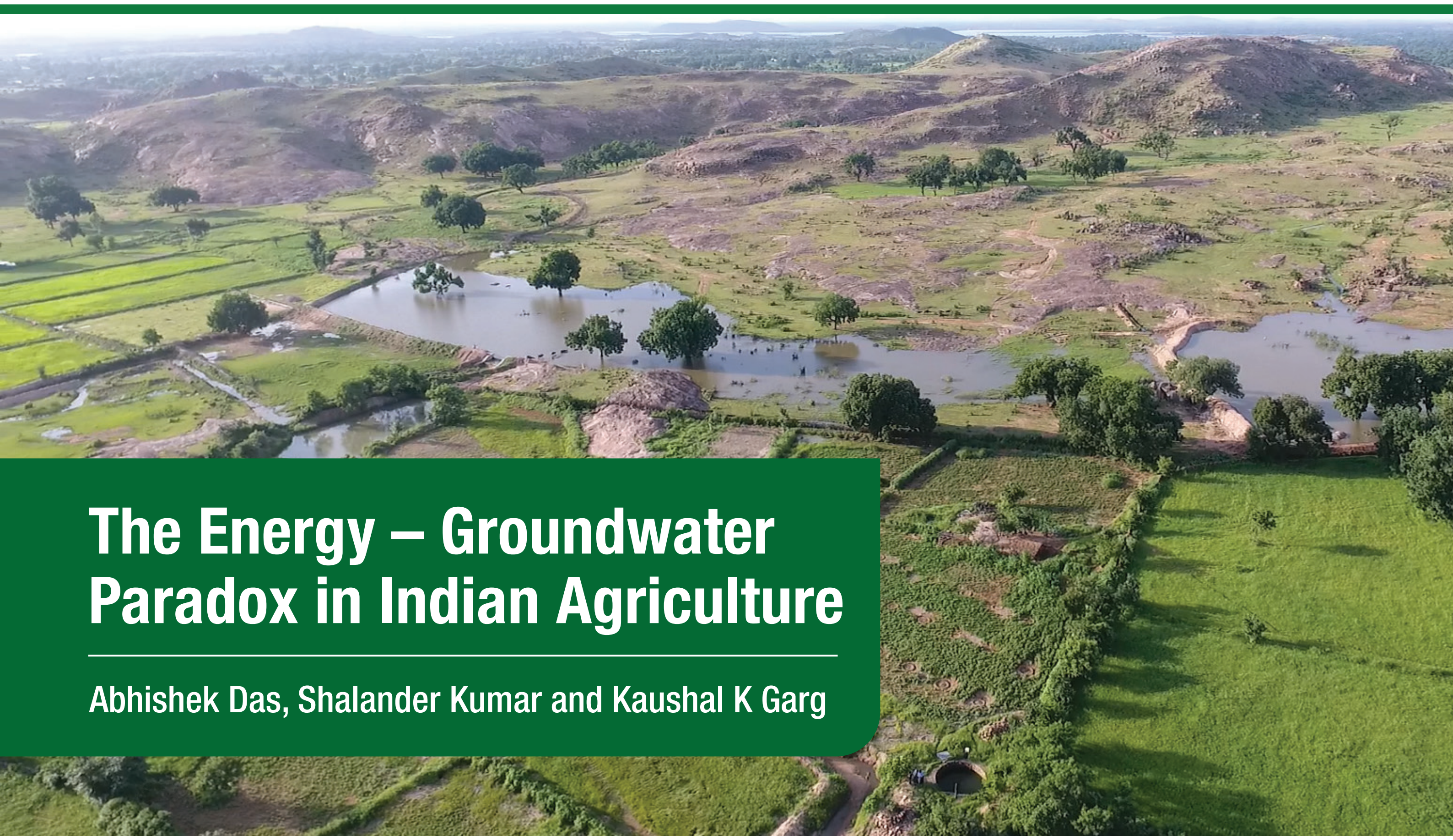
Policy Note

December 2025



The Energy – Groundwater Paradox in Indian Agriculture

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1. Background

Groundwater underpins Indian agriculture, supporting the majority of irrigated area and enabling multiple cropping and farming systems, yield stability, and risk management in a highly variable monsoon environment. For millions of farmers, particularly in semi-arid and rainfed regions, access to groundwater has transformed agriculture from a single-season activity into a year-round livelihood strategy. At the same time, this growing dependence has increased vulnerability, as groundwater availability is finite, unevenly distributed, and under rising stress across large parts of the country.

The expansion of groundwater irrigation has been closely associated with electricity subsidies for agriculture. Introduced as welfare- and productivity-enhancing measures, subsidized or free electricity for farming reduced pumping costs and accelerated the spread of tube wells/bore wells. Over time, these subsidies became embedded in rural political economies as a form of income support and risk mitigation. While they contributed significantly to production growth and climate risk buffering, they also removed the marginal cost of groundwater extraction from farm-level decision-making. As a result, groundwater overexploitation has emerged as a systemic outcome of policy design rather than individual farmer behavior. By decoupling energy use from water scarcity, existing incentive structures encourage extraction beyond natural recharge, particularly in hard-rock aquifers and intensively cultivated regions, reducing the effectiveness of parallel investments in water conservation and efficiency.

These interlinked pressures have direct implications for food security, rural livelihoods, and climate resilience. Declining groundwater levels threaten the sustainability of irrigated agriculture, widen inequalities in water access, and increase exposure to climate-related shocks. Addressing these challenges requires treating irrigation, groundwater, Price policy/ MSP, and energy policies as an integrated policy system rather than as separate sectoral domains.

Policy focus and governance locus. This policy note is directed primarily toward state governments, electricity distribution companies, and central ministries responsible for agriculture, power, and water resources, where key levers for electricity pricing, subsidy design, and irrigation governance are located. While groundwater is a local resource, the incentives shaping its extraction are largely determined by state-level electricity policies and centrally supported subsidy and technology programs. Effective reform therefore depends less on new schemes and more on coordinated adjustments to existing policy instruments at the state level and political economy.

2. The Policy Contradiction: Subsidies vs. Sustainability

A central contradiction in India's irrigation economy, most visibly shaped by state-level electricity subsidy regimes, lies in the coexistence of free or near-free electricity for agriculture with policy commitments to groundwater conservation and sustainable resource use. By eliminating the marginal cost of pumping, electricity subsidies distort irrigation incentives. Farmers respond rationally by increasing pumping duration, irrigation frequency, and well depth, largely independent of local groundwater conditions. In effect, electricity policy functions as a de facto groundwater policy, despite not being designed or governed as such (Shah, 2009; Scott & Shah, 2004).

This incentive structure weakens the effectiveness of water conservation efforts. Public investments in micro-irrigation, water-use efficiency, rainwater harvesting, and recharge structures operate alongside energy policies that reward higher extraction. When pumping costs remain detached from water scarcity, efficiency gains from technology or agronomic improvements are frequently offset by expanded irrigated area, higher cropping intensity, or shifts toward water-intensive crops, patterns widely observed in groundwater-stressed regions (Perry, 2011; Fishman et al., 2015). As a result, efficiency-enhancing technologies often increase effective demand rather than reduce aggregate groundwater abstraction, underscoring the limits of technology-led solutions in the absence of aligned price and governance signals.

The fiscal and institutional consequences of this contradiction are equally significant. Agricultural electricity consumption accounts for a substantial share of power demand in many states but contributes minimally to utility revenues, imposing persistent fiscal burdens on state governments and weakening the financial viability of electricity distribution companies (Rao, 2018). In response, utilities rely on rationing rather than pricing, reinforcing inefficient pumping behavior and diffusing accountability across sectors. Groundwater overuse, in this context, is not a failure of farmers, but a predictable, policy-induced outcome rooted in systemic incentive misalignment.

This incentive distortion provides the analytical foundation for understanding why subsequent policy interventions, despite scale and intent, have struggled to deliver groundwater sustainability.

3. Solar Irrigation and Technological Pathways: Promise and Risk

Solar-powered irrigation has emerged as a prominent policy response to growing tensions between agricultural electricity subsidies, power sector stress, and climate mitigation objectives. Its promotion is driven by multiple goals, including reducing the fiscal burden of agricultural power subsidies, improving the reliability of irrigation energy, lowering dependence on diesel, and supporting the transition to renewable energy. In principle, solar irrigation offers farmers predictable daytime power while contributing to decarbonization and energy security (IRENA, 2016; World Bank, 2018).

When assessed through the same incentive lens that characterizes electricity subsidies, however, solar irrigation presents significant risks. Once installed, solar pumps operate at near-zero marginal cost, removing economic constraints on pumping decisions in much the same way as free grid electricity. In groundwater-stressed regions, this can lead to longer and more frequent pumping, often exceeding recharge rates. Evidence from multiple contexts indicates that, in the absence of effective groundwater governance, solar irrigation can accelerate depletion rather than mitigate it (Shah et al., 2018; Gupta et al., 2020). These effects are not distributionally neutral: capital subsidies and access to credit tend to favor larger farmers, while intensified pumping by early adopters can lower water tables and reduce access for smallholders relying on shallow wells.

Solar irrigation is not inherently incompatible with groundwater sustainability. Grid-connected models that allow farmers to sell surplus electricity back to utilities introduce an opportunity cost to pumping, transforming energy generation into an alternative income stream. Where supported by reliable pricing and institutional capacity, such buy-back mechanisms have demonstrated potential to realign incentives toward conservation (Shah et al., 2021). The central policy insight is that technology functions as an incentive amplifier: outcomes depend less on the technology itself and more on the governance framework within which it is deployed.

4. Why Existing Policies Underperform: A Policy Effectiveness Lens

Despite extensive public investment and a proliferation of programs across agriculture, water, and energy, policy outcomes related to groundwater sustainability remain weak. This underperformance reflects not a failure of implementation, but a structural consequence of fragmented mandates, misaligned accountability, and evaluation frameworks disconnected from aquifer-level outcomes. This diagnosis underpins the need for incentive-aligned policy directions rather than additional standalone schemes.

Responsibilities for electricity supply, irrigation development, groundwater management, and agricultural support are distributed across separate agencies with limited coordination. Each sector operates with internally coherent objectives yet collectively generates outcomes that weaken groundwater sustainability. As a result, no single institution is accountable for aquifer outcomes, despite these outcomes emerging from combined policy actions (Shah, 2009; Mukherji et al., 2017). This fragmentation explains why reforms must explicitly link electricity governance with groundwater management, as emphasized in the Policy Directions.

The political economy of electricity subsidies further constrains reform. Free or highly subsidized power is embedded in rural social contracts and electoral competition, making direct pricing or withdrawal politically difficult. Consequently, past reforms have relied on incremental adjustments, such as rationing, feeder separation, or technological substitution, rather than changes to subsidy design. While these approaches have reduced fiscal pressure or improved supply reliability, they have largely failed to alter incentives for groundwater extraction, reinforcing the case for shifting from input subsidies to outcome-based support (Rao, 2018).

Current conditions, however, create a more favorable window for reform. Rising fiscal stress, persistent financial fragility of distribution companies, rapid expansion of solar irrigation, and the maturation of direct benefit transfer infrastructure together enable a transition toward more transparent and targeted support. These factors reduce political resistance by allowing income protection to be decoupled from resource use, directly informing proposed directions on incentive-compatible solar models and subsidy reorientation.

Policy effectiveness is also weakened by an over-reliance on output indicators. Success is commonly measured by connections provided, pumps installed, hectares covered, or solar capacity added—metrics that capture delivery rather than outcomes. They obscure whether groundwater extraction has declined, aquifers have stabilized, or farmer vulnerability has been reduced (Perry, 2011).

Strengthening accountability requires complementing delivery metrics with a limited set of outcome-oriented indicators, such as trends in groundwater levels, stabilization of well depths, or seasonal pumping intensity. Explicitly linking these indicators to policy objectives reinforces the role of information and smart monitoring as transition tools, as outlined in the Policy Directions.

Finally, existing policies have uneven impacts across farmers and regions. Larger and better-capitalized farmers are better positioned to benefit from subsidies and new technologies, while smallholders and groundwater-scarce regions bear the costs of depletion. Together, these dynamics reinforce a central insight: policy failure in this domain is structural, rooted in incentive misalignment and fragmented governance, underscoring the need for coordinated reform across the energy–water–agriculture nexus.

5. Policy Directions: Aligning Incentives Across the Nexus

Addressing groundwater depletion and energy inefficiency requires policy reform that realigns incentives across the water–energy–agriculture nexus, rather than isolated adjustments within individual sectors. The following policy directions focus on reshaping signals that guide farmer behavior, institutional priorities, and public expenditure, while remaining compatible with livelihood and political realities.

Rationalising Electricity Subsidies for Irrigation

Currently, electricity subsidies for agricultural irrigation are largely provided without differentiation based on farm size, cropping patterns, or actual water and energy requirements. This uniform approach, while administratively simple, weakens the ability of subsidies to support efficient resource use and long-term sustainability.

A gradual transition toward a more targeted subsidy framework could enhance both equity and effectiveness. Under this approach, the subsidy value would be transferred directly to farmers' bank accounts, calculated based on standard electricity tariffs, cultivated land area, and crop-specific normative water requirements. This would preserve income support while making the cost of additional electricity use transparent at the farm level. If a farmer's actual electricity consumption exceeds the subsidised entitlement, the incremental use would be billed at the prevailing tariff. This design introduces an incentive to align irrigation practices with agronomic and water-efficiency norms, without withdrawing support for essential irrigation needs.

Such a reform reframes electricity subsidies from an open-ended entitlement to a predictable and transparent support mechanism, striking a balance between farmer welfare and responsible resource use, while maintaining fiscal discipline. Implementation should be phased and voluntary in the initial years, starting with pilot districts, while fully protecting current income support through direct transfers. Farmers retain flexibility in irrigation decisions, with higher efficiency directly translating into savings they can keep, ensuring the reform is seen as a benefit rather than a restriction.

Link electricity governance with aquifer-level management

Electricity supply arrangements should be explicitly connected to local groundwater conditions. Treating energy allocation as a tool for aquifer management, rather than a uniform entitlement, can enable collective limits on extraction while avoiding direct regulation of individual wells. This linkage recognizes electricity policy as a central lever of groundwater governance. Implementation can be routed through locally agreed feeder- or village-level electricity norms, informed by observed groundwater trends and developed with farmer participation, so that limits apply collectively rather than to individual wells. This protects farmers from arbitrary controls while ensuring reliable power today and water security for future seasons.

Align crop support and procurement with water availability

Agricultural support policies implicitly shape water demand through crop choices. Aligning price support, procurement, and extension services with local agroecological and hydrological conditions can reduce incentives for water-intensive cropping in stressed regions, easing pressure on aquifers while supporting diversified and climate-resilient livelihoods. Transition support, including extension and market access, is required to ensure that farmers in water-stressed regions are not penalized for shifting away from water-intensive crops. Implementation can begin by guaranteeing assured procurement, price support, and extension services for less water-intensive crops in stressed regions, so that farmers face no income risk when shifting cropping patterns. Gradual alignment allows farmers to transition based on clear market signals rather than compulsion.

Shift from input subsidies to outcome-based incentives

Public support should progressively move away from subsidizing energy and pumping capacity toward rewarding outcomes such as groundwater conservation, stabilized aquifer levels, or improved water-use efficiency. Outcome-based incentives can preserve income support while internalizing resource scarcity, transforming conservation from a regulatory obligation into an economically rational choice for farmers. Implementation can start by offering voluntary bonus payments or top-ups to existing support for farmers who demonstrate reduced pumping, stable well levels, or efficient irrigation, without withdrawing current subsidies. Over time, these incentives make conservation a source of additional income rather than a compliance burden.

Design incentive-compatible solar irrigation models

Solar irrigation must be embedded within incentive structures that discourage unrestricted pumping. Models that enable farmers to sell surplus electricity to the grid create an opportunity cost for groundwater extraction, reframing energy generation as an alternative source of income. Such designs align renewable energy goals with water conservation, rather than undermining them. Priority access for smallholders, safeguards against excessive capital concentration, and protections for shallow well users are necessary to prevent solar adoption from amplifying existing inequalities in groundwater access. Implementation should prioritize grid-connected solar pumps with assured buy-back prices, allowing farmers to earn reliable income from selling surplus power instead of pumping more water. Phased rollout with priority for smallholders ensures solar irrigation improves incomes without increasing water risk.

Reorient subsidy expenditure toward resilience and recharge

Fiscal resources currently absorbed by open-ended electricity subsidies can be redirected toward groundwater recharge, storage infrastructure, and resilience-enhancing investments. Reorientation of subsidies toward long-term system sustainability strengthens public returns on expenditure and reduces the need for escalating support in the future. Implementation can begin by reinvesting a portion of subsidy savings into locally visible recharge works, water storage, and drought-resilience assets that directly improve well reliability and reduce irrigation risk for farmers. Linking investments to local benefits builds trust and support for gradual subsidy reorientation.

Moving toward sustainable groundwater and energy use in agriculture requires a shift from fragmented interventions to coherent reform guided by a small set of principles that align incentives, institutions, and outcomes. Policy coherence across electricity, water, and agriculture must take precedence over sectoral optimization, recognizing that energy access is a primary driver of groundwater extraction, while reforms must be regionally differentiated to reflect wide variation in aquifer conditions, farming systems, and institutional capacity. Transitions should be gradual rather than abrupt, using phased realignment of incentives to protect livelihoods, build trust, and enable learning, with income security treated as a prerequisite for conservation rather than a residual concern. Groundwater must be recognized as a shared resource, strengthening the case for coordinated energy governance and aquifer-level management. Managing distributional impacts is central to political feasibility: reforms that visibly protect smallholder incomes, reduce downside risk, and offer credible transition pathways are more likely to gain acceptance and sustain compliance, making equity-sensitive design a core condition for durable policy reform rather than an add-on.

6. Conclusions

India's groundwater crisis is not simply the result of hydrological stress or individual farmer behavior; it is fundamentally shaped by policy choices that disconnect irrigation, energy use, and resource limits. Electricity subsidies and technology-driven interventions, while designed to support agricultural growth and welfare, have unintentionally reinforced patterns of overextraction by misaligning incentives across the water-energy-agriculture nexus. As climate change intensifies rainfall variability and dependence on irrigation, and as solar irrigation scales rapidly across rural landscapes, the costs of maintaining these contradictions are rising.

This moment presents both urgency and opportunity. Integrated policy reform offers a pathway to sustain agricultural livelihoods while restoring coherence between productivity, resource conservation, and fiscal stability. Aligning incentives, strengthening governance linkages, and reframing groundwater as a shared asset can transform current trade-offs into mutually reinforcing outcomes. The challenge ahead is not choosing between growth and sustainability, but designing institutions and incentives that allow both to endure under increasing environmental and climatic pressure.

Acknowledgement

This work was supported by the CGIAR Policy Innovations Science Program for Food, Land, and Water system transformation through CGIAR Fund Donors and bilateral funding agreements, and the Indian Council of Agricultural Research. The contents of this publication are the responsibility of the authors and do not necessarily reflect the views of the funders

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a pioneering non-profit organization focused on scientific research for development, committed to transforming dryland farming and agri-food systems. Working with global partners, ICRISAT develops innovative solutions to address hunger, poverty, and environmental degradation, benefiting 2.1 billion people across the drylands of Asia, Africa, and beyond.

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