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CENTRE FOR A
People-centric
Energy Transition

Summary for Policymakers on Sectoral Analysis of India's Low-Carbon Transition

Glimpses into Transport, Industry, Agriculture, and Electricity

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About the Ashoka Centre for a People-centric Energy Transition (ACPET)

The Ashoka Centre for a People-centric Energy Transition (ACPET) is a research-focused, transdisciplinary centre within Ashoka University, India, established to drive a sustainable, equitable, and "people-centric" shift towards net-zero emissions. It bridges the knowledge gap in energy transition by collaborating with industry and government to create scalable solutions, covering areas like renewable energy, policy, and technology.

For further information about ACPET, please visit: acpet.ashoka.edu.in

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Why This Study Matters

India is simultaneously the world's third-largest energy consumer and third-largest CO_2 emitter - and it is also one of the world's fastest-growing major economies. The country faces a dual imperative that few nations have had to navigate at this scale: delivering the Viksit Bharat @2047 vision (a USD 30 trillion developed economy by the centenary of independence) while honouring its Panchamrit commitments under the Paris Agreement, including net-zero emissions by 2070.

Achieving both requires a fundamental understanding of how energy demand will evolve across the sectors that drive India's growth - transport, industry, and agriculture - and how electricity supply must be transformed to power this new economy cleanly. Despite the availability of broad national strategies and sectoral targets, India needs a comprehensive, integrated, and data-driven analytical framework that systematically links energy demand and supply projections with technology transitions, policy interventions, and structural changes.

Using the LEAP-STELLA-ACPET modelling framework, we produced sector-specific, scenario-based projections for energy consumption and greenhouse gas emissions through 2047–2070 - providing the evidence base that policymakers, investors, and development partners need to make strategic decisions with confidence.

19%	35%	~18%	15×
of final energy	**of final energy**	**of total electricity**	**demand growth**
Transport sector share	Industry sector share	Agriculture sector share	Electricity by 2070 vs 2022

1. INDIA'S DEVELOPMENT CONTEXT

Setting the stage for an integrated energy assessment

India stands at a pivotal juncture. Its population of 1.4 billion people - growing in income, urbanising rapidly, and demanding higher standards of living - will drive energy consumption to levels that dwarf today's numbers. The electricity sector alone is projected to see demand grow nearly fifteenfold compared to 2022, driven by cooling, electric mobility, industrial expansion, and the rise of data centres. Transport activity will surge as more Indians own vehicles and freight networks intensify. Industry will consume enormous quantities of steel, cement, and aluminium to build the infrastructure of a developed nation. Agriculture will require more water, more power, and more machines to feed a growing population.

These pressures are not abstract projections - they are the structural consequences of development at scale. The question India faces is not whether energy demand will rise, but how rapidly, in what form, and with what carbon footprint. The Panchamrit commitments - 500 GW of non-fossil electricity capacity by 2030, 50% of energy from renewables, 45% reduction in carbon intensity of GDP relative to 2005, and net-zero by 2070 - set a clear long-term direction. But the pathway between today and those goals requires detailed, sector-by-sector analysis of what transformations are technically feasible, economically achievable, and policy-compatible.

2. RESEARCH DESIGN & ANALYTICAL FRAMEWORK

How the study was built and what makes it distinctive

The study employs the Low Emissions Analysis Platform (LEAP), developed by the Stockholm Environment Institute, as its core modelling engine. LEAP is extended within the LEAP-STELLA-ACPET framework with system dynamics modelling and Gompertz-based demand saturation functions - a suite of complementary analytical methods that together provide a rigorous, internally consistent platform for multi-sector scenario analysis. All GDP projections use constant 2011–12 INR, aligned with national accounting practices, and draw on NITI Aayog's IESS 2047 Version 3. Population projections are sourced from the United Nations World Population Prospects.

Critically, macro-economic parameters - GDP and population - are held constant across scenarios within each sector. This means that differences in results between scenarios arise exclusively from changes in technology shares, efficiency assumptions, modal composition, and policy-driven structural shifts. The design is deliberate: it isolates the precise impact of policy choices against a common economic backdrop, making scenario comparisons analytically clean and policymaker-relevant.

Transport	Industry	Agriculture	Electricity Supply
Road · Rail · Domestic Air | ASIF Framework | Base: 2019–20 | Horizon: 2050	Steel · Cement · Aluminium| Base: 2022 | Horizon: 2047	Irrigation · Farm Mechanisation |FEW Nexus | Base: 2020 | Horizon: 2047	Coal · Gas · Solar · Wind · Hydro · Nuclear | Base: 2024 | Horizon: 2070

Two scenarios are constructed for each sector. The **Business-as-Usual (BAU)** scenario assumes continuation of existing trends and policies with only marginal improvements from currently enacted measures. The **Ambitious scenario** models accelerated electrification, adoption of cleaner fuels and production technologies, improvements in energy efficiency, modal and material composition shifts, circular economy expansion, and increased renewable penetration. In each case, the scenarios are developed using the same analytical levers - they differ only in the level of ambition applied to each lever, making their comparative results directly interpretable.

3. KEY FINDINGS:

3.1. TRANSPORT SECTOR

Road, Rail, and Domestic Air Transport - 2019–20 to 2050

Transport is one of India's most energy-intensive and rapidly growing sectors. It currently accounts for nearly 19% of total final energy use and approximately 14% of energy-related GHG emissions. Road transport alone is responsible for over 90% of sector emissions and absorbs nearly 90% of India's total crude oil demand - the vast majority of which is imported. This import dependence creates both an energy security vulnerability and a macroeconomic cost that will compound as vehicle ownership expands alongside rising incomes.

The ACPET transport model covers passenger and freight activity across road, rail, and domestic air transport, using the ASIF (Activity–Structure–Intensity–Fuel) framework. Transport demand is projected using a saturation-based logistic function linking GDP per capita to per capita mobility, grounded in observed development trajectories from OECD countries. The model's BAU and Ambitious scenarios have been cross-validated against published Indian transport models from CEEW and ICCT, with ACPET's BAU projections sitting comfortably within the range of nationally recognised estimates.

Energy Demand & Emissions - BAU vs. Ambitious (2050)

Business-as-Usual	Ambitious
Energy demand rises from 4.59 EJ (2020) to 16.16 EJ by 2050 - a compound annual growth rate of approximately 4.3%. This growth is driven by sustained expansion in passenger and freight activity, continued reliance on fossil fuels, and the absence of major structural change in the vehicle fleet. GHG emissions surge from 325 Mt CO_2e in 2020 to 1,063 Mt CO_2e by 2050 - more than a threefold increase. Light commercial vehicles (LCVs) emerge as the single largest contributor to both energy use and emissions by 2050, reflecting the boom in last-mile logistics and small freight. The BAU trajectory represents a path of fossil fuel lock-in: as the vehicle fleet expands, the dominance of diesel and petrol creates path dependency in fuel infrastructure, limiting future flexibility.	Energy demand is 14.06 EJ by 2050 - approximately 13% lower than BAU. The difference becomes increasingly visible after 2035 as EV penetration deepens and modal shifts compound. GHG emissions reach 744 Mt CO_2e - nearly 30% lower than BAU. The curve begins to flatten after the mid-2040s, suggesting the sector could approach a peak and potentially decline if EV scale-up and grid greening are sustained beyond 2050. The Ambitious scenario assumes accelerated electrification across all vehicle segments, higher deployment of hydrogen fuel cell vehicles, and a structural shift from private to shared and public transport - all underpinned by a cleaner electricity grid.

A critical cross-cutting insight emerges: electrification alone is not sufficient. EVs charged on India's current coal-heavy grid reduce lifecycle GHG emissions by only 20–35% relative to diesel vehicles. Charged on a renewable-dominated grid, the reduction reaches 85–90% (ICCT, 2024). This means that transport decarbonisation is inseparable from electricity sector transformation - the two must proceed in lockstep.

The study also identifies a behavioural dimension to the transition. Complementing technology shifts, low-cost interventions such as fare affordability for public transport, default EV procurement in government fleets, and social norm campaigns can significantly accelerate modal shifts and clean vehicle adoption. Evidence from Bengaluru shows that a 10% bus fare cut generated a 33% increase in ridership over five months. Germany's €9 monthly public transport ticket sold 52 million passes and avoided an estimated 1.8 Mt CO_2 in a single summer.

3.2. INDUSTRY SECTOR

Iron & Steel · Cement · Aluminium - 2022 to 2047

India's industrial sector is the backbone of its development aspirations and one of its most formidable decarbonisation challenges. Industry accounts for approximately 35% of total final energy consumption and close to 30% of national GHG emissions. In 2019, aggregate emissions from steel, cement, and chemicals alone totalled 678 Mt CO_2e - nearly 68% of total industrial sector emissions. Under business-as-usual conditions, industrial emissions are projected to exceed 2,657 Mt CO_2e by 2050, driven by a more-than-tripling of steel output and a doubling of cement production as India builds its infrastructure base.

The central challenge in industry is structural, not merely technical. Unlike energy efficiency improvements - which deliver only 10–20% reductions by mid-century in global assessments - deep mitigation requires changing what is produced, how it is produced, and what inputs are used. Process emissions in cement and primary metals, dependence on coal for high-temperature heat, and long-lived capital stock (plants last 30–40 years) create transition inertia that no efficiency programme alone can overcome. The study models three technology pathways for each sub-sector: a Baseline (no structural change), a BAU (gradual market-driven evolution), and an Ambitious (policy-led structural transformation).

Iron & Steel

India is the world's second-largest steel producer, with 2022 crude steel output of 125.3 million tonnes. Per capita consumption of just 93.5 kg (compared to global averages of ~230 kg) indicates enormous latent demand as infrastructure buildout accelerates. The current fleet is dominated by coal-based Blast Furnace-Basic Oxygen Furnace (BF-BOF) routes, producing over 2.5 t CO_2 per tonne of crude steel - above the global average. Baseline energy demand rises from 3.83 EJ (2022) to 9.62 EJ by 2047, a more-than-twofold increase. The Ambitious scenario - which scales hydrogen-based Direct Reduction Iron (H-DRI) with Electric Arc Furnaces and expands scrap-based secondary steel production through a formalised circular economy - holds demand to 6.03 EJ by 2047, a 37% reduction relative to the Baseline. Scrap-based EAF saves 60–65% of final energy per tonne compared to BF-BOF; H-DRI with renewables reduces process emissions by 85–95%.

Cement

Cement production is dominated by Ordinary Portland Cement (OPC), which is clinker-intensive and coal-fired. Baseline demand rises 79% from 0.86 EJ (2022) to 1.53 EJ by 2047, closely tracking production growth. Coal accounts for over 90% of final energy even in later projection years, meaning fuel substitution alone delivers limited gains. The primary lever is clinker intensity reduction: blended cements (Portland Pozzolana Cement, Portland Slag Cement, Composite Cement) lower the clinker-to-cement ratio and directly cut both thermal energy demand and process CO_2. The Ambitious scenario - which aggressively scales blended cement standards and mandates low-clinker compositions - limits demand growth to just 27% (1.09 EJ by 2047), a 29% reduction relative to Baseline.

Aluminium

Aluminium is India's most electricity-intensive industrial sub-sector, dominated by the Hall-Héroult primary smelting process. Baseline demand more than quadruples from 0.87 EJ (2022) to 3.77 EJ by 2047. The defining structural lever is the shift from primary to secondary (recycled) aluminium production. Secondary aluminium requires only a fraction of the energy of primary smelting and bypasses energy-intensive stages of bauxite mining, alumina refining, and electrolytic reduction entirely. In 2022, secondary aluminium accounted for approximately 40% of production. The Ambitious scenario scales this to ~80% by 2047 - supported by robust scrap collection systems, formalised informal recycling networks, and enabling policy - reducing energy demand by 33% relative to Baseline and demonstrating the transformative potential of circular economy approaches.

3.3. AGRICULTURE SECTOR

Irrigation, Farm Mechanisation & the Food-Energy-Water Nexus - 2020 to 2047

Agriculture employs close to 45% of India's total workforce and contributes approximately 16–18% of Gross Value Added. It is also one of the largest consumers of commercial energy in the economy, responsible for roughly 17–20% of total electricity consumption. This energy demand is dominated by two drivers: irrigation pumping and farm mechanisation.

India operates an estimated 30–32 million irrigation pump sets, approximately two-thirds of which are electrically powered and the remainder diesel-powered. More than 60% of India's irrigated area now depends on groundwater, compared to much lower shares in the early post-independence period. This expansion has enabled higher cropping intensity and output, but it has also caused steadily rising energy consumption - compounded by the fact that average pump efficiency remains below 40%, meaning the final energy consumed for water lifting is more than double the useful energy actually required. India's tractor fleet, which has grown from 0.02 kW per hectare in the 1970s to nearly 1.93 kW per hectare by 2021–22, adds a substantial diesel-consumption dimension to the sector's energy profile.

Agricultural Energy Demand - BAU vs. Ambitious (2020 to 2047)

Business-as-Usual

Total agricultural energy demand rises from 32.3 Mtoe (2020) to 43.6 Mtoe by 2030, and continues to 61.8 Mtoe by 2047. This growth reflects rising mechanisation intensity, expanding irrigation requirements, and unchanged pump efficiencies.

Irrigation pump sets account for the dominant share: electricity demand from pumping rises from 15.67 Mtoe (2020) to 18.60 Mtoe by 2047, while diesel use for pumping remains at 7–8 Mtoe. A growing solar pumping contribution of 20.93 Mtoe by 2047 is notable but does not eliminate the efficiency problem.

Tractor energy consumption, entirely diesel-based in BAU, rises from 9.26 Mtoe (2020) to 14.53 Mtoe by 2047, tracking growth in tractor stock from the current base of over 9 million units.

Ambitious - 10% Efficiency Improvement

A uniform 10% efficiency improvement across all agricultural technologies - diesel tractors, electric tractors, and all pump set types - reduces demand to 55.2 Mtoe by 2047: an absolute saving of 6.57 Mtoe annually over BAU.

By 2030, the Ambitious scenario saves 7.44 Mtoe - a 17% reduction relative to BAU - achieved without any change in agricultural activity levels, irrigation requirements, or mechanisation intensity. No crops are cut; no farmers are displaced.

These savings translate into reduced pressure on rural distribution networks, lower diesel import requirements, and enhanced energy security - making efficiency improvement one of the highest-leverage, lowest-risk interventions available to the agriculture sector.

The Food–Energy–Water Nexus: A Structural Demand-Side Solution

Beyond equipment efficiency, the study examines a deeper structural intervention: strategic crop substitution as a demand-side energy management tool. India's water-intensive staple crops - particularly rice and wheat cultivated under flood irrigation - require approximately 200 kg/ha of fertiliser and emit 3 kg CO_2e per kilogram produced. They also require enormous volumes of groundwater to be lifted and distributed, which is the root cause of irrigation energy demand growth.

Millets, by contrast, require only 50 kg/ha of fertiliser and emit just 0.5 kg CO_2e per kilogram - delivering a sixfold reduction in GHG emissions while simultaneously improving nutritional outcomes (superior protein, fibre, and micronutrient density per unit of land and water). By fundamentally reducing the volume of water that needs to be lifted, millet substitution addresses the root cause of energy stress in irrigated agriculture rather than merely treating its symptoms. Integrating crop diversification into the national energy strategy is not merely an agricultural recommendation - it is a prerequisite for long-term energy security.

3.4. ELECTRICITY SUPPLY

Generation Mix, Emissions & Infrastructure - 2024 to 2070

The electricity sector sits at the intersection of all other sectors' decarbonisation ambitions. Transport electrification only reduces emissions if the grid is clean. Industrial hydrogen production is only low carbon if powered by renewables. Agricultural solar pumping only lowers the system carbon footprint with an efficient, renewable-rich supply mix. And India's electricity demand itself is projected to grow nearly fifteenfold relative to 2022 - driven by urbanisation, rising per capita incomes, electric mobility, data centres, and the cooling demands of a warming climate.

The LEAP-STELLA-ACPET electricity supply model assesses the period 2024–2070 across nine generation sources: coal, gas, solar, wind, biomass, waste, small hydro, large hydro, and nuclear. Two scenarios are compared: the Business-as-Usual pathway (continuation of current trends in generation mix and efficiency) and the Low-Carbon pathway (accelerated renewable penetration, improved thermal efficiency, and expanded storage and transmission infrastructure).

A key and counterintuitive finding is that the choice of generation pathway does not significantly change the volume of electricity India produces - but it fundamentally changes how that electricity is generated. Electricity demand is driven primarily by economic and social factors, which are common to both scenarios. What changes is the composition of the system: emissions, fuel use, and infrastructure requirements. This reframes the transition debate: it is not a trade-off between development and decarbonisation, but a choice about the infrastructure mix that delivers the same electricity outcomes.

Emissions Outlook: 2024–2070

Total GHG emissions from electricity generation are projected to rise from 1,371 $MTCO_2$e (2023–24 base) to 3,934 $MTCO_2$e by 2070 under the BAU scenario - a 187% increase. Under the Low-Carbon scenario, emissions reach 2,939 $MTCO_2$e - a 114% increase, but with ~995 $MTCO_2$e of avoided annual emissions by 2070, representing a 25% reduction relative to BAU.

Both scenarios track closely until approximately 2040, after which they diverge as renewable penetration deepens in the Low-Carbon pathway. Emissions in both scenarios continue to rise until the 2040s before beginning to moderate under the Low-Carbon pathway - a sobering reminder that even ambitious renewable deployment cannot offset growing demand in the near term.

Critically, neither scenario achieves net-zero emissions from the electricity sector by 2070. The Low-Carbon pathway should therefore be understood as an intermediate step - representing the maximum reduction achievable through changes in generation mix and efficiency improvements alone. Achieving net-zero would require additional measures: demand growth moderation, accelerated coal retirement, and technologies such as carbon capture and storage, which fall outside the scope of this analysis.

A particularly consequential finding concerns the long economic lifetime of coal assets. Coal plants built in the current decade are likely to still operate in the 2050s, creating financial lock-in (long-term debt and contracts), operational lock-in (systems designed around coal are harder to adapt to renewables), and political lock-in (coal-related jobs and revenues make it difficult to reduce dependence). The Low-Carbon pathway also requires a larger total installed capacity than BAU, because renewable energy systems need more capacity headroom for the same firm energy output. If renewable energy, storage, and transmission are not developed as assumed, coal will continue to play a larger role than modelled - leading to higher cumulative emissions.

4. POLICY RECOMMENDATIONS

Priority interventions to align India's energy trajectory with Viksit Bharat 2047 and Net Zero 2070

A consistent finding across all four sectors is that incremental efficiency improvements within existing structures yield only modest reductions in energy demand and emissions. True alignment with India's climate commitments requires managed structural transformation - a deliberate reshaping of production processes, modal composition, technology choices, and material flows. The following recommendations translate the modelling insights into concrete policy priorities. They are not presented as a wish list, but as the minimum set of enabling conditions that the scenario results show are necessary to achieve the Ambitious pathway outcomes.

4.1. Transport Sector

1 **Enhance public transport attractiveness through fare reform and infrastructure investment**

The modelling demonstrates that even the Ambitious scenario sees transport energy demand continue to rise, underscoring the indispensability of reducing private vehicle dependence. Investments in fare affordability, first- and last-mile connectivity, and dedicated cycling and pedestrian infrastructure are essential. Evidence from Bengaluru (a 10% fare cut generating 33% higher ridership) and Germany's €9 monthly ticket (52 million tickets sold, 1.8 Mt CO_2 avoided) demonstrate that demand responds powerfully to affordability and access improvements. Behavioural nudges - default EV procurement for government fleets, social norm messaging, integrated ticketing - are low-cost, scalable complements to infrastructure investment.

2 **Green the grid as a prerequisite for electrification benefits**

The emission reductions from EV adoption are directly proportional to the cleanliness of the electricity used to charge them. EVs charged on India's current grid emit about 20–35% less GHG than diesel vehicles; charged on renewables, the reduction is 85–90%. This means that transport decarbonisation and electricity sector transformation are inseparable. Rapid renewable capacity addition, grid flexibility improvements, and coal retirement must proceed in parallel with EV scale-up - not sequentially.

3 **Build public charging infrastructure and sustain targeted subsidies**

EV adoption is constrained not just by upfront cost but by range anxiety and charging accessibility. Scaled deployment of public charging stations and battery-swapping facilities in urban areas, along highways, and near freight corridors is critical. FAME-type fiscal incentives for consumers and fleet operators must be sustained and extended. Public-private partnerships can accelerate infrastructure rollout and reduce the fiscal burden on government while ensuring equitable geographic distribution of charging access.

4 **Prioritise heavy freight electrification through dedicated corridors**

Heavy trucks account for over 40% of on-road fuel consumption despite representing only ~2% of the vehicle stock. This concentration makes freight electrification a high-leverage intervention. Zero-emission freight corridors, integrated with logistics hubs and renewable-powered charging and refuelling infrastructure, should be developed as pilot initiatives with a clear scale-up pathway. India is already laying initial groundwork through early industry trials - building on this foundation systematically is the priority.

5 **Establish segment-wise EV adoption targets to improve policy accountability**

The EV30@30 goal (30% EV sales by 2030) is too aggregated to monitor effectively or to attribute responsibility across vehicle types. Different segments - two-wheelers, passenger cars, commercial vehicles, buses, and freight trucks - are growing at very different rates and face different adoption barriers. Setting specific targets for each segment enables more granular tracking of progress, identifies where policy support is lagging, and allows for targeted resource allocation.

4.2. Industry Sector

1 **Reorient industrial strategy from efficiency optimisation to structural transformation**

Policy instruments must move beyond energy efficiency frameworks and actively shape technology adoption and material flows. In steel, this means enabling hydrogen-based DRI and accelerating the expansion of scrap-based EAF by emphasising circular economy imperatives. In cement, the priority is structurally lowering clinker intensity through blended cement standards and mandatory material substitution requirements. In aluminium, the dominant lever is a rapid scale-up of secondary production supported by a robust recycling ecosystem. Each of these requires explicit policy mandates, not just incentives.

2 **Create enabling markets for low-carbon materials through public procurement**

A recurring barrier across sectors is the absence of strong demand signals for low-carbon alternatives. Without assured markets, private investment in hydrogen steel, low-clinker cement, or recycled aluminium will remain cautious. Government-funded infrastructure projects can incorporate embodied carbon disclosure requirements and preferential sourcing criteria. Over time, these measures can evolve into performance-based carbon intensity standards. Alignment with emerging global carbon border mechanisms provides an additional market signal.

3 **Coordinate energy infrastructure development with industrial cluster strategy**

Hydrogen production corridors, renewable energy zones, and transmission grid expansion must be co-planned with the location and phasing of industrial clusters. Dedicated renewable corridors for major industrial hubs, streamlined access to long-term power purchase agreements, and support for captive renewable systems are essential enabling conditions for industrial decarbonisation. Without this spatial and temporal coordination, industries will remain dependent on coal-based power regardless of national renewable targets.

4 **Mobilise de-risked finance for first-mover low-carbon industrial technologies**

Low-carbon industrial technologies - H-DRI steelmaking, electric kilns, large-scale secondary aluminium - are capital-intensive and face significant cost uncertainty during early deployment. Blended financing frameworks, concessional instruments, and carbon pricing signals are necessary to de-risk investment decisions and reduce the financial gap between incumbent and low-carbon technologies. Carbon pricing, in particular, needs to be legitimised as a long-term investment signalling mechanism.

5 Strengthen formal circular economy infrastructure across the supply chain

Circularity is not just an environmental aspiration - it is a structural energy reduction strategy, particularly for steel and aluminium. Expanding scrap availability, formalising collection and sorting systems, integrating informal recycling networks, establishing digital material tracking, and setting recycled content benchmarks in construction, automotive, and packaging are institutional reforms that need to be implemented at scale.

4.3. Agriculture Sector

1 Mandate efficiency standards for irrigation pump sets and implement targeted replacement programmes

With 30–32 million pump sets operating at average efficiencies below 40%, the potential energy saving from a systematic upgrade programme is enormous. Performance-based efficiency standards for new pump sets, combined with subsidised replacement schemes for legacy equipment, can deliver substantial reductions in agricultural electricity demand without affecting irrigation service delivery. This is a high-leverage, low-risk intervention - the energy saving requires no change in farming activity.

2 Integrate efficiency criteria into all renewable energy deployment programmes in agriculture

Solar pumping is growing rapidly and is explicitly included in national renewable energy targets. However, installing inefficient solar pump sets converts the efficiency problem from a grid-load problem into an over-extraction problem - causing excessive groundwater depletion at lower operating cost, which creates a different set of risks. All PM-KUSUM and related solar pump schemes must embed minimum efficiency thresholds to ensure that renewable deployment in agriculture also advances resource sustainability.

3 Align agricultural policy with energy and rural infrastructure planning

Policies promoting mechanisation and irrigation expansion must be accompanied by efficiency standards to avoid unintended energy demand increases. Rural electricity infrastructure planning - feeder capacity, transformer sizing, and system reliability - must explicitly incorporate agricultural energy demand projections, including the efficiency assumptions used to moderate growth. Where efficiency improvements are demonstrated, infrastructure planners should credit these as an alternative to supply-side expansion.

4 Pursue strategic millet substitution as a Food–Energy–Water Nexus intervention

Moving from water-intensive crops such as paddy rice to millets delivers a sixfold reduction in agricultural GHG emissions while providing superior nutritional outcomes. At 50 kg/ha of fertiliser versus ~200 kg/ha for rice and wheat, millets also reduce fertiliser energy consumption substantially. Integrating crop diversification incentives into the national agricultural policy framework - including procurement support, minimum support price parity, and farmer income protection mechanisms - is essential to make this transition economically viable for farmers while delivering large-scale energy and water co-benefits.

4.4. Electricity Supply

1 **Shift emissions monitoring to track absolute emissions trajectories, not just capacity or generation shares**

As renewable energy expands, share-based indicators will increasingly show progress even as total emissions continue rising in absolute terms. India's planning and monitoring frameworks must be updated to include absolute emissions benchmarks alongside existing metrics. This is not merely a reporting adjustment - it changes the policy targets that investment and regulatory decisions are optimised against, and is essential for accurately assessing progress toward Net Zero 2070.

2 **Implement thermal efficiency improvements in parallel with renewable expansion, not instead of it**

Improving coal plant efficiency reduces emissions per unit of electricity and is a critical near-term strategy. However, high-efficiency coal is still coal, and if efficiency gains reduce operating costs sufficiently, they could extend the economic life of coal assets and slow the renewable transition. Efficiency improvements deliver their full benefit only when implemented alongside - not as a substitute for - a rapidly rising renewable share. Planning approaches must advance both dimensions simultaneously.

3 **Plan for the full system infrastructure requirements of a high-renewable electricity system**

Compared to a thermal-dominated system, a renewable-heavy system requires significantly higher total installed capacity, expanded high-voltage transmission networks, utility-scale storage systems, and sophisticated grid balancing capabilities. These requirements must be incorporated early in integrated resource planning to prevent the infrastructure gaps that may slow renewable deployment or force continued reliance on coal to maintain reliability. Storage and transmission are not optional add-ons - they are structural prerequisites.

4 **Account explicitly for coal asset lifetimes in current investment and permitting decisions**

New coal plants approved in the current decade are likely to still be operating in the 2050s, creating a decades-long emissions obligation. The cumulative emissions associated with these assets must be explicitly modelled and disclosed alongside their short-term cost and reliability benefits. Regulatory frameworks and lending standards that incorporate climate-aligned investment criteria - including international capital markets and development finance institutions - can play a powerful role in constraining new coal commitments.

5. STRATEGIC CONCLUSIONS

India's energy future is a challenge of strategic alignment, not a trade-off between growth and sustainability

The overarching conclusion from this study is clear and consequential: India's development aspirations and its climate commitments are not inherently in conflict, but reconciling them requires a deliberate, coordinated, and structurally ambitious policy response. Energy demand will rise - this is certain. What can be shaped is the rate, composition, and carbon intensity of that demand. The modelling consistently shows that incremental efficiency improvements within existing structures are insufficient. Ambition must be structural.

Transport	30% emissions reduction possible by 2050 through combined EV scale-up, modal shift, and grid greening. Light commercial vehicles are the biggest single lever; heavy freight electrification is the hardest but highest-impact challenge.
Industry	37% energy reduction in steel, 29% in cement, 33% in aluminium - but only through structural transformation: hydrogen steelmaking, clinker reduction, and circular economy-led secondary production. Marginal efficiency gains alone will not move these sectors.
Agriculture	17% energy savings by 2030 from a 10% efficiency improvement alone - with no impact on agricultural output. Millet substitution adds a 6× GHG reduction pathway by addressing the root cause of irrigation energy demand.
Electricity	~1,000 $MTCO_2e$ of avoided annual emissions by 2070 under the Low-Carbon pathway. But net-zero requires additional demand moderation and technology beyond generation mix changes. Current-decade coal investment decisions will shape emissions for 40 years.

The Central Message for the Policymakers

India's transition is not a distant event - it is being determined by decisions made in the current decade. Coal plants approved today will shape emissions in 2055. Industrial technologies adopted now will operate for 30–40 years. Vehicle fleet composition in 2030 will constrain (or enable) net-zero progress in 2050. Infrastructure investment in renewable energy, storage, and grid capacity must begin accelerating immediately if the Low-Carbon pathway assumptions are to hold.

The study demonstrates that deploying circular economy frameworks, creating markets for low-carbon materials through public procurement, integrating agriculture and energy planning, and mobilising concessional finance for first-mover technologies are not peripheral measures - they are the structural foundations of a credible transition. India does not need to choose between development and sustainability. But it does need to choose, quickly, which version of its development path it will build.

Campus Location

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