Green Industrialization Vs. Farmland Preservation: A Comparative Study of Hungary and India

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Abstract. This study compares how countries (India and Hungary) navigate trade-offs owing to industrialisation initiatives while pursuing climate goals. Hungary faces farmland loss and ecological risks from large Electric Vehicles (EV) battery plants, while India struggles with land diverted to solar parks and fast-growing battery-related e-waste.

Objectives

The study is conducted based on following objectives: a) Evaluate impacts on agricultural land and ecosystems; compare renewable and battery-sector growth and rising lithium demand; b) analyse India's e-waste surge; and c) identify regulatory gaps affecting sustainable development.

Materials and Methods

Hungary's constitutional protections and hasty permissions for major battery projects were examined. India's EV projections, lithium demand, e-waste data, and land-use conflicts linked to solar and storage expansion were assessed.

Results

Hungary's EV fleet is growing, supported by large subsidies and expanding battery capacity. India faces escalating battery demand, rising e-waste, and farmland displacement.

Conclusions

Both countries advance climate goals but face land and waste challenges requiring stronger governance.

Keywords: Electric vehicles, Lithium batteries, E-waste, Sustainability, regulations

1 Introduction

The twenty-first-century shift toward a low-carbon future has set off an extraordinary surge of what is now widely described as "green industrialisation" (OECD, 2011). This wave is driven by the rapid expansion of electric mobility, the construction of large battery manufacturing facilities, and the rollout of land-hungry renewable energy projects, ranging from utility-scale solar parks to sprawling wind farms. Although these

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initiatives are championed for their ability to curb emissions and address chronic air-quality problems, they also compete intensively with agriculture for land, water, and public funding. In many countries, farmland is not merely an economic asset but the backbone of food security, rural livelihoods, and deeply ingrained cultural practices. As such, governments face a tricky structural question: how to accelerate decarbonization without undermining the agricultural and ecological systems upon which societies ultimately depend?

Hungary and India exemplify two distinctly different yet revealing manifestations of this global tension. Hungary is a relatively small and high-income EU member (Hungary UNFCCC National Communication, 2023). with dense settlement patterns and a long agricultural tradition that has tried to reinvent itself as Europe's new battery-production hub, courting multi-billion-euro investments but facing local opposition due to heavy water consumption, pollution hazards, and the conversion of productive farmland into industrial zones (GGGI et al. 2023). Viewed on a completely different scale, India is a lower-middle-income country where agriculture still employs large sections of the population and whose energy demand is growing at one of the fastest rates in the world. Here, the rapid rollout of solar and wind capacity, and the projected surge in battery requirements for transport electrification and grid stability, has started to overlap with cultivable land, creating friction within already vulnerable rural economies. In both contexts, how state institutions regulate land-use conversion, respond to water stress, and manage the surging burden of e-waste and hazardous materials will determine whether the green transition ultimately strengthens or undermines long-term sustainability.

This paper brings Hungary and India within a comparative frame along three interlinked dimensions. First, it examines the material footprint of green industrialisation, considering the pressure on land, water, and waste systems. Second, it assesses the legal and institutional mechanisms each country counts on to balance industrial expansion with the preservation of agricultural landscapes. Third, it evaluates the capacity and accountability of environmental governance systems in mitigating these tensions. The study uses a mixed methodology: doctrinal and policy analysis of formative legal instruments and national climate strategies, complemented with quantitative indicators drawn from government datasets, international indices like the Climate Change Performance Index and the Environmental Performance Index, and sector-specific data on the deployment of EVs and the production of batteries. It is hoped that this comparison of a highly regulated European case with a rapidly industrialising Asian democracy can highlight both the shared risks, farmland degradation, water scarcity, and toxic waste accumulation, and demonstrate how differences in scale, political economy, and regulatory design shape country-specific challenges and possible pathways toward a greener yet food-secure development trajectory.

1.1 Evolution of Statistical Growth Over Time

Across the three decades from 1990 to 2020, the emissions patterns of Hungary and India move in almost opposite directions, revealing how differently the two economies have evolved. Hungary enters the 1990s with per-capita emissions of **2.64**, but this figure steadily drops through the decade and into the 2000s. By **2004**, it sinks below **1.0**, and from then on it remains fairly settled, hovering around **0.97 to 1.23**. This gradual decline is closely tied to the country's post-transition economic restructuring, the shutting down or modernising of older industrial facilities, and the environmental rules that accompanied EU integration (Prasada, Nugroho & Lakner 2023).

India's trajectory looks very different. Beginning at **1.80** in 1990, its numbers dip modestly during the mid-1990s before picking up again in the 2000s. From 2005 onward, per-capita emissions rose more steadily, landing between **1.14 and 1.73** throughout the 2010s. The increase reflects the realities of a rapidly growing economy, characterised by expanding industries, large-scale urban growth, and rising energy use across transportation, construction, and manufacturing (European Environment Agency 2025).

Seen together, these trends underline a clear divergence. Hungary exhibits the profile of a smaller, more mature economy transitioning to cleaner production, while India displays the pattern of a large developing country striving to meet rising energy demands while also moving toward decarbonization. Understanding these contrasting starting points is crucial when comparing how each country now navigates green industrialisation, the pressure on agricultural land, and the broader challenges of environmental governance (Statista 2025).

2 Hungary: Balancing Green Industrial Expansion and Protection of Agricultural Land

In recent years, Hungary has deliberately repositioned itself as a key player in Europe's electric vehicle battery ecosystem. This push toward large-scale green manufacturing has fundamentally altered the country's approach to balancing industrial growth with the protection of agricultural landscapes. A defining example is the CATL plant in Debrecen—Hungary's largest foreign investment to date, valued at €7.34 billion. Designed to achieve an output of 100 GWh by 2030, the project occupies approximately 221 hectares of high-value farmland and is expected to generate around 9,000 jobs (Xinhua News 2022).

2.1 Industrial Ambitions and Emerging Environmental Trade-offs

The rapid industrial shift has been encouraged by significant state intervention, with nearly 308 billion forints (approximately $850 million) in public financing, along with extensive tax incentives and infrastructure support, being offered to attract battery manufacturers. To streamline these developments, the government created Special Economic Zones that shorten approval timelines but also reduce avenues for public input and environmental scrutiny. Critics argue that such centralised decision-making strengthens cooperation between European automakers, Asian battery manufacturers, and external energy partners, yet it simultaneously raises concerns about transparency, accountability, and the long-term consequences of repurposing productive farmland for industrial estates (CATL 2022).

2.2 Water Stress and Declining Farmland Quality

The expansion of battery production has also intensified pressure on regional water resources, particularly in areas already battling desertification. Early estimates indicated that the CATL facility would require up to 40,000 cubic meters of water daily, nearly double Debrecen's supply of potable water. Following significant public resistance, the company revised its estimate to 30,750 cubic meters per day, with cooling operations accounting for the largest share (Hungarian Ministry of Agriculture 2023).

This extraction is planned in the Great Hungarian Plain, an area experiencing accelerating soil degradation due to persistent drought and rising temperatures. Roughly one-fifth of Hungary's cropland became unproductive in 2022, underscoring the fragility of this landscape (Business & Human Rights Resource Centre 2023). The decision to convert some of the Plain's most fertile loess soil, capable of sustaining the nation's food needs, into industrial zones has therefore heightened community and expert concerns. Hydrologists warn that tapping deep groundwater reserves for industrial use risks depleting the surface ecosystem and emergency reserves intended for future drinking water. By replacing agricultural land with water-intensive factories, the country risks undermining its food security while increasing the vulnerability of an already climate-stressed region (Heinrich Böll Foundation 2024).

2.3 Legal Protections, Judicial Pushback, and Enforcement Challenges

Hungary's legal framework provides robust constitutional protection for its environmental resources. Articles P and XXI of the Fundamental Law describe natural assets as part of the nation's shared heritage, and they affirm citizens' right to a healthy environment. In practice, however, these principles have been tested by the fast-track authorisations granted to major battery projects. The “priority investment” classification given to the Debrecen plant allowed it to bypass several procedures mandated under Act LIII of 2006, prompting legal challenges from civil-society groups and neighbouring residents.

Courts have begun to push back against this accelerated model. In November 2023, the Curia annulled CATL's disaster management permit, signalling that even highly favoured investments must comply with legal safeguards (Business & Human Rights Resource Centre 2023). In May 2024, the Budapest District Court took an even stronger stance by overturning Samsung SDI's ten-year environmental permit for its Göd facility, requiring operations to halt until a lawful approval process is completed. Despite these judicial interventions, enforcement remains uneven. Between 2019 and 2022, the Göd plant released approximately 88 tons of N-methyl-2-pyrrolidone (NMP), a hazardous reproductive toxin, with traces subsequently detected in nearby groundwater. Instead of suspending operations, authorities responded by raising fines, an approach that signals a preference for maintaining production rather than ensuring strict adherence to environmental rules. This pattern illustrates the tension between Hungary's constitutional commitments and its current industrial strategy, highlighting unresolved questions about oversight, public participation, and the sustainability of prioritising rapid industrialisation over environmental compliance.

2.4 Climate Policy Gaps and Conflicting Priorities

Hungary's climate governance exhibits a persistent mismatch between the ambitions expressed in official strategies and the policies implemented on the ground. In the 2025 Climate Change Performance Index (CCPI), the country is placed 45th and is categorised as a *low overall performer*. While its greenhouse-gas emission levels earn a "medium" rating, its climate-policy score falls into the "very low" category, revealing a widening gap between commitments and credible action (CCPI 2024).

Although Hungary has endorsed the European Union's long-term objectives, carbon neutrality by mid-century and a 40 per cent cut in emissions by 2030 relative to 1990, experts observing national policy argue that the measures currently in force fall short of what is required. Several national strategies outline clear principles, but the steps needed to execute them remain either delayed or insufficient. CCPI analysts caution that existing and forthcoming policies may, in practice, lead to an increase in emissions rather than a decrease.

One of the clearest examples of this contradiction is the treatment of wind energy. A 2016 rule effectively prevented the construction of wind farms anywhere in the country by barring turbines within a 12-kilometre radius of any populated area, an impossible condition in a country with more than 3,000 municipalities. In response to pressure from the European Commission, particularly regarding access to €5.8 billion from the Recovery and Resilience Facility, Hungary reduced the exclusion zone to 700 metres, effective January 2024. Nevertheless, no new wind facilities can become operational before 2030, severely constraining the diversification of the renewable energy mix.

At the same time, the electricity grid is already strained by the rapid growth of solar installations. Solar power is projected to make up around 90 per cent of the 13,400 MW in renewable capacity planned for 2030, yet transmission infrastructure has struggled to keep pace with this expansion. Further complicating matters, the Constitutional Court struck down Article 3(1) of the Climate Protection Act in July 2025. The court reasoned that the legislated target, to reduce emissions by 40 per cent, had already been met by 2023, rendering the statute outdated and inadequate for guiding future climate policy. This ruling highlighted the distance between evolving climate realities and the static nature of Hungary's legal framework (Energiaklub 2025).

2.5 Industrial Expansion and the Growing Backlash from Local Communities

The rapid development of Hungary's battery-manufacturing sector has introduced a host of environmental and social burdens that extend beyond water consumption and the conversion of farmland. Facilities producing batteries routinely handle toxic substances, including N-methyl-2-pyrrolidone (NMP). Tests near the Samsung SDI plant in Göd revealed traces of this solvent in groundwater, renewing concerns about chemical leaks and inadequate containment. Internal assessments have also identified repeated incidents in which workers were exposed to hazardous levels of heavy metals and other toxic compounds, sometimes exceeding permissible limits.

Residents living close to these manufacturing sites report a steady deterioration in quality of life, persistent noise, unpleasant odours, worries about contaminated soil and water, and the loss of agricultural livelihoods. Protests led by local parents, including public marches, reflect mounting frustration. In some districts, families have already chosen to relocate to avoid the perceived health risks associated with the pandemic.

These tensions have been deepened by the government's designation of certain industrial areas as Special Economic Zones. In practice, this has meant that farmland could be compulsorily taken over for industrial development, while local governments lost decision-making power and tax benefits associated with the facilities. Communities, therefore, shoulder the environmental impacts without receiving the economic rewards, creating a profound sense of injustice.

Although constitutional guarantees and court rulings provide tools for environmental protection, enforcement remains weak. Environmental impact assessments often remain inaccessible to the public, and regulators seldom impose meaningful penalties when breaches occur. Companies responsible for environmental harm are frequently allowed to continue operating with minimal consequences.

Hungary's push to become the world's third-largest battery producer has therefore fuelled concerns that environmental safeguards are eroding. Critics warn that the country risks turning parts of its landscape into a "battery corridor" marked by declining regulations, weakened oversight institutions, and communities increasingly excluded from decisions that shape their environment (European Parliament 2025).

3 India: Green Industrialisation and the Challenge of Protecting Farmland

India's transition toward a low-carbon economy has accelerated significantly over the past decade, reshaping the country's use of land, resources, and energy. As the government pushes for large-scale renewable energy deployment and the rapid electrification of transportation, tensions have emerged between the need to expand green industries and the imperative to safeguard fertile agricultural zones. This debate is no longer theoretical; India now faces a genuine trade-off between scaling up clean-energy infrastructure and maintaining its long-term food security.

3.1 Rising Battery Demand and Mounting Pressures from the Energy Transition

The shift toward electric mobility and renewable power has generated an extraordinary rise in demand for lithium-ion batteries. India’s requirement for such batteries, barely 4 GWh in 2023, is expected to jump to nearly 139 GWh by 2035, an increase of more than thirty-fold (JMK Research 2025). This surge is driven largely by the growth of electric vehicles and the need for battery-based storage systems to stabilise an increasingly solar-heavy electricity grid (S&P Global Mobility 2024).

Meeting these targets will require massive capital flows: the International Energy Agency estimates that India must invest roughly $160 billion every year until 2030 to stay on track for its 2070 Net Zero pledge, nearly three times what the country currently spends on clean-energy expansion.

Electric mobility has already begun to affect the market. More than 20 lakh EVs were sold in FY25, a 22% increase over the previous year, pushing EVs to nearly 8% of all vehicle sales. Projections suggest that this could climb into the 7–10 per cent range by FY28. To support such growth, India will need an estimated 150–200 GWh of domestic cell-manufacturing capacity by 2030, which would require close to ₹75,000 crore in investment. At present, however, India remains heavily dependent on imported battery cells, with import exposure projected to exceed $5 billion by the end of the decade.

The country's renewable-energy buildout mirrors this pattern of rapid expansion. By October 2024, solar capacity had reached 92 GW, a nearly 28 per cent jump in a single year, and now accounts for roughly three-fifths of India's renewable capacity (excluding large hydropower). Most of this growth, however, has occurred on agricultural or semi-agricultural land, rather than on degraded or unused plots, which has sharpened concerns about long-term land availability for food crops.

3.2 Encroachment on Agricultural Land and Intensifying Land-Use Conflicts

India's push for renewable energy infrastructure has begun to collide directly with agricultural livelihoods and ecologically sensitive landscapes. A major study by The Nature Conservancy found that more than 85 per cent of utility-scale solar plants were built in areas with potential biodiversity or food-security impacts. Nearly 68 per cent were situated on cultivated land, while another 19 per cent occupied natural habitats. Much of this farmland—about 38 per cent—could otherwise support seasonal crops, while nearly 29 per cent was suitable for orchards and plantation agriculture (S&P Global Mobility 2024).

Current patterns of deployment illustrate the scale of this transformation. Roughly 45 GW of solar projects have already taken up around 800 square kilometres of farmland and an additional 280 square kilometres of natural landscapes, including forested areas, swamp forest, and biodiversity-rich scrublands. By contrast, only 189 square kilometres of degraded wastelands have been used to generate a mere 4.3 GW of solar power (Agri-Solar Clearinghouse 2023).

If these trends continue, India's ambition of reaching 300 GW of solar by 2030 will consume vast tracts of cultivable land. Studies anticipate that nearly 60 per cent of areas best suited for solar generation and over one-third of wind-power zones overlap with agricultural regions. The Institute for Energy Economics and Financial Analysis estimates that reaching net-zero through solar and wind alone could require between five and seven million hectares of land, up to 2.5 percent of the country's landmass. States generally prefer acquiring wastelands for renewable projects because such land falls outside the stringent provisions of the 2013 Land Acquisition Act, making it quicker and politically easier to acquire (ICRIER 2024).

Local opposition has intensified in response to these land pressures. In Maharashtra's Jalgaon district, for instance, more than 130 farming families from five villages have accused solar developers of misleading them into selling land at far below the official valuation, with projects reportedly violating wildlife protection norms near the Gautala Autramghat sanctuary. Similar conflicts are emerging in Rajasthan, Karnataka, Tamil Nadu, and Andhra Pradesh—signalling a nationwide trend.

3.3 Governance Failures and Weak Enforcement of Environmental Standards

Despite possessing one of the most comprehensive environmental legal frameworks in the global South, India continues to perform poorly on environmental outcomes. In the 2024 Environmental Performance Index, India ranks 176 out of 180 countries, with severe weaknesses in air quality, biodiversity protection, and ecosystem health (Yale Center for Environmental Law & Policy 2024).

Institutional challenges lie at the heart of this discrepancy. Environmental decision-making involves several layers of government, often resulting in slow approvals and fragmented responsibility. At the same time, enforcement is weak: more than six per cent of India’s registered industrial units do not comply with environmental norms, and penalties are typically too small to deter violations.

The Environment Protection Act of 1986 provides the foundation for modern environmental regulation, including the establishment of the Central Pollution Control Board and the framework for Environmental Impact Assessments. Yet the system suffers from over-centralisation, poorly resourced state-level regulators, overlapping jurisdictions, limited public awareness, and inadequate monitoring capacity. In the Indo-Gangetic region, one of the world's most polluted zones, State Pollution Control Boards routinely report staff shortages and insufficient equipment even while generating financial surpluses (RGICS 2025).

To encourage renewable energy development, the government has also relaxed oversight for green energy projects (MoEFCC 2016). Since 2016, wind and solar PV plants have been exempted from the requirement of environmental clearance under the EIA Notification, and their classification under the “White Category" removed any obligation to obtain Consent to Operate from state pollution boards. While these exemptions were intended to accelerate the clean-energy transition, they have also eliminated structured environmental scrutiny in the very sector expected to reshape India's land-use patterns at an unprecedented scale.

3.4 E-Waste Surge and the Strain on India's Recycling Capacity

India's rapid move toward electric vehicles and large-scale energy storage has created an escalating waste problem that threatens to overshadow the environmental gains of the green transition. In 2022 alone, the country generated more than 1.6 million tonnes of electronic waste. Close to half of this, roughly 700,000 tonnes, was linked to lithium-ion batteries, and projections indicate that this number could exceed two million tonnes by 2030 if recycling systems do not expand at the same pace as demand.

At present, only a very small fraction of end-of-life lithium batteries, somewhere between 1% and 5%, passes through formal recycling channels. The overwhelming majority is processed informally by small, unregulated units that rely on crude and dangerous methods such as burning or soaking components in acids. These practices release toxic compounds, contaminate water and soil, and pose serious health risks to workers and surrounding communities.

With battery demand expected to increase from 4 GWh in 2023 to an estimated 139 GWh by 2035, the volume of spent cells requiring safe disposal is also expected to rise sharply. By 2030, India is likely to face nearly 128 GWh worth of batteries needing recycling each year. To manage this influx, the country would have to expand its formal recycling capacity roughly 60 times over the next few years. Yet the current system can process only about 60,000 tonnes annually, and less than half of that material is converted into “black mass” suitable for extracting critical minerals like lithium, cobalt, and nickel.

The 2022 Battery Waste Management Rules introduced an Extended Producer Responsibility mechanism, requiring manufacturers to ensure the collection and recycling of 70–90% of the batteries they introduce into the market. However, compliance remains extremely weak. In practice, manufacturers often opt to pay modest penalty fees rather than fulfil their collection obligations, and formal e-waste recovery remains under one per cent nationwide.

Most assessments suggest that by the mid-2030s, India could face a shortfall of more than 1.3 million tonnes in lithium-battery recycling capacity, creating substantial environmental, economic, and public health threats that could erode the climate benefits of electrification (CPCB 2022).

3.5 Contradictory Policies and Infrastructure Constraints

India’s clean-energy goals are undermined not only by the waste challenge but also by significant infrastructure delays and regulatory contradictions. As of 2024, the country has installed a remarkable 92 GW of solar capacity, but transmission systems and grid stability measures have not kept pace. The network is already struggling to absorb the volume of renewables coming online, and balancing intermittent solar and wind power has become a growing operational concern.

In 2024, peak electricity demand touched 250 GW, a six per cent jump from the previous year, yet many planned projects face bottlenecks that could jeopardise the national target of 500 GW of renewable capacity by 2030. Compounding these challenges is India's overwhelming dependence on China for solar components, accounting for nearly four-fifths of the global supply chain. This reliance exposes India to price volatility, geopolitical risks, and supply-chain disruptions.

Several states have introduced legal amendments that allow renewable-energy developers to bypass both Environmental Impact Assessments and Social Impact Assessments on the grounds that electricity generation is an essential service. Maharashtra, Jharkhand, Telangana, and Tamil Nadu, among others, now permit solar and wind projects to acquire land without mandatory community consultations or independent environmental reviews. This shift has raised concerns about transparency, land grabs, and weakened safeguards for rural communities (LARR Act 2013 §2(f),(m).

The Khavda Renewable Energy Park in the Rann of Kutch illustrates these contradictions (Roy & Michael 2024). Promoted under state policies designating wastelands for renewable use, the mega-project occupies ecologically fragile terrain. Its construction is expected to disturb soil carbon stores, limit grazing access for pastoral communities, and pose risks of electrocution and collision to migratory birds that use the Kutch region as a key flyway. Of the six developers that received land allocations, only one carried out a full Environmental Impact Assessment aligned with international standards. The remaining companies, controlling over 60 per cent of the land, either did not conduct EIAs at all or have not disclosed them publicly. Despite its size and environmental impact, the project has progressed with minimal public scrutiny.

4 Comparative Analysis: Structural Contrasts and Shared Vulnerabilities

Hungary and India offer two strikingly different examples of how countries attempt to industrialise “green” sectors while still relying heavily on agricultural land. Their experiences reveal the broader tension between climate ambition and land protection, but the pressures shaping each country's path are fundamentally distinct.

Hungary's challenges are highly **concentrated**. A single battery plant in Debrecen, spread over 221 hectares of some of the region’s most fertile land, has become a flashpoint for national debates. The scale of water this one facility demands, at one stage nearly twice the volume of the city's own daily drinking supply, illustrates how quickly a localised industrial project can overwhelm ecological limits in a small and densely populated country.

India's pressures, by contrast, are **diffuse**. Solar parks and wind installations are scattered across the country, gradually occupying hundreds of thousands of hectares. No single project attracts the kind of public outcry seen in Hungary, yet the cumulative footprint is far more dramatic. More than 85% of India's solar infrastructure has been built on farmland or natural ecosystems, and nearly 40% of its total installed solar capacity is situated directly on land that would otherwise support food production for a population of 1.4 billion.

These structural differences give rise to two distinct governance challenges. Hungary grapples with how to restrain the executive’s ability to fast-track large projects. India struggles with how to regulate thousands of smaller ones that escape scrutiny through exemptions and fragmented oversight.

4.1 Governance Gaps: Different Systems, Similar Outcomes

Despite the differences in scale and structure, both countries face deep flaws in environmental governance, though the weaknesses arise from opposite sources.

In Hungary, the issue is **excessive centralization**. The government has designated vast industrial areas as Special Economic Zones, a move that effectively sidesteps local government authority, weakens environmental review, and excludes citizens from the decision-making process. “Priority investment” status functions almost like an override, enabling executive authorities to dilute procedural safeguards whenever a project is deemed strategically important.

India's shortcomings stem from the **opposite condition**: an over-fragmented regulatory system. Environmental approvals require navigating central, state, and district-level authorities, causing long delays that often encourage shortcuts. Pollution control agencies lack staffing, equipment, and enforcement power. State governments routinely waive environmental assessments for renewable energy projects, treating them as essential utilities exempt from the normal checks that other industries face.

Both countries score poorly on international environmental indices: Hungary in the CCPI for weak climate policy implementation, and India at the bottom of the EPI due to severe air pollution and biodiversity loss. In neither case is the problem a lack of written rules; rather, policies remain under-implemented, weakly enforced, or selectively applied.

Hungary's courts have shown that judicial review can act as a barrier, voiding CATL's disaster permit and halting Samsung SDI's operations until environmental compliance is verified. However, these actions came only after projects had already caused harm. India's courts occasionally intervene as well, but cases often drag on for years while projects continue to operate, reflecting how legal remedies can become ineffective without strong political backing or administrative capacity.

4.2 Water Stress: A Shared Vulnerability with Different Triggers

Both nations are confronting water crises linked to green industrialisation, though the character of the threat differs.

In Hungary, water scarcity has become most visible around the Debrecen battery plant. The original projection of 40,000 cubic meters of water per day, nearly twice the city's entire drinking-water supply, exposed a stark contradiction: the same industry meant to support green mobility risks endangering a region already suffering from climate-driven drying and soil degradation (Heinrich Böll Foundation 2024). Although public pressure prompted a reduction in the extraction estimate, the core dilemma remains: a single facility's water demand is comparable to that of an entire municipality (Transnational Institute 2024).

India's water challenges are broader and more deeply rooted. Across much of the country, groundwater already lies at precarious levels, and large solar farms frequently worsen the situation. Panels increase temperatures at ground level, reducing moisture retention, while the concrete bases and access roads used in solar parks reduce natural recharge of aquifers. In regions where farmers depend almost entirely on groundwater, this creates what experts call a **"solar–water–agriculture conflict"**—a dynamic where land dedicated to renewable energy reduces the viability of agriculture in ways that are not yet fully acknowledged in policy.

Neither country has developed a comprehensive framework for assessing the water implications of clean-energy expansion. Hungary's debates have begun to address this as a legal question, while India has not yet integrated water risk into its renewable energy approval process.

4.3 E-Waste and Recycling: India's Scale Problem vs. Hungary's Toxicity Problem

Battery recycling is the clearest area where the two countries diverge sharply. India faces a **scale crisis**. By 2035, it is expected to generate more than 1.3 million tonnes of lithium-battery waste annually, driven by the rapid growth of EV sales and increasing reliance on energy storage systems (Int'l J. Innovative Science Research & Technology 2025). Formal recycling capacity is just a fraction of what is needed, and over 80% of discarded batteries end up in the informal sector, where unsafe recycling methods expose workers and nearby communities to toxic chemicals. Extended Producer Responsibility rules exist on paper but are often sidestepped through penalty payments rather than actual compliance (Aranca 2024).

Hungary does not face the same volume of battery waste, but it has dealt with **serious contamination incidents** (Indian J. Occupational & Environmental Medicine 2015) from the facilities it does host. Samsung SDI in Göd released significant quantities of NMP, a hazardous solvent, into the environment over multiple years, highlighting regulatory weaknesses despite the country's smaller industrial base. Both nations prioritize expanding manufacturing capacity over building robust end-of-life recycling systems, creating a disconnect between production and responsibility.

India plans new incentives for critical mineral recovery and aims to significantly expand formal recycling by 2027, but the timelines remain far behind the projected growth in waste. Hungary, with its smaller market, could theoretically implement tighter oversight, yet past events show that even limited-scale industries can overwhelm local monitoring bodies (PAHL India 2024).

5 Way Forward: Integrated Measures and Long-Term Strategic Choices

Resolving the tension between accelerating green industries and protecting productive farmland will require both countries to change the order in which they make policy decisions. Currently, the pattern is the same in both places: large manufacturing facilities are approved first, and concerns about recycling, land pressure, or water use are addressed later, typically only after problems arise. A more sensible approach would be to build recycling systems, establish clear land-use protections, and set water-use rules **before** expanding battery production or renewable energy infrastructure (CSIRO 2021).

Hungary's approval of CATL's large facility, which lacks a domestic recycling base, highlights the backwards nature of this sequence. India is following a similar path, licensing EV factories and storage projects, even though it lacks the capacity to handle the volume of battery waste these facilities will eventually generate. India's plan to offer incentives for recovering critical minerals and to require a minimum percentage of recycled content in new batteries is a good starting point, but these ideas should be funded and operational long before additional production lines are established (Fraunhofer India 2024). In Hungary, the reduction in CATL's water requirement, achieved only after protests and legal pressure, illustrates that corrections are possible; however, it would have been far less disruptive to apply strict water-use standards during the approval phase. Mandatory water budgeting for battery plants, tied to legally enforceable thresholds, would help prevent these disputes from recurring (CERRE 2024).

A more coherent land-use strategy is equally important. Both India and Hungary can draw on the FAO's integrated planning framework, which balances farming, ecological conservation, and industrial expansion, rather than treating them as competing silos. Hungary's Special Economic Zones currently stand outside normal planning controls, effectively creating industrial islands with limited accountability. Bringing these zones back under regional planning processes, where they must align with food-security needs, ecological capacity, and local consultation, would correct this imbalance. India needs a complementary framework: states should formally protect agricultural belts and restrict renewable projects on such land unless the terrain has been independently verified as degraded. Without these guardrails, India risks undermining its own food-security base as solar and wind installations continue to expand.

One of the most promising solutions is agrivoltaics, which combines farming with solar generation on the same plot of land. Instead of replacing crops, solar panels are elevated, allowing farmers to continue cultivating underneath. Studies suggest that farms equipped with agrivoltaic systems can retain 70–80% of their normal crop output while still generating roughly two-thirds of the electricity produced by conventional ground-mounted panels. India has already tested several such systems. CAZRI's pilot in Jodhpur demonstrated improvements in soil moisture and food output, Sahyadri Farms integrated solar energy with vineyards to diversify farm income, and the floating solar system in the Muradpur irrigation scheme helped sustain triple cropping (IISD 2023). These examples show what is possible, but they remain exceptions. Scaling agrivoltaics, particularly for large solar parks, would enable India to protect farmland while meeting its energy targets. Hungary, with its far more limited agricultural base, arguably needs agrivoltaics even more urgently; making it a requirement for solar projects located in farming regions could ease pressure on its constrained land resources. Adoption will require financing support, transitional income protection for farmers, and clear technical standards to ensure panels do not interfere with cultivation.

Battery recycling infrastructure cannot remain an afterthought. India needs time-bound mandates for recycled content, starting modestly and increasing steadily, to guarantee market demand for recovered minerals. Penalties for failing to meet collection and recycling obligations must be substantial enough that compliance becomes the cheaper option. Fixed fines simply become routine business costs; instead, penalties need to be tied to production value or market turnover. Hungary's regulatory system can adopt a similar logic: the renewal of operating permits should be contingent upon verifiable recycling performance. A joint India–EU recycling partnership would strengthen both economies: India has cost advantages in hydrometallurgical processing, while the EU has advanced refining technology and strict recovery standards. Together, they could reduce dependence on mineral imports and establish a genuinely circular battery supply chain (EU Battery Regulation 2025).

Water security must also become a central criterion in evaluating industrial projects. Both countries should establish water-use caps based on local availability, rather than project design preferences. Anything above those limits would require a separate clearance, based on a strict environmental review (Lukat et al. 2023). India should end the practice of exempting solar and wind projects from environmental assessment. These installations may be "green," but their impacts on groundwater, soil temperature, and biodiversity are significant. Assessments should consider the entire energy–water–agriculture nexus rather than evaluating each sector separately. Similarly, Hungary could incorporate water-use accounting systems directly into its permitting rules, allowing battery factories to expand only within defined ecological limits.

Strengthening environmental assessments is one of the most important institutional reforms for both countries. Hungary's alignment with EU law is strong on paper, but “priority investment” status has allowed major projects to bypass strict review. Eliminating such exemptions would restore procedural integrity. India likewise needs to restore full EIA requirements for renewable plants, with sector-specific guidelines for farmland, groundwater, and biodiversity. Public consultation must also shift from a symbolic exercise to a process that can genuinely inform and shape decisions. In Hungary, objections to the CATL plant were acknowledged only after approvals had been granted, whereas in India, farmers frequently report that projects proceed despite their concerns.

Ultimately, both countries require stronger governance and more effective coordination across ministries. Hungary must insulate environmental regulators from political interference and reinstate oversight within special economic zones. India must substantially strengthen its pollution control boards through enhanced staffing, adequate funding, and genuine autonomy. As long as these institutions remain weak, even the best-designed laws will fail in practice. Cross-sector coordination is essential; agricultural, water, energy, and environmental agencies must work within a single, unified planning framework, rather than parallel systems that compete.

The India–EU Trade and Technology Council, and related green transition dialogues, provide platforms that can be expanded into direct cooperation on environmental governance, capacity building, battery recycling, and transparent supply chain standards. Both countries stand to benefit from this alignment: India gains technical expertise and institutional support, while the EU benefits from secure, lower-cost recycling and diversified sources of critical materials (EEAS 2024).

6 Conclusion: Sequencing as a Strategic Discipline

The clearest lesson from comparing Hungary and India is that the success of green industrialisation depends less on ambition and more on the order in which decisions are made (Khoshsepehr et al. 2023). When countries rush to license factories before they have the systems to deal with waste, or convert farmland without identifying safer alternatives, the transition begins to work against itself. The same is true when water-intensive industries move ahead without a basic understanding of local hydrology, or when environmental rules are waived in the name of speed. Under these conditions, the energy transition does not simply stumble; it can actively damage the very foundations it is meant to protect.

Neither Hungary nor India can pursue the rapid expansion of their EV and battery industries and safeguard their agricultural land, water reserves, and environmental quality unless they intentionally structure the transition. Both need to put the "back-end" elements in place, including recycling systems, land-use zoning, water safeguards, and strong oversight, before approving new industrial capacity. Likewise, both countries should upgrade existing renewable installations with land-saving systems, such as agrivoltaics, before establishing new solar parks on agricultural land (Voukkali et al. 2023). A sequence that moves from foundations to expansion, rather than the reverse, offers a way to grow without eroding food systems or compromising long-term ecological security.

This approach does not reject the energy transition; it simply acknowledges that while the move to renewable energy and electric mobility is unavoidable, **the pace, location, and design of that transition are choices**. Those choices determine whether countries end up with a resilient green economy or a landscape degraded by poorly planned development (Kumar et al. 2023).

For Hungary, the priority now is measured restraint. The country would benefit from suspending approval of new battery plants until domestic recycling facilities can handle at least half of the material those plants will produce. Special Economic Zones should be brought back under normal environmental scrutiny, rather than being exempt from it. Industrial water-use rules need to be tightened, and solar development should shift toward agrivoltaic designs that allow for the coexistence of farming and energy generation, especially in the Great Hungarian Plain, where arable land is already scarce.

India, meanwhile, must accelerate the implementation of parts of the transition it has delayed, including large-scale recycling capacity, clear agricultural protection zones, the restoration of environmental assessments for renewable projects, and a national framework for agrivoltaics. India's scale provides it with an opportunity to shape global circular-economy norms, especially when paired with European partners who can supply technology and help establish high-quality mineral recovery systems. A strong India–EU partnership around critical-mineral recycling could reduce reliance on raw mining and move both economies toward a more self-sustaining battery supply chain (CEEW 2024).

Ultimately, no pathway will succeed unless the underlying governance structure changes. Both countries require environmental authorities that operate independently of political pressure and decision-making processes that facilitate meaningful coordination across agriculture, water, energy, and industry. Without this institutional grounding, even the best-crafted sectoral policies will be overridden when economic or political interests demand rapid industrial expansion.

In the end, green industrialisation does not fail because the technology is flawed or the economics are impossible; it falters when governments treat it as a race rather than a carefully sequenced transformation. Hungary and India demonstrate that sustainable outcomes depend on governance discipline, political commitment to long-term planning, and a willingness to establish foundational safeguards before advancing to the next stage of the energy transition.

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