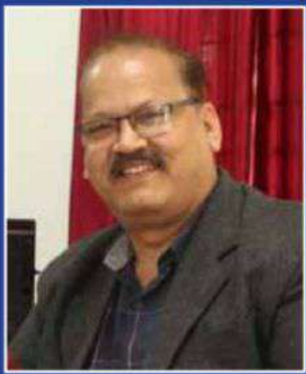
Renewable Energy: A New Paradigm for Growth



Ajai Singh
Professor, Department of Civil Engineering & Dean School of Engineering and Technology, Central University of Jharkhand, Ranchi, India, Email: ajai.singh@cuj.ac.in

Agriculture is the backbone of India's rural economy, employing nearly 42% of the workforce and accounting for about 85% of freshwater withdrawals. Coverage of irrigation area increased between 2016 and 2021 from 49.3 to 55% of gross cropped area. Irrigation reliability, however, depends on access to affordable and dependable energy. The agricultural sector in India consumes nearly 20% of total electricity and a large share of diesel fuel, primarily for irrigation pumping and this has led to high fiscal stress, inefficient water use, and unsustainable groundwater extraction. For decades, expansion of irrigation relied on canals, diesel pump-sets, and heavily subsidized grid power. As climate variability, groundwater depletion, and energy subsidies strain both ecosystems and state budgets, renewable energy (RE) offers a transformative opportunity to decouple irrigation growth from fossil dependence. The renewable energy transition aligns with India's commitments under the Paris Agreement and the Nationally Determined Contributions targeting 50% of cumulative power capacity from non-fossil sources by 2030. In agriculture, it promises a dual dividend: energy self-sufficiency for irrigation and decarbonization of a high-emission sector. The adoption of RE technologies, especially solar photovoltaic (PV) irrigation pumps, agrivoltaics, canal-top and floating solar, and biomass-based micro-grids—marks a structural shift toward sustainability and circular resource use.

Agricultural power demand in India is approximately 280 TWh/year, with more than 21 million electric and 8 million diesel pumps in operation. The sector contributes about 17% of national CO_2 emissions through diesel use and embedded electricity. Subsidized tariffs result in annual fiscal burdens exceeding Rs.1 lakh crore for state utilities. Furthermore, erratic grid supply, often at night, causes over-pumping and inefficient irrigation practices. PM-KUSUM and the State Solar Policy should offer strategic levers to mainstream decentralized RE in irrigation. Research on the water–energy nexus in agriculture highlights both opportunities and risks of renewable integration. This has been reported that solar pumps under Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) increased irrigation

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reliability and cropping intensity by 20-25% in semi-arid regions. Many researchers emphasized that cheap solar irrigation can empower smallholders but requires groundwater governance to prevent over-extraction. More recent experiments in Gujarat, Rajasthan, and Jharkhand show the techno-economic viability of solar-powered drip irrigation and community-owned micro-grids for tribal farmers.

Solar Photovoltaic (Solar-PV) powered pumps, micro-grids, and canal-top systems are now mature technologies. Component B of PM-KUSUM targets 1.4 million stand-alone solar pumps, while Component C promotes feeder solarization for daytime supply. Bio-gas and biomass gasifiers can fuel micro-irrigation pumps and farm machinery while utilizing crop residues. Digestate (nutrient-rich by-product of anaerobic digestion) from biogas plants improves soil fertility and reduces synthetic fertilizer dependence. Small-hydro units along canal falls and minor dams can complement solar variability. Pumped-storage or hybrid micro-grids integrating Solar PV and hydro can ensure continuous operation for irrigation cooperatives. Agrivoltaic systems elevate solar panels 3-5 m above the field, allowing simultaneous electricity and crop production. Pilot projects at Coimbatore and in Gujarat show increased water productivity by up to 45%. Soil-moisture sensors and remote pump controllers optimize irrigation schedules; start-ups like Kheyti and Fasal integrate these with solar units. International Water Management Institute pilot project in Bihar and Jharkhand show that solar-irrigation service companies operating cooperative models can ensure equitable access. These innovations show that the next stage of RE growth in agriculture will be data-driven, modular, and digitally connected.

As far as economic and environmental implications are concerned, solar-pump levelized cost of irrigation is Rs.1.5–2.0 per m^3 of water compared to Rs.4–6 for diesel. Even after accounting for capital costs (Rs.2–3 lakh per pump), payback is under four years with subsidies or feeder solarization. At system level, each MW of decentralized solar offsets ~1,000 t CO_2 per year. Unregulated solar pumping may increase water abstraction. Studies recommend linking pump capacity to groundwater zoning and encouraging solar-power buy-back so that surplus energy, not water, is sold. Combining solar with drip or sprinkler systems can reduce water use by 30-60%, protecting aquifers. Despite all these advantages, the sector suffers from challenges also. Small farmers lack upfront capital even with 60-70% subsidy. Absence of volumetric limits, metering, and aquifer-level planning can negate RE's benefits. Only a few states offer fair tariffs for excess solar power; regulatory uniformity is needed. Accredited local technicians are to be nurtured.

A basin-wise plan aligning renewable-energy deployment with groundwater potential is crucial. There is a need for convergence of PM-KUSUM and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY). Schemes should be implemented jointly, treating solar, microirrigation and soil-moisture sensors as one package. This "per-drop-per-watt" approach could be piloted in rainfed areas. Cluster-based solar irrigation cooperatives financed through NABARD's Micro-Irrigation Fund must be promoted. Public Private Community Partnerships for canal-top projects may be encouraged. CSR funds from mining and power companies earmarked for solar irrigation demonstration units should be planned.

Finally, renewable energy integration into India's agricultural and irrigation systems represents a structural transformation from resource exploitation to resource regeneration. Solar, bio-, and small-hydro technologies can jointly deliver reliable, clean, and affordable power for irrigation while enabling climate-resilient agriculture. The challenge is institutional and not technical. The energy policy, water governance, and agricultural planning must be aligned. RE-based irrigation can drive both productivity and equity. The path forward lies in coupling technology with governance—deploying solar where water is sustainable, enforcing groundwater caps, incentivizing micro-irrigation, and integrating data systems. A state-specific mission linking PM-KUSUM and PMKSY can make RE the cornerstone of rural growth. Ultimately, renewable energy in irrigation is not merely an energy substitution; it is a new paradigm—transforming how water, land, and livelihoods interact in the era of climate change. Renewables are not just a new power source for Indian farms; they are a new operating system for irrigation.