Estimating Social Costs of Big Energy: A novel approach combining NLP with Satellite Imagery

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July 26, 2025

Latest Version

Abstract

This paper develops a novel empirical framework to quantify the social costs of infrastructure development in India, focusing on displacement from large-scale energy projects—coal, hydro, and solar—over the past 50 years. Combining over 25,000 land acquisition notices with satellite-derived settlement data, I construct the first spatio-temporal estimates of project-affected persons (PAPs). Results show displacement varies sharply across sectors, with coal mining imposing the highest burden, particularly on tribal populations in central and eastern India. Displacement from hydro projects peaked in the 1970s-1990s, while coal-related displacement has surged in recent decades. Solar projects, though less intensive, increasingly threaten common lands. This methodology enhances the integration of social costs into infrastructure planning and contributes to debates on equitable energy transitions. Without addressing compensation gaps, legal fragmentation, and grievance failures, India's infrastructure push risks perpetuating displacement and deterring future investments.

Keywords: Infrastructure, Displacement, Energy Transition, Land Acquisition, Remote Sensing, India

JEL Classification: O13, O18, Q34, R52, R58

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1 Introduction

Large-scale infrastructure investments have long been central to theories of economic development, industrialization, and structural transformation. From classic big-push models to contemporary growth diagnostics, infrastructure is widely seen as a critical input for raising productivity, connecting markets, and reducing spatial inequality. Yet, the developmental promise of infrastructure often obscures its redistributive consequences. Land-intensive infrastructure projects, particularly in emerging economies, generate complex social costs—most visibly through displacement of communities residing on or near project sites. These social costs remain poorly documented and weakly integrated into infrastructure appraisal, often resulting in projects that are economically ambitious but socially undesirable.[1]

Globally, megaprojects are characterized by chronic cost overruns, implementation delays, and low ex-post returns. Flyvbjerg (2009) documents that 9 out of 10 large infrastructure projects exceed initial cost estimates, with hydro projects showing real cost overruns of nearly 200% on average. These inefficiencies stem in part from flawed ex-ante benefit-cost analysis: project benefits are frequently overstated due to optimistic demand forecasts, while social and environmental costs are systematically underestimated or ignored. These planning failures are not merely technical—they often result in intense legal and extralegal resistance from local populations, eroding the very legitimacy of the development process. This resistance, popularly understood as NIMBYism (Glaeser et al., 2017), is especially pronounced in contexts where compensation is inadequate, civic participation is limited, and grievance mechanisms are weak.

In India, the social costs of infrastructure expansion are particularly salient. Over the past seven decades, the country has pursued an ambitious program of energy infrastructure development—spanning coal mines, large hydro dams, and utility-scale solar parks—requiring extensive land acquisition, often from marginalized and vulnerable communities, with minimal rehabilitation support. While rich qualitative accounts of displacement exist (Levien, 2013; Baviskar, 2004), there remains a striking absence of empirical, spatially disaggregated estimates of project-affected persons (PAPs). Administrative data are fragmented, rehabilitation records incomplete, and official estimates too coarse and often biased to support serious evaluation. This lack of reliable displacement metrics not only undermines accountability but also constrains the ability to design infrastructure transitions that are both equitable and socially sustainable.

This paper fills that gap by developing a new methodology to measure displacement from large energy infrastructure projects in India over the past 50 years. I focus on three land-intensive sectors, coal mining, hydro, and solar energy (which collectively account for 90% of the enery production supply chain) and construct project-level estimates of PAPs by combining administrative land acquisition records with high-resolution satellite data on human settlements. Specifically, I extract over 25,000 Gazette Notifications (GNs)—official land acquisition notices—using a custom natural language processing (NLP) pipeline, and georeference each project to the village or subdistrict level. My empirical strategy builds on the analytical frame-

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[1] See Flyvbjerg and Gardner (2022) for an excellent discussion on project delays.

work of spatial and temporal project “footprints”—defined as the geographic zone and time window within which a project directly displaces or indirectly exposes human settlement due to project siting. I then combine these data with the Global Human Settlement Layer (GHSL) to detect spatial and temporal changes in settlement density before and after project initiation. This yields a novel spatio-temporal panel of infrastructure-driven displacement across India.

The results show that displacement varies systematically by sector, geography, and time. Coal projects have the highest displacement intensity (4.67), followed by solar (2.43) and hydro projects (1.90). While hydro projects acquire large spatial areas, coal projects are concentrated in comparatively denser regions, resulting in higher displacement effects. Over time, displacement from hydro projects peaked in the 1970s–1990s during India’s dam-building era, whereas coal-related displacement has risen sharply over the last two decades. Disaggregated results also reveal that a majority of coal mining–related acquisitions have occurred on tribal lands in Scheduled Areas, disproportionately affecting Scheduled Tribes and other vulnerable groups, particularly in central and eastern India.

The paper also highlights the heterogeneity in project delays across India’s energy sectors and explains these differences through the political economy of land acquisition, viewed through the lens of NIMBYism. Using sector-specific legal frameworks and project-level data on delays, I argue that NIMBYism operates through three main channels: (1) legal pluralism and policy design, which shape the procedural space for contestation; (2) litigation over compensation and rehabilitation delays, which prolong timelines and escalate costs; and (3) mistrust and extra-legal conflict, which can entrench opposition and stall projects. By comparing coal, hydropower, and solar, the paper shows how these channels interact with institutional arrangements to produce distinct patterns of delay, cost overrun, and incentives in India’s energy transition.

These findings contribute to multiple strands of the development economics literature. First, they offer a systematic empirical account of infrastructure-induced displacement in one of the world’s fastest-growing economies. Second, they provide new tools for integrating social costs into infrastructure planning, using remote sensing and NLP-based data extraction. Third, they underscore the political economy constraints to socially optimal infrastructure: poor compensation, multiple land acquisition routes, and legal delays not only generate immediate costs but also erode the long-term investment climate.

Finally, by offering a replicable and scalable framework for estimating displacement, this paper contributes directly to academic and policy debates on energy transitions. The findings challenge the prevailing narrative of just transitions, showing that while solar projects have achieved rapid rollout and maintain a smaller acquisition footprint, their displacement intensity rivals that of traditional infrastructure. Weak community safeguards and the limited recognition of customary land rights—combined with the siting of solar parks on common lands near populated areas—are triggering new forms of ”green dispossession”.

As India accelerates toward ambitious renewable energy targets and a low-carbon transformation, the intertwined issues of land, equity, and displacement will become even more pressing. In a country where two-thirds of the population remains directly dependent on land, integrating distributive justice into infrastructure planning is not just an ethical imperative but a prerequisite for sustained, conflict-free growth. Without a credible accounting of these social costs, the green transition risks repeating—and legitimizing—the injustices of earlier development paradigms.

The rest of the paper is organized as follows: Section 2 reviews the background of energy infrastructure and outlines the legal and institutional frameworks governing land acquisition. Section 3 discusses the data sources and NLP pipeline for the novel data on big energy projects. Section 4 presents the empirical strategy used to estimate displacement effects. Section 5 presents the results, and Section 6 interprets the findings through the political economy lens of NIMBYism as a social bargaining process. I conclude with the future direction of research and policy recommendations for infrastructure planning in weak institutional settings.

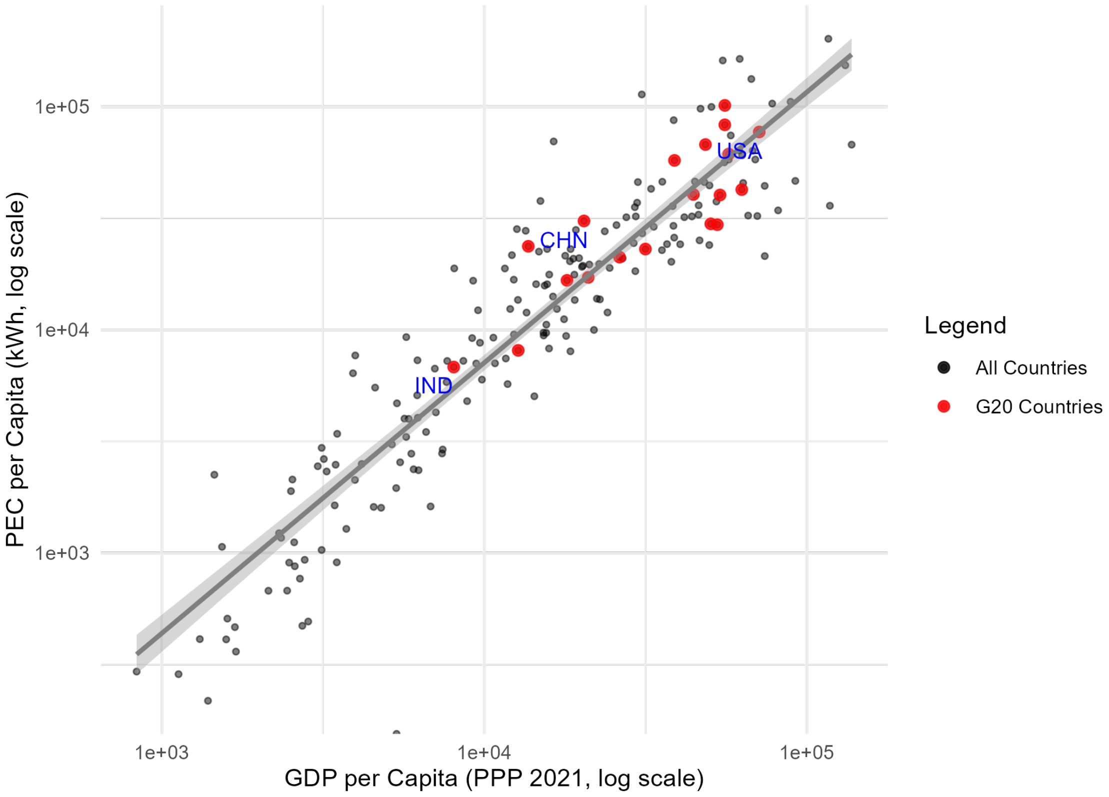
2 Background

2.1 India and the Global Energy Transition

The global energy landscape has undergone a profound transformation over the past five decades, reshaping the political economy of energy and climate governance. In the 1970s, the global energy mix was overwhelmingly dominated by coal and oil, with fossil fuels accounting for nearly 95% of global primary energy consumption. This fossil fuel dependency entrenched carbon-intensive growth models and heightened vulnerability to price volatility and supply disruptions during the oil crises of that era (Energy Institute, 2023). Since then, global energy markets have diversified substantially, driven by climate mitigation imperatives, rapid technological innovation, and shifting geopolitical dynamics. The share of renewables in global electricity generation increased from less than 5% in 1973 to over 30% in 2023, with solar photovoltaic (PV) systems alone accounting for nearly two-thirds of new renewable capacity additions between 2018 and 2023 (International Renewable Energy Agency, 2024). These trends reflect not only the steep decline in the levelized cost of electricity (LCOE) for renewables but also the growing policy momentum toward decarbonization, energy diversification, and long-term energy security.

Within this transition, India has emerged as a pivotal actor in the global energy–climate nexus. Once a marginal energy consumer, it is now the world's third-largest carbon emitter, following China and the United States, yet its per capita energy consumption remains among the lowest in the G20. As shown in Figure 1, India's per capita primary energy consumption ranks lowest among G20 member states, underscoring significant inequities in global energy use. To meet the surging energy demands of its rapidly expanding economy, India's energy strategy has adopted an "all-of-the-above" approach — accelerating the deployment of solar and wind power, while maintaining substantial investments in coal and hydropower, and recently advancing an ambitious expansion of nuclear energy capacity (International Energy Agency, 2023). This integrated strategy encapsulates the inherent policy trade-offs between rapid decarbonization, energy access and equity, and energy security. Given the magnitude of its future energy demand and its centrality to global carbon budgets, India is widely recognized as a decisive player in shaping the

Figure 1: **Global Outlook on Energy Consumption**



Note: The graph depicts the relationship between Primary Energy Consumption (PEC) per capita and Gross Domestic Product (GDP) per capita on a log scale. G20 countries are highlighted in red and the top 3 carbon emmitters are labeled. Source: Author's analysis based on the data from U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2024); Eurostat, OECD, and World Bank (2025) obtained via Our World in Data.

trajectory of global climate mitigation efforts (World Bank, 2023; Intergovernmental Panel on Climate Change, 2022)

2.2 Sectoral Trends in Big Energy

Figure 2 illustrates the evolution of India's electricity generation mix since 1985, underscoring the structural persistence of coal alongside the gradual rise of solar power as a meaningful contributor. In 1985, coal accounted for approximately 62% of electricity generation, hydropower for 28%, and solar was non-existent. Through the 1990s and early 2000s, coal's share rose gradually, stabilizing around 66–70%, while hydro declined steadily. From 2010 onward, solar began registering measurable growth, increasing from near-zero to over 6% in 2023. Over the same period, hydro's share continued to fall, dropping below 10% by the late 2010s. By 2023, coal contributed more than 75% of total generation, reinforcing its dominance despite the rapid acceleration of solar deployment. These patterns reflect entrenched coal-based infrastructure and path dependency in energy investment, even amid policy ambitions for accelerated decarbonization and renewable integration.

India's energy infrastructure has developed across three distinct historical phases: colonial extraction, post-independence nation-building, and market-oriented liberalization. During the colonial period, infrastructure investments were primarily designed to serve imperial economic interests, particularly coal mining for railroad expansion and export markets (Roy, 2006). Following independence in 1947, energy development became a central pillar of state-led industrialization, embedded in the Five-Year Plans and implemented through large public sector undertakings (PSUs). The 1990s ushered in an era of economic liberalization, opening energy markets to private and foreign investment, which catalyzed both public and private sector expansion in generation capacity, transmission infrastructure, and cross-border energy trade (Ahluwalia, 2002).

India holds the world's fifth-largest proven coal reserves and was the second-largest coal producer in 2022 (Ministry of Coal, Government of India, 2023). The earliest recorded coal mining dates to the 1770s in the Raniganj coalfields under British colonial administration. Colonial-era coal mining was predominantly financed by foreign private capital and served commercial rail and export demands. In the post-independence period, ownership transitioned to domestic private actors. However, investment limitations and strategic considerations led to the nationalization of coal mining in 1972–73, creating a state monopoly through the Coal Mines (Nationalization) Act of 1973.[2] This monopoly persisted until 2018, when reforms re-opened the sector to private commercial mining. Coal production rose steadily from the early years of independence through the 1980s and 1990s, with Coal India Limited (CIL) emerging as the dominant producer. Rapid industrialization and electricity demand growth in the subsequent decade spurred significant increases in coal production.[3] These developments highlight the tension between short-term energy security and long-term decarbonization commitments under India's net-zero 2070 pledge (Ministry of Environment, Forest and Climate Change, Government of India, 2021).

Hydropower development has a long history, beginning with the commissioning of the Shivanasamudra hydroelectric station in 1902—Asia's first major hydropower project. Post-independence, large multipurpose dams such as Bhakra–Nangal and Hirakud became icons of Nehruvian developmentalism, integrating irrigation, flood control, and power generation. This vision underpinned a surge in hydropower investments between the 1950s and 1980s. However, since the 1990s, expansion has slowed, constrained by environmental concerns, displacement-related social conflicts, and more stringent regulatory clearance processes in ecologically sensitive zones (Khagram, 2004). As of 2025, India operates over 100 mega hydropower stations (above 25 MW capacity), contributing roughly 10% of total electricity generation.

India's engagement with solar energy began in the 1970s but remained marginal

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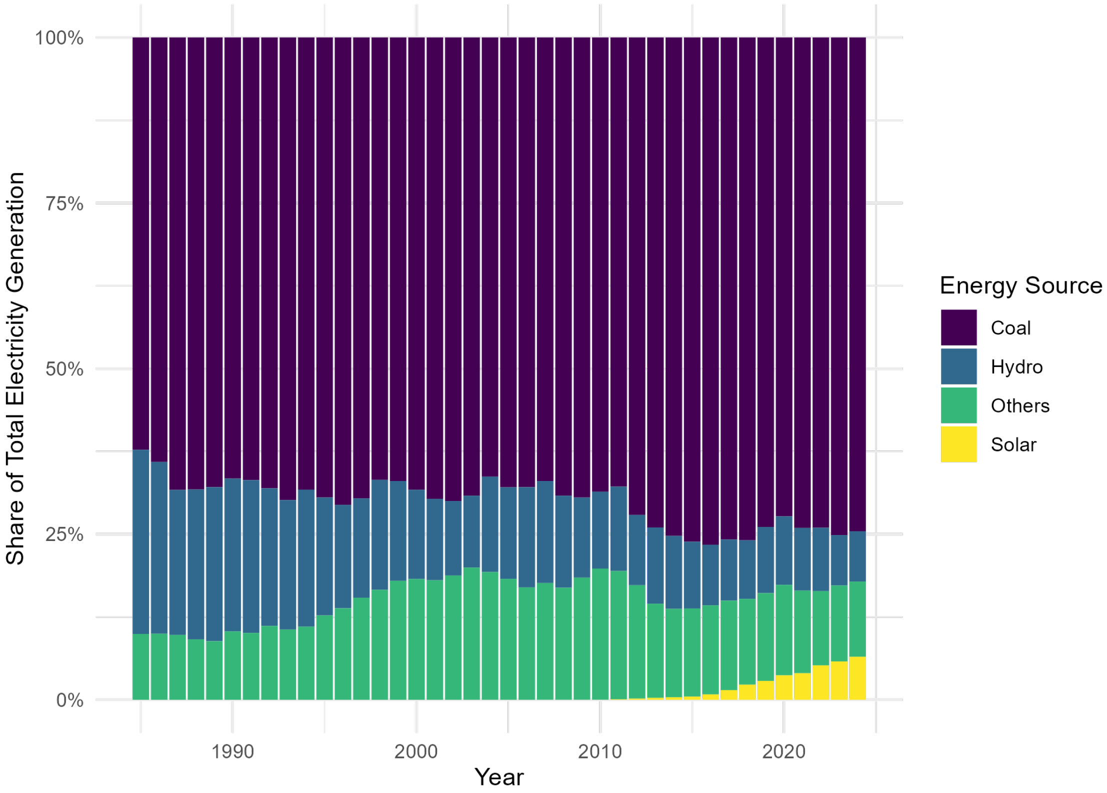
[2] The nationalization was implemented in two phases: first with coking coal mines in 1971–72 under the Coking Coal Mines (Emergency Provisions) Act, and later in 1973 with the nationalization of non-coking coal mines through the Coal Mines (Nationalization) Act. See `https://web.archive.org/web/20171109081113/https://www.coalindia.in/en-us/company/aboutus.aspx` for further details.

[3] In the early 2000s, output hovered around 300–400 million tonnes annually. By 2015, output exceeded 600 million tonnes annually. Between 2015 and 2023, production surged further, reaching approximately 893 million tonnes in FY 2022–23, with CIL accounting for 79% of national output. The government has set a target of 1 billion tonnes annually by 2026, supported by commercial mining auctions, expedited environmental clearances, and digital monitoring systems.

Figure 2: **Electricity Generation Mix in India (1985-2024**



Note: The graph shows electricity generation mix in India between 1985 and 2024. The others category include oil, gas, wind, nuclear, and biofuels. Source: Author's analysis based on the data from Ember (2025) and Energy Institute - Statistical Review of World Energy (2025) obtained via the Our World in Data.

until the early 2000s due to high capital costs, limited technological capabilities, and inadequate policy support. A turning point came with the Jawaharlal Nehru National Solar Mission (JNNSM) launched in 2010, which catalyzed investment and deployment. Installed solar capacity expanded from 2.6 GW in 2014 to over 75 GW by 2025, with a national target of 280 GW by 2030 (Ministry of New and Renewable Energy, Government of India, 2023). The launch of the International Solar Alliance (ISA) in 2015, headquartered in India, underscores its aspiration to lead the global solar transition and align domestic policy with its net-zero ambitions. India now ranks among the world's top five solar producers, with utility-scale solar parks—especially in Rajasthan, Gujarat, and Andhra Pradesh—leading capacity growth.

In recent decades, private sector participation has become central to India's energy market transformation, particularly in renewable energy deployment. Appendix Table A1 shows that the private sector now accounts for more than half of total installed capacity.[4] While it holds less than 10% of large hydro capacity and about one-third of coal-based capacity, private firms dominate in renewables, operating

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[4] Installed capacity does not directly equate to generation output. Coal still produces around 70% of total electricity, while solar generation is constrained by intermittency, limited storage, and grid integration challenges (Central Electricity Authority, 2024).

over 95% of installed capacity in this segment. This structural composition reflects broader global patterns in the energy transition, where private capital increasingly drives renewable capacity expansion, while fossil fuel baseload generation remains anchored in legacy public-sector infrastructure.

2.3 Land Acquisition for Big Energy

Access to large, contiguous land parcels is a critical prerequisite for the planning and execution of utility-scale energy infrastructure. The siting of thermal power plants, hydropower dams, and solar parks frequently requires land consolidation in rural, common, or forested landscapes—processes that often involve complex trade-offs between energy security, climate mitigation goals, and the rights and livelihoods of local populations. Land acquisition in these contexts raises profound questions of displacement, consent, and compensation for affected communities (Bhattacharya, 2018). Beyond economic considerations, project siting decisions are frequently shaped by legal, social, and ecological constraints, underscoring the multidimensional nature of energy transition governance. Consequently, land acquisition strategies exert significant influence not only on project timelines and cost structures but also on the social license to operate and the perceived legitimacy of large-scale energy projects (Jain, 2022).

Eminent domain—the legal principle empowering the state to acquire private property for public purposes—remains central to energy infrastructure expansion. While it typically requires adherence to procedural norms and provision of compensation, the institutional design of acquisition laws and the quality of their enforcement critically determine both the equity and efficiency of outcomes for affected landowners and communities. Under India's federal structure, land acquisition is a concurrent subject, enabling both the central and state governments to legislate on it. The central government establishes broad legislative norms, while states often adapt acquisition frameworks to local political economy contexts, industrial priorities, and developmental strategies.

The colonial-era Land Acquisition Act of 1894 was the principal eminent domain instrument for infrastructure development for over a century. Engineered to serve colonial needs, it prioritized capital mobilization and infrastructural expansion over social or environmental safeguards. Its provisions for compensation were weak, consent requirements absent, and ecological or livelihood protections minimal (Goetz, 2020).[5] In doing so, the Act minimized regulatory burdens for private investors and reinforced land-based structural inequalities well into the postcolonial era.

Mounting public opposition, grassroots mobilization, and protracted litigation eventually precipitated comprehensive reform with the passage of the Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (LARR) Act in 2013. The LARR framework sought to rebalance state, investor, and community interests by mandating higher compensation benchmarks,

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[5] Although the 1894 Act mandated prior notification and "just compensation," the valuation mechanisms relied on outdated land prices, excluded livelihood considerations, and ignored informal and customary land rights—particularly in tribal and forested areas. Its expansive definition of "public purpose" enabled acquisition for private industrial or speculative projects, further entrenching inequities

compulsory Social and Environmental Impact Assessments (SEIAs), explicit consent thresholds, and enforceable Rehabilitation and Resettlement (RR) provisions (Wahi and Bhatia, 2017). Yet, sustained lobbying by industry associations led to the progressive dilution of these safeguards. In several states, amendments and executive orders created exemptions for strategic and industrial projects, enabling circumvention of LARR through alternative acquisition pathways such as land pooling, leasing arrangements, and industrial promotion policies.

Many large-scale renewable and conventional energy projects overlap with protected forests, revenue lands, or common property resources. The complexity of land acquisition for energy projects is further compounded by overlapping statutory regimes. In particular, the Forest Rights Act, 2006 (FRA) recognizes the customary and community rights of forest-dwelling populations, creating a parallel legal framework and generating ambiguities over jurisdiction, procedural consent requirements, and compensation entitlements (Levien, 2018). These intersecting legal mandates—combined with gaps in institutional coordination—often precipitate disputes between affected communities and project developers. Such contestations contribute to implementation delays, social resistance, and, in many cases, long-drawn litigation, thereby reinforcing the political economy constraints on India's energy transition (Saha, 2020).

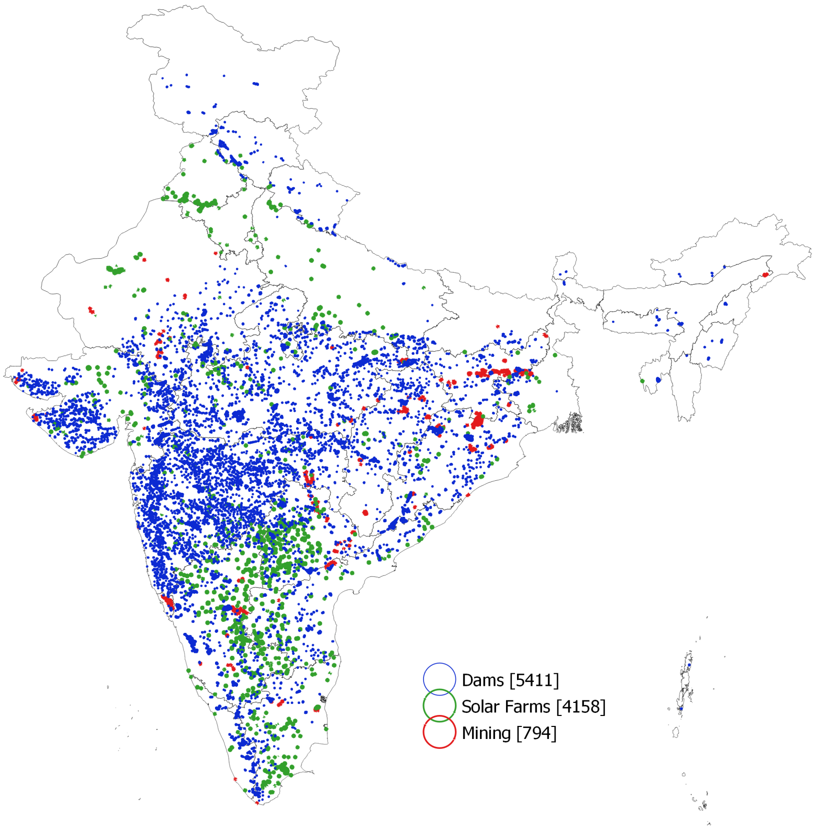
In sum, the governance of land acquisition constitutes a structural bottleneck in India's energy transition. While coal, hydropower, and large-scale renewables differ in technology and carbon intensity, they share a dependence on land-intensive project siting, making the political economy of and acquisition a critical determinant of both energy security and decarbonization trajectories.

3 Data

3.1 Novel Spatio-Temporal Datasets on Big Energy

Estimating the cumulative social costs of large-scale energy infrastructure requires spatially and temporally resolved, project-level land acquisition data. Such data, however, are largely absent from the public domain. To address this gap, I construct a novel spatio-temporal dataset for India covering the period 1970–2020 through a three-stage process: First, I compile sector-specific project documentation from official publications issued by relevant central and state-level ministries or departments. Second, I apply natural language processing (NLP) techniques to extract structured information from unstructured project documents. Third, I cross-reference these administrative data with independent spatial databases to validate records and geocode project locations. The resulting dataset constitutes a space–time panel of large energy projects across India, enabling historical and spatial analysis of infrastructure expansion and its social costs. Figure 3 shows the spatial distribution of energy projects.

Figure 3: **Distribution of Dams, Mining, and Solar Farms in India**



Note: Hydro includes both irrigation and multipurpose dam projects. Source: Author's computation based on methodology in Data Appendix A and Section 4.

Coal Mining

For coal mining, I leverage Gazette notifications issued by the Government of India—legally mandated public records that document land acquisition under the principle of eminent domain. These notifications are authoritative sources detailing the applicable acquisition law, the acquiring agency, notification dates, the stated public purpose, location identifiers, parcel measurements, land use classifications, and occasionally, ownership information.[6]

Despite their value, extracting structured data from Gazettes presents challenges: (i) inconsistent formatting and typography across time, (ii) degraded scan quality in older documents, complicating optical character recognition (OCR), and (iii) multiple notifications for a single project corresponding to different acquisition phases, which complicates project-level consolidation.

Since the nationalization of coal mining in the early 1970s, all central government-led acquisitions have been systematically published in the Gazette of India (egazette.nic.in). From a corpus of approximately 500,000 Gazette files, I apply a custom NLP pipeline to identify relevant notifications and extract structured fields. The step-by-step data

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[6] See a sample Gazette text here: `https://www.dropbox.com/scl/fi/kj39etaeq4prdydzxr8zx/156738.pdf?rlkey=hn7w472721m93vipyiagyksr9&st=2xf3xzhk&dl=0`

construction process is documented in Data Appendix A1. The final product is a village-level dataset on land acquisition for 474 coal mining projects between 1960 and 2020, with the displacement analysis restricted to 1975–2020 to align with both the availability of the Global Human Settlement Layer (GHSL) raster data and the post-nationalization policy context.

Hydro Projects

Because land acquisition for hydropower is largely administered by state governments, central repositories do not contain systematic Gazette records for such projects. I therefore rely on a hybrid approach combining administrative and spatial datasets.

The primary source is the National Register of Large Dams (NRLD), which contains technical specifications and geospatial coordinates for approximately 5,745 large dams commissioned between 1860 and 2020.[7] These data are merged with the ESRI Living Atlas reservoir layer, which delineates reservoir polygons via remote sensing, producing a high-resolution geospatial database of operational and planned dam projects.

A critical limitation is that NRLD reports only completion years, not precise commissioning dates. Given the multi-year construction timelines of large dams, reliance on completion years can produce temporal bias—especially in displacement estimation, where population growth during construction is non-trivial. To address this, I scrape project-level data on time and cost overruns for 569 projects from the Water Resources Information System (WRIS) and use propensity score matching algorithms based on project characteristics to infer commissioning years for the full set. Each estimated commissioning year is then matched to the nearest GHSL time point (available at five-year intervals) for subsequent analysis.

Lastly, I use reservoir extents from ESRI as a proxy for acquired land area, acknowledging that this measure excludes canals, catchment areas, and transmission corridors. This approach likely underestimates the true extant of total acquisition for large dams but but still provides a robust second-best estimates for comparative discussion on displacement intensities across projects.

Solar Projects

Utility-scale solar projects in India—implemented predominantly by state governments with private sector participation—also lack centralized Gazette documentation. To fill this gap, I draw on the geospatial dataset of Ortiz et al. (2023), which maps over 1,100 operational solar PV farms in India as of 2020, with detailed footprint geometries and infrastructure attributes.

Because commissioning dates are not included in this dataset as well, I use Google Earth Engine to automate, retrieve and visually inspect high-resolution satellite imagery for each site from 2000 onward. By identifying the earliest visible signs of activity—such as land clearing, panel installation, or perimeter fencing—I approximate commissioning years. This methodology, described in Data Appendix A2, enabled construction of a spatio-temporal panel of solar projects for 2000–2020.

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[7] The NRLD follows the ICOLD definition of large dams; see NRLD (2019), p. 3.

The dataset has two limitations: (i) it underestimates total acquired land by excluding buffer zones and ancillary infrastructure, and (ii) it ends in 2020, missing the significant capacity expansion from 2021–2025.[8]

3.2 Secondary Data

Global Human Settlement Layer (GHSL)

The Global Human Settlement Layer (GHSL), developed by the European Commission in collaboration with the UN Statistical Commission, provides 100m × 100m resolution gridded data on population and built-up areas from 1975 to 2025 at five-year intervals. This dataset enables longitudinal analysis of spatial population change around project sites. See `https://human-settlement.emergency.copernicus.eu/`.

Population Census of India

To validate displacement and population change estimates derived from GHSL, I use village-level demographic data from the decennial Population Census of India. These data enable disaggregation by social group (Scheduled Castes, Scheduled Tribes), gender, and rural–urban classification, providing a ground-truth benchmark for remote sensing-based estimates. See `https://censusindia.gov.in/`.

Parliamentary Debates

Finally, I use digital archives of Parliamentary Debates from both the Lok Sabha and Rajya Sabha to obtain project-specific records of land acquisition compensation. These text-based parliament records—accessible at `https://esanad.nic.in/`—provide authoritative official information on compensation practices, disputes, and procedural deviations, complementing spatial and administrative data sets.

4 Empirical Strategy

I estimate the social costs of large-scale energy infrastructure by operationalizing a project-level measure of Project-Affected Persons (PAPs). This approach builds on five key components. First, I compile a sector-wise inventory of coal mining, multipurpose hydropower, and utility-scale solar photovoltaic projects from administrative records and remote sensing datasets. Second, I delineate project boundaries by parsing village-level land acquisition descriptions from Gazette notifications and validating them through spatial overlays. Where Gazette detail is limited—especially for hydro and solar—I supplement with high-resolution remote sensing imagery. Third, I determine commissioning years from Gazette texts or, when unavailable, estimate them using sector-specific project delay datasets and historical satellite imagery (as described in Data Appendix A). Fourth, I apply sector-specific spatial

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[8] I am extending the methodology by Ortiz et al. (2023) to capture post-2020 projects, which will be incorporated in future revisions.

radii and temporal buffers, informed by engineering assessments and social science literature, to define potential zones of exposure. Finally, I integrate high-resolution gridded population data to estimate PAP counts at 5-year intervals from 1975 to 2020, aligning with the Global Human Settlement Layer (GHSL) temporal resolution.

4.1 Analytical Framework

Measuring PAPs is inherently complex because the spatial–temporal footprint of energy projects varies significantly by sector and technology. For example: Coal mining generates localized but immediate impacts, primarily via air pollution, dust deposition, and land clearance. Hydropower projects often have delayed effects (e.g., vector-borne disease risks, altered hydrology) that extend far beyond physical boundaries through reservoir inundation and downstream ecological change. Solar photovoltaic projects typically have minimal operational-phase environmental hazards but can cause significant land-use displacement at the siting stage.

To capture these sector-specific dynamics, I define two critical frameworks: (i) *Spatial footprint* – the geographic area directly or indirectly affected by the project, which may exceed physical boundaries due to spillovers such as groundwater stress, habitat fragmentation, or loss of common property resources. (ii) *Temporal footprint* – the time span over which project-induced effects occur, encompassing both pre-construction disruptions and post-commissioning ecological or socio-economic changes.

PAPs are further disaggregated into: (i) *Directly displaced* – households and communities physically removed from the project footprint (e.g., inundation zones for dams, open-cast mine pits). (ii) *Indirectly exposed* – populations within the broader zone of influence whose livelihoods, resource access, or health are affected by spillovers without physical displacement.

I define a population settlement as affected if it is within the spatial and temporal footprint of a project during its operational period. Formally, let project p be defined by its spatial extent S_p and temporal window $[t_p^{\text{start}}, t_p^{\text{end}}]$. A settlement i is considered affected if it is located within S_p and inhabited at any time t during the operational period. The total number of PAPs for project p in sector s is then given by:

$$\text{PAP}_{p,s} = \sum_{t=t_{p,s}^{\text{start}}} \text{Pop}_{i,t}^{i \in S_{p,s}} + \sum_{t=t_{p,s}^{\text{start}}}^{t_{p,s}^{\text{end}}} \text{Pop}_{i,t}^{i \in S_{p,s} + buffer_s}$$

where $\text{Pop}_{i,t}$ denotes the GHSL-derived population of settlement i in year t. The first summation captures direct displacement effects, while the second incorporates indirect exposure effects within sector-specific buffer zones.

4.2 Buffer Exposure and Inter Temporal Estimation

Drawing on the empirical literature on infrastructure-induced displacement and environmental externalities, I define three concentric buffer zones around project boundaries: 1 mile to capture severe exposure (e.g., complete land loss, high-intensity pollution), 3 miles for moderate exposure (e.g., degraded resource access, chronic pollution), and 6 miles for light exposure (e.g., habitat fragmentation, reduced mobility). These buffers reflect sector-specific impact gradients documented in India and globally across coal, hydropower, and solar projects (Terminski, 2015). Integrating both spatial and temporal dimensions enables the framework to account for lagged, diffuse, and cumulative effects extending beyond immediate physical footprints. Disaggregating PAPs across these exposure zones and over time facilitates cross-sectoral comparisons of social cost intensity, regional equity assessments of who bears the burden of energy development, and temporal profiling of when costs are incurred relative to project commissioning.

5 Results

5.1 Land Acquisition Estimates

Patterns of land acquisition in India's energy sector exhibit strong sectoral heterogeneity and are deeply shaped by historical phases of state-led development, liberalization-era reforms, and the geography of resource endowments. Consistent with state-led developmentalism growth phase, the largest land footprint is associated with hydropower, which accounted for over 1.9 million hectares across 5,411 projects—more than six times the area acquired for coal mining. Notably, 67.4% of this area was acquired between 1950–1990, corresponding with India's irrigation–hydropower expansion during the command-and-control planning era. This aligns with the "high-modernist" infrastructural paradigm, in which large dams symbolized both developmental ambition and centralized state authority over land and water (Scott, 1998; Bauer, 2014; Delang and Toro, 2018).

Coal mining, by contrast, expanded most sharply during the post-1990 liberalization period, with 63.4% of coal-linked land acquisition occurring between 1990–2020. This shift reflects the market-oriented energy demand, wherein liberalization created regulatory space for large-scale resource extraction. Despite accounting for a smaller aggregate footprint, solar photovoltaic (PV) projects proliferated rapidly post-2005, acquiring over 41,000 hectares across 1,389 projects. This growth is consistent with global patterns in renewable infrastructure deployment, where land requirements remain significant despite lower carbon intensity (Pasqualetti and Hägerstrand, 2019).

Tribal land acquisition is particularly high in coal mining, where 58.3% of acquired land lies within constitutionally protected Scheduled Areas—far above the 18.8% observed for hydro and 2.3% for solar. This systematic overlap between energy resource zones and Adivasi territories reflects the geographies of India's coal reserves (Chakraborty and Dutta, 2022), but also resonates with broader scholarship on the resource curse and internal colonialism (Watts, 2004; Guha, 2013). These regions are ecologically sensitive and socio-politically fragile, where state-led acquisition has historically triggered distributive conflicts and challenges to constitutional provisions such as the Fifth Schedule and the Panchayats (Extension to Scheduled Areas) Act (PESA) (Levien, 2018).

The temporal evolution of project scale further underscores changing institutional logics of land governance. Average hydro project size declined from 404 ha

Table 1: **Land Acquisition Estimates by Sector and Period**

Period	Projects	Land Acquired			
		Total (ha)	Share (%)	Tribal Land (%)	Avg Size (ha)
Panel A: Coal Mining					
1960–1990	140	112,886	36.6	61.9	806.3
1990–2020	334	195,323	63.4	56.0	584.8
Total	474	308,209	100.0	58.3	650.2
Panel B: Hydro					
Pre–1950	355	143,426	7.5	1.6	404.0
1950–1990	3,485	1,286,481	67.4	12.7	369.1
1990–2020	1,571	479,901	25.1	4.5	305.5
Total	5,411	1,909,808	100.0	18.8	352.9
Panel C: Solar PV					
2005–2020	1,389	41,376	100.0	2.3	29.8

Note: Land acquisition refers to the total area acquired per project, measured in hectares. Displacement estimates are expressed in millions and include lower, central, and upper bounds. The displacement factor is defined as the ratio of displaced population to land acquired per hectare. Tribal land percentage denotes the share of total land acquired falling within Scheduled Areas. Source: Author's calculations based on Gazette notifications, government land records, and gridded population estimates from GHSL.

pre-1950 to 305 ha after 1990, while coal projects fell from 806 ha (1960–1990) to 584 ha (1990–2020). This mirrors the transition from mega-scale projects emblematic of high-modernist planning to more numerous, mid-scale projects under post-liberalization, multi-actor governance (McLennan, 2022). Yet, as displacement literature cautions, smaller footprints do not necessarily imply reduced social cost (Cernea, 1997). Acquiring fragmented parcels in densely settled or contested landscapes often entails greater procedural complexity, prolonged litigation, and intensified local resistance, especially when projects target common property resources such as grazing lands. For example, solar projects, despite minimal ecological degradation during operation, frequently encounter opposition when sited on village commons, illustrating the social embeddedness of land in rural livelihoods.

5.2 PAP Estimates

Table 2 presents sector- and period-specific estimates of population displacement linked to land acquisition for energy projects in India, with lower, central, and upper bounds calculated from gridded population data (GHSL) overlaid with notified land acqusition spatial extents. Displacement intensity—defined as persons displaced per hectare—offers a normalized metric for cross-sectoral comparison.

Coal mining emerges as the most displacement-intensive energy sector, consistent with the literature on extractive enclaves and the "resource curse" in domestic contexts (Bebbington et al., 2008). Between 1975–1990, coal projects displaced an estimated 0.36 million people (0.29–0.42 million), with an intensity of 3.19 persons/ha. In the liberalization era (1990–2020), both absolute displacement and intensity rose sharply: 1.08 million people (0.87–1.26 million) displaced, with intensity increasing to 5.53 persons/ha—a 75% rise. This escalation reflects the geographic expansion of mining into denser settlements, as well as the cumulative effect of population growth in mineral-rich belts. Over five decades, coal mining has displaced an estimated 1.44 million people, averaging 4.67 persons/ha, highlighting its persistently high social cost per unit of land.

Hydropower and irrigation projects account for the highest aggregate displacement but at lower intensities. Between 1975–1990—the height of India's dam-building era—hydro projects displaced an estimated 2.62 million people (2.15–3.05 million), with intensity at 2.04 persons/ha. Post-1990, displacement fell to 0.74 million, with intensity declining to 1.55 persons/ha, reflecting a slowdown in dam construction and siting in higher-altitude, lower-density areas (World Commission on Dams, 2000). Since the 1970s, total hydropower-linked displacement is estimated at 3.36 million people, consistent with the broader literature showing that large-scale water infrastructure displaces more people in absolute terms, but less per hectare than extractive industries.

Solar PV projects, though comprising a smaller share of displacement in absolute terms, carry non-trivial local impacts. Between 2005–2020, over 0.1 million people (0.07–0.10 million) were displaced, with intensity at 2.43 persons/ha—higher than hydropower and comparable to early coal projects. This pattern is linked to the repurposing of common property resources—particularly village grazing lands—in semi-arid zones (**?**). Such acquisitions often fall outside formal rehabilitation frameworks yet impose livelihood losses and silent dispossession.

Overall, the displacement-to-land ratio is highest for coal (4.67), followed by solar (2.43), and lowest for hydro (2.02). These findings challenge narratives of renewables as inherently "just" or socially neutral, instead revealing that energy transitions can reproduce historical patterns of dispossession unless accompanied by robust safeguards (Healy and Barry, 2019). These patterns reveal that India's energy transition is as much a land governance challenge as it is a technological one. Sectoral trajectories are shaped not only by resource distribution and policy regimes, but also by the historical legacies of eminent domain. This aligns with comparative findings from other resource-rich democracies, where energy infrastructure expansion often reproduces spatial inequalities and triggers resistance in marginalized territories (Bridge and Billon, 2018; Hinojosa and Bebbington, 2015; Kirsch, 2014).

5.3 Comparison with Existing Estimates

The estimates presented here reconcile systematic biases found in both official and civil society displacement statistics. Official government figures—typically based only on formal, legally recognized dispossession that triggers compensation—severely undercount affected populations. For example, administrative data attribute just 3,000 displaced tribal persons to major power projects and 5,000 to mining projects, despite these projects acquiring tens of thousands of hectares (Lok Sabha, 2022). Such figures imply implausibly low population densities given the extent of land involved.

Table 2: **Population Displacement by Sector and Period**

Period	Population Displaced (millions)			Displacement Intensity
	Lower Bound	Estimate	Upper Bound	
		Panel A: Coal Mining		
1975–1990	0.289	0.360	0.421	3.19
1990–2020	0.867	1.080	1.264	5.53
Total	1.156	1.440	1.686	4.67
		Panel B: Hydro		
1975–1990	2.152	2.619	3.053	2.04
1990–2020	0.600	0.742	0.908	1.55
Total	2.752	3.361	3.961	1.90
		Panel C: Solar PV		
2005–2020	0.072	0.101	0.086	2.43

Note: Land acquisition refers to the total area acquired per project, measured in hectares. Displacement estimates are expressed in millions and include lower, central, and upper bounds. The displacement factor is defined as the ratio of displaced population to land acquired per hectare. Tribal land percentage denotes the share of total land acquired falling within Scheduled Areas. Source: Author's calculations based on Gazette notifications, government land records, and gridded population estimates from GHSL.

At the other extreme, civil society and advocacy estimates—such as those from the Xaxa and Bhuria Committees—tend to overstate displacement. This often happens because they extrapolate from a small set of high-profile mega-projects and include broader livelihood and ecological impacts beyond direct physical displacement. For instance, the widely cited claim that dams displaced 16.4 million people between 1950 and 1990 (Ministry of Tribal Affairs, Government of India, 2007) would mean that roughly 2.4% of India's mid-century population was displaced solely by dams—an unlikely figure given that dam reservoirs account for about 0.7% of India's total land area and are often located in relatively low density regions.

My geo-spatial triangulation method—combining administrative land acquisition notifications with satellite-based exposure metrics—produces dam-related displacement estimates of 2.7–3.9 million people. These figures are higher than official counts but far more conservative than most advocacy estimates. The conservatism stems from the fact that these estimates include only the area directly inundated by reservoirs; in practice, total land acquisition for dam projects often exceeds the reservoir footprint due to ancillary infrastructure such as canals, access roads, and worker settlements. If we assume an additional 25% of land was acquired for these purposes, total dam-related displacement would rise to 3.5–5.0 million—still well below the highest advocacy claims but consistent with plausible population density assumptions for dam sites. This imputation is further supported by project composition data: only about 5% of dams qualify as "mega" projects of national importance, while the vast majority are medium- to small-scale, with correspondingly smaller land and population footprints.

The analysis also reveal sharp sectoral asymmetries but remain consistent with the existing literature. Although constitutionally designated Scheduled Areas cover only about 16% of India's landmass, they account for 18% of all land acquired for hydropower and fully 56% of land acquired for coal projects. This disproportionate concentration in tribal territories reflects persistent structural biases in land governance and the entrenched political economy of extraction. These findings underscore the need to rethink how displacement is defined, measured, and reported. Narrow, compensation-based official metrics obscure the full social costs of infrastructure, while broad, generalized advocacy figures risk undermining credibility. A middle-ground approach—spatially explicit, empirically grounded, and transparent about assumptions—offers a more credible basis for policy reform and for designing just energy transition strategies.

6 Discussion

6.1 Heterogeneity in Project Delays

Globally, large infrastructure projects are notoriously prone to cost and time overruns. A rich body of scholarship investigates the causes, consequences, and institutional dynamics of these delays in the context of development planning. In an early and influential work, Hirschman (1958) advanced the *hiding hand theory*, arguing that underestimated costs and overestimated challenges may, paradoxically, catalyze adaptive responses, ultimately yielding unanticipated net benefits. Relatedly, the so-called *just-start-digging* perspective interpreted delays as manageable externalities within big-push development models, rather than as indicators of structural weaknesses in project delivery systems.

However, subsequent empirical evidence has challenged these optimistic framings. Flyvbjerg (2009) find that more than 90% of large-scale projects exceed initial budgets or schedules, with average cost overruns in the energy and transport sectors approaching 30%. This expanding literature attributes persistent delays to optimism bias, strategic misrepresentation, and the systematic underestimation of social and environmental risks—each contributing to inflated benefit–cost projections and overly ambitious timelines. In response, the reference class forecasting methodology advocates benchmarking proposed projects against historical data from comparable undertakings to mitigate cognitive and political biases in planning.

In developing economies, delays are often more acute, reflecting deeper market failures, capacity constraints, and weak oversight mechanisms. India is no exception. Table 3 summarizes the analysis of central sector projects from the Ministry of Statistics and Programme Implementation (1995–2020) and shows that delays are the norm, with substantial cost overruns in most sectors. Coal mining, however, stands out as comparatively cost-efficient: around 40% of projects were delayed, but the average inflation-adjusted cost overrun was only about 5%. Nevertheless, delays of three to five years have become increasingly common in coal mining since the 2000s, frequently linked to protracted land acquisition disputes and the drawn-out environmental clearance process (Centre for Science and Environment, 2022).

By contrast, multipurpose hydropower and irrigation projects have historically been the worst performers in terms of schedule and budget adherence. As the Public Accounts Committee noted, in the first 25 years of independent India's irrigation and

Table 3: **Performance of Central Sector Projects (1995-2020)**

Sector	**Projects Delayed** (%)	**Cost Overrun** (%)	**Avg. Project Cost** (INR cr)
Coal Mines	41	5	15.4
Fertilizers	52	6	5.3
Petroleum	53	11	18.7
Power Generation	57	25	25.5
Petrochemicals	63	33	21.6
Steel	69	16	27.1
Atomic Energy	72	19	72.2
Civil Aviation	73	25	5.2
Surface Transport	83	11	4.9
Finance	89	151	1.3
Railways	90	91	8.0
Telecommunication	90	28	7.9
Hydro/Irrigation*	95	137	13.1

Note: Hydro/ irrigation is not part of central sector projects; they are included here for comparative purposes. Projects delayed are calculated based on completion timelines compared to the original timelines. Cost overrun estimates are inflation-adjusted based on WPI estimates from the Reserve Bank of India. Source: Author's calculation using data from the Ministry of Statistics and Project Implementation (MoSPI), Government of India, and Water Resource Information System (WRIS).

hydropower planning, "not a single" major project was completed on time or within its approved budget (Public Accounts Committee, 1983). My analysis of project-level data web-scraped from the Water Resources Information System confirms the persistence of this pattern: 95% of large hydropower and irrigation projects have faced delays, with an average cost overrun of 137% (Table 3). This stands in sharp contrast to the colonial planning period (1850–1950), when archival records for 73 projects show that only 20% were delayed, while 35% were completed ahead of schedule and under budget.[9] At the other extreme, solar PV projects have achieved rapid rollout, demonstrating relatively high implementation efficiency and notable resilience to prolonged delays.

What explains this stark performance variation? As Flyvbjerg et al. (2003) observes, factors such as technical standardization, procurement policy, competitive bidding, and administrative efficiency can all shape implementation outcomes. However, building on the NIMBYism framework, I argue that sectoral differences in efficiency also reflect the political economy of land acquisition. Projects tend to progress more quickly where local opposition is limited—either because dispossession is perceived as legitimate by affected communities or because legal and extra-legal avenues for protest are constrained. In contrast, when acquisition is contested, disputes over land rights and tenure security can heighten resistance, prolong negotiations, and substantially extend implementation timelines.

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[9] Author's analysis based on archival data on dams from The Data on High Dams (Vol. I and II), published by the Central Board of Irrigation, Government of India.

6.2 NIMBYism as a Social Process

Glaeser et al. (2017) outline a three-phase theory of infrastructure resistance, often framed through the lens of NIMBYism (Not-In-My-Backyard). In phase one, the state pursues rapid infrastructure expansion with minimal regard for social and environmental externalities. In phase two, civil society mobilizes against the disruptive effects of these projects, slowing the rate and scale of new investments. In phase three, institutional frameworks adapt to internalize social costs, enabling more equitable and sustainable project design.

6.2.1 Do Empirical Patterns Support NIMBYism?

The trajectory of multipurpose hydro development in India offers suggestive support for the three-phase NIMBYism theory. As shown in Figure 4, project completion accelerated sharply during the Planning Era (1950–1990). In the early post-independence decades, large dams were prioritized as flagship investments under a centrally planned development model, with little consideration for displacement or ecological impacts. Project completions peaked in the 1980s but declined steeply thereafter, coinciding with the rise of global environmental norms and strengthened domestic civil society opposition to large dams. The release of the World Commission on Dams report in 2000 marked a key turning point, as it documented the extensive social and ecological costs of such projects.

Using project-level data from WRIS, I assess efficiency trends in hydro development. Average project timelines fell slightly from 20 years in the 1950s to 18 years in the 1960s but rose to 28 years by the 1980s, reflecting systemic backlogs. As delays escalated, cost overruns followed an inverted-U pattern—doubling from roughly 120% in the 1950s to 250% in the 1970s before averaging 137% between 1950 and 2000 (see Appendix Table A2). These figures underscore that escalating expenditures in hydro development did not translate into proportional developmental gains.

Initially, medium-sized projects were implemented more quickly and efficiently than large ones.[10] However, policy emphasis on reviving stalled large projects—driven in part by sunk-cost considerations—led to medium projects being deprioritized after the 1980s (Figure 5). As a result, medium projects eventually suffered comparable delays and, in some cases, even higher cost overruns. By the 1970s, the cost-adjusted benefits of large projects had converged to the level of medium projects. Nevertheless, schemes of “National Importance” and those under the Accelerated Irrigation

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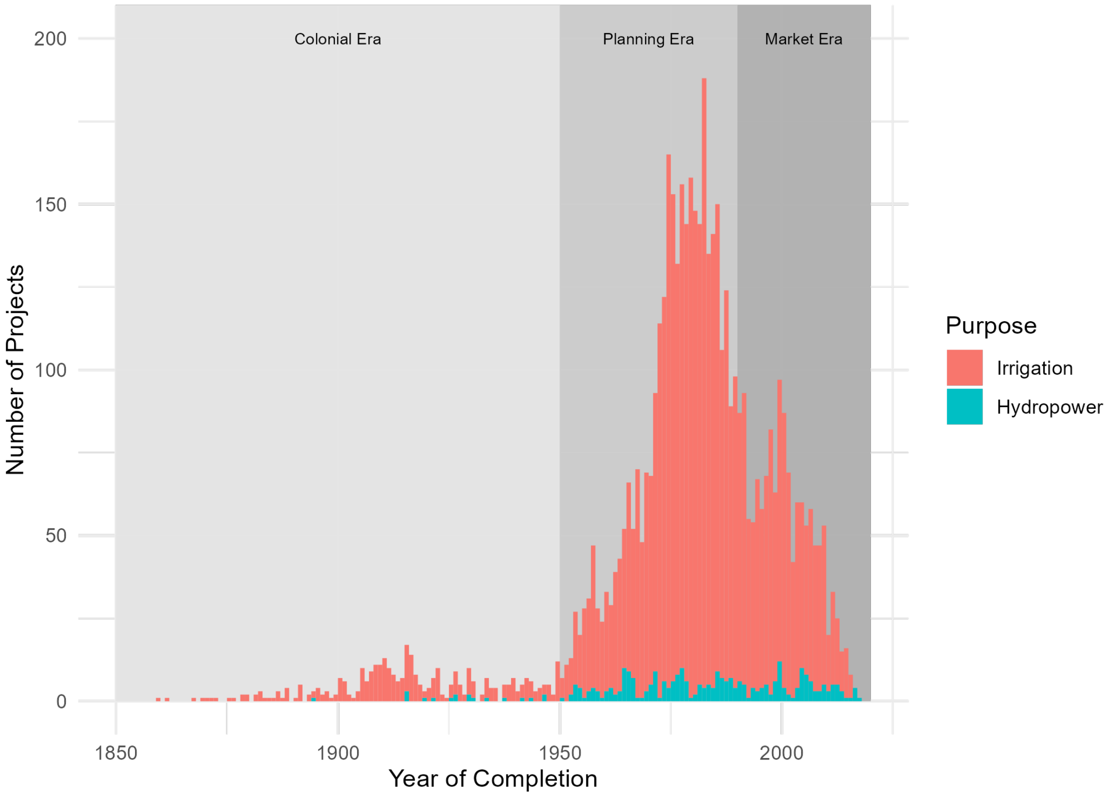
[10] For details on the classification of hydropower projects over time, see PAC (1982). From September 1958 to September 1975, irrigation schemes costing more than Rs. 5 crores were classified as major irrigation schemes. Since September 1975, all irrigation projects with a culturable command area of more than 10,000 hectares have been classified as major. Earlier, schemes costing between Rs. 5 crores and Rs. 10 lakhs were classified as medium. From April 1970, the lower limit was raised to Rs. 25 lakhs in plain areas and Rs. 30 lakhs in hill areas. From September 1975, 75 schemes with C.C.A. of 10,000 hectares or less and an estimated cost more than Rs. 25 lakhs for plain areas and Rs. 30 lakhs for hill areas were classified as medium. With effect from the Annual Plan 1978–79, medium irrigation schemes were classified as those with a C.C.A. above 2,000 ha and up to 10,000 ha.

Figure 4: **Trends of Irrigation and Hydro Projects in India**



Note: The colonial era is defined as 1850–1950; the planning era as 1950–1990; and the market era as 1990 onward. Source: Author's calculations using project-level data from the National Register for Large Dams, Ministry of Water Resources, Government of India.

Benefit Programme (AIBP) retained relatively higher realized gains due to preferential financial and administrative support.[11]

This divergence between rising costs and declining benefits reflects the dynamics described in the second phase of the NIMBYism framework, where mounting public opposition and procedural complexity slow project execution, increase transaction costs, and erode developmental returns. It also aligns with infrastructure planning theory, which predicts that without adaptive governance mechanisms, the social costs of large-scale projects are increasingly internalized through longer timelines, higher financial outlays, and diminishing marginal benefits. A key driver of these delays was the proliferation of sanctioned projects driven by local political and economic demands, which strained fiscal capacity and delayed compensation processes for affected communities (Comptroller and Auditor General, 2019). The thin stretching of resources limited fiscal space and frequently provoked local resistance, further impeding execution.

To probe these patterns further, I compiled and coded project-level data from Parliamentary debates and audit reports. Figure 4 shows, between the 1960s and 1990, land acquisition and environmental clearance bottlenecks accounted for nearly

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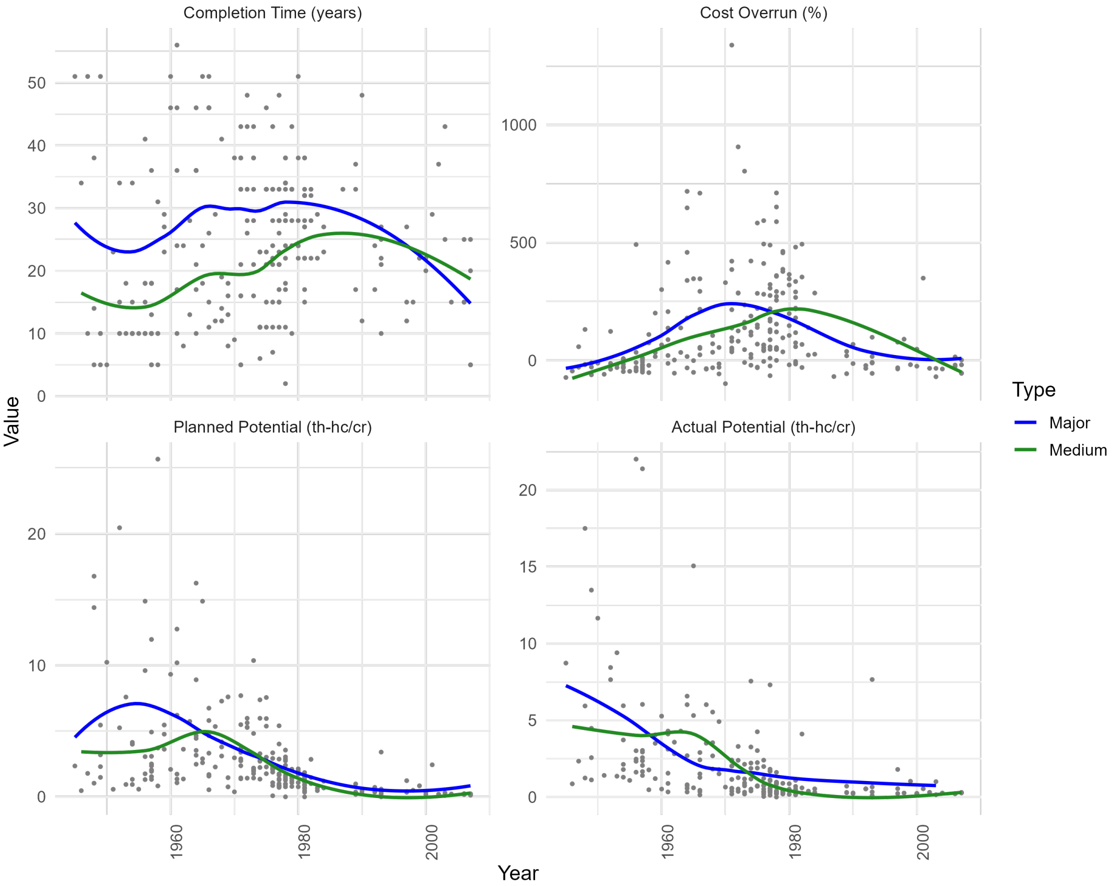
[11] For more details on AIBP, see https://prsindia.org/policy/report-summaries/accelerated-irrigation-benefits-programme.

Figure 5: **Trends of Irrigation and Hydro Projects Cost Overuns**



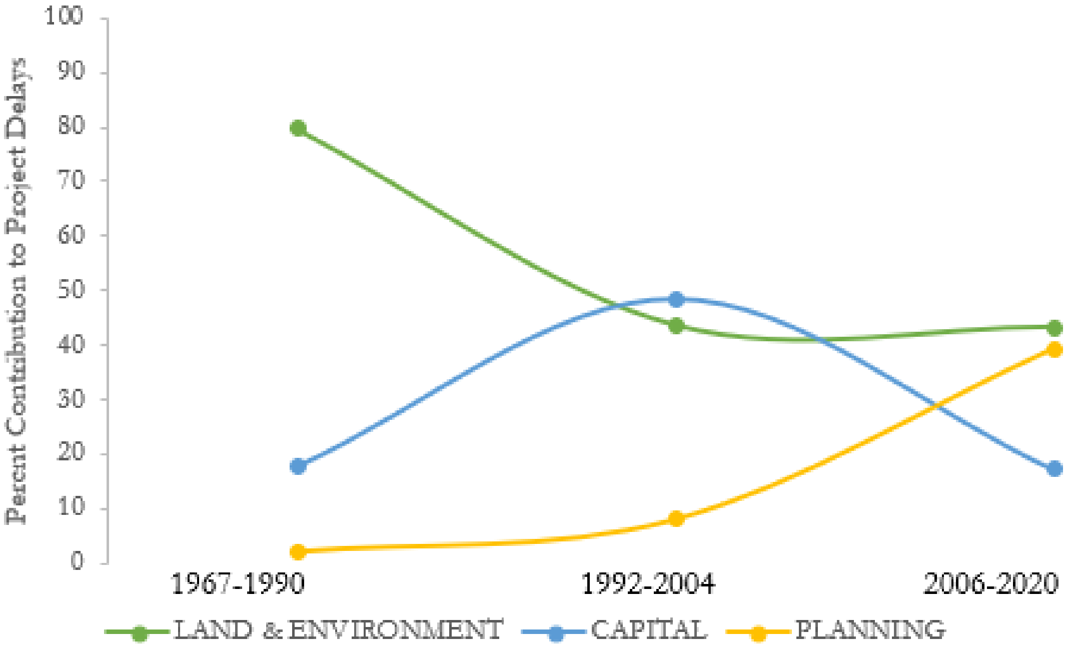
Note: Projects delayed are calculated based on completion timelines compared to the original timelines based on the Five-Year plans. Cost overruns and benefits estimates are inflation-adjusted based on WPI estimates from the Reserve Bank of India. Project benefits are measured in cultivable command area in '000 hectares per INR 10 million. Source: Author's calculation using project-level data from the Water Resource Information System (WRIS).

80% of all project delays. By contrast, between 1990 and 2020, the share attributable to these factors declined to around 45%, while planning-related shortcomings rose from less than 5% to nearly 40%, with capital constraints playing a smaller but consistent role. This post-1990s shift from post-implementation resistance to organized opposition during the planning phase reflects the evolution of civic participation, corresponding to the third-phase dynamics of NIMBYism.

A potential solution to persistent social and political risks would have been to site projects farther from densely populated areas. However, technical constraints—such as the need for specific river gradients and flow characteristics—limit such flexibility, particularly for irrigation projects that must be located at lower elevations to ensure effective water distribution (Molle et al., 2009; World Bank, 1996). These constraints introduce a complex cost–benefit trade-off into project planning: while moving projects to higher elevations may reduce displacement risks, it can also diminish the developmental benefits, especially for agricultural and irrigation outcomes (Scudder, 2005; Duflo and Pande, 2013).

Using a Digital Elevation Model in combination with geo-locational data on

Figure 6: **Time Series Distribution of Project Delay Factors**



Note: Period segmentation is based on the time frame of the original data. Source: Author's calculation using project-level data from Parliamentary Debates.

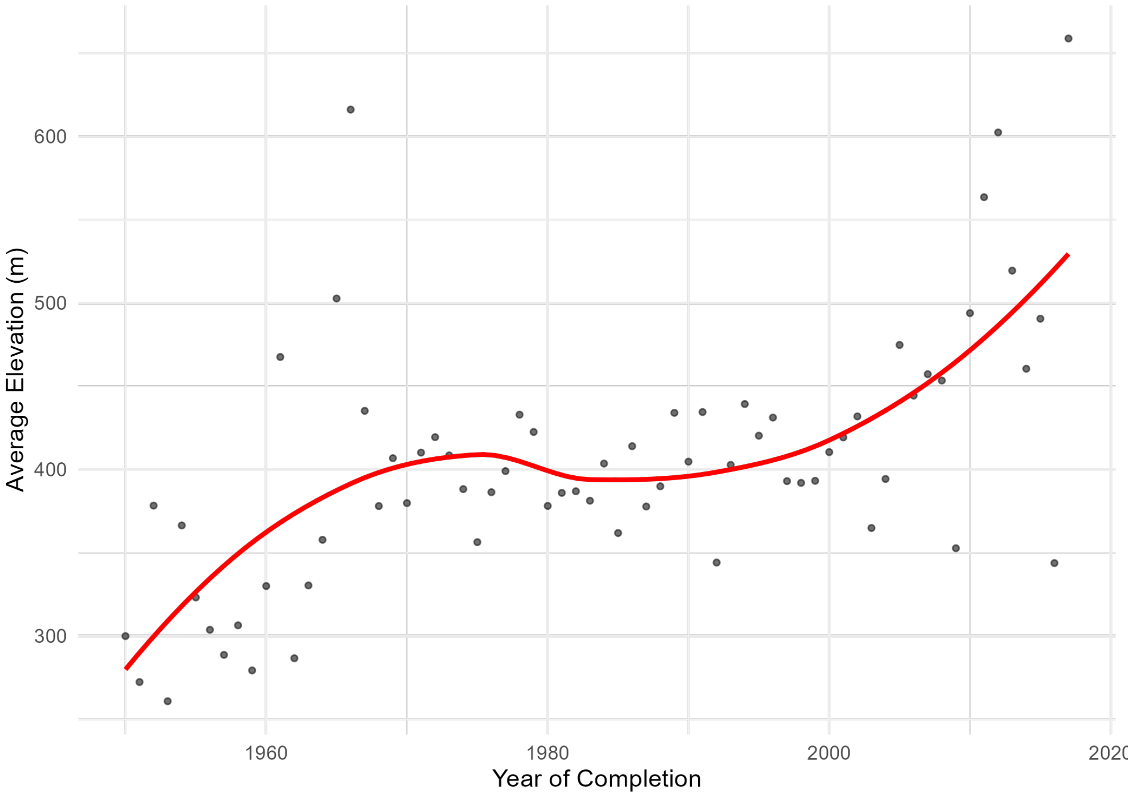
dams, Figure 7 reveals a clear trend: over time, new hydropower projects have increasingly been sited at higher elevations and in less populated zones. This pattern suggests a strategic, albeit constrained, response to the twin challenges of social resistance and technical feasibility. The evidence indicates that the three-phase NIMBYism framework offers a compelling explanation for the trajectory of hydro development in India. Planners responded to social resistance by either scaling down projects or relocating them away from densely populated areas to minimize displacement impacts. However, these adaptations came at a cost—project benefits declined significantly over time despite efforts to mitigate opposition.

In contrast, the coal mining sector presents a markedly different pattern. Despite persistent social resistance, cost overruns and delays have remained relatively stable over the past 25 years, and project execution continues at scale (Centre for Science and Environment, 2022). This divergence suggests that NIMBYism has exerted a far stronger influence on hydro development than on coal mining. The following section develops an analytical framework to explain how NIMBYism operates differently across India's energy sectors and empirically examines the institutional and political channels through which it shapes project performance.

6.2.2 When Does NIMBYism Affect Infrastructure Planning?

The Indian state's model of land acquisition has historically followed a logic of concentrated benefits and diffused costs (Olson, 1965), wherein infrastructure investments disproportionately serve strategic industries, state-owned enterprises, and elite political constituencies, while the social and ecological costs—particularly dis-

Figure 7: **Trends of Dam Elevation Over Time by Purpose**



Note: Project-level elevation is imputed using the Digital Elevation Model from ArcGIS. Source: Author's calculation using project-level data from the National Register for Large Dams, Ministry of Water Resources, Government of India.

placement, livelihood disruption, and environmental degradation—are systematically externalized or rendered invisible . In this context, NIMBYism is not merely a reactionary impulse to localized project siting; rather, it reflects an endogenous and historically conditioned response to the deliberate dilution of local property, tenure, and resource rights.

A key driver of resistance has been the discretionary and opaque use of eminent domain powers, often justified in the language of "public purpose" but deployed in ways that facilitate private enrichment, speculative gains, and entrenched rent-seeking (Banerjee and Prasad, 2022). Figure 8 presents a stylized decision tree illustrating how land acquisition trajectories are shaped by the willingness of project-affected persons (PAPs) to part with their land and relocate. When communities exhibit high willingness to relocate and accept compensation—either because the compensation package meets their perceived opportunity cost or because they face political or economic pressure to acquiesce—the acquisition process typically proceeds without major contestation, aligning the state's willingness to pay with the community's willingness to accept.

By contrast, when communities resist relocation, they often pursue either *legal* or *extra-legal* strategies to secure more favorable compensation or rehabilitation terms. Legal strategies, such as filing petitions in courts, can yield improved monetary settlements or expanded resettlement entitlements. However, these gains are typically offset by protracted procedural timelines, uncertainty in adjudication, and the opportunity costs of stalled investments. Extra-legal strategies—ranging from sit-ins, *gheraos*, and hunger strikes to road blockades and occupation of project sites—carry higher personal, legal, and social risks (Narain, 2017). Where movements succeed in mobilizing broad coalitions, attracting media attention, and leveraging political intermediaries, they can force renegotiation of terms, delay or scale down projects, or in rare cases secure project cancellation. Where mobilization fails, however, coercive acquisition and forced eviction often follow, deepening grievances, fragmenting community structures, and eroding trust in state institutions.

Even when communities achieve more favorable settlements through resistance, the economic and social benefits may be substantially eroded by cumulative delays, escalating transaction costs, and enduring mistrust between state agencies, private developers, and local stakeholders. These dynamics underscore that grievance mechanisms, conflict escalation, and project delays are not exogenous shocks but endogenous features of the acquisition process, shaped by the mode of contestation—*legal*, *negotiated*, or *coercive*—that unfolds in specific political-economic and institutional contexts. Next, I examine how these NIMBYism dynamics vary systematically by project type, focusing on three core channels of intermediation:

A: Legal Pluralism and Policy Innovation: As discussed in Section 2, India's constitutional architecture permits both the central and state governments to legislate on land acquisition, producing a dense and fragmented legal landscape in which more than 100 central and state statutes with eminent domain provisions operate in parallel (Wahi and Bhatia, 2017).[12] While, in principle, all acquisition proceedings are expected to align with the central LARR framework, in practice, sector- and state-specific statutes, direct purchases by public sector enterprises, and acquisitions under colonial-era Land Acqusition frameworks generate substantial heterogeneity in compensation levels, acquisition timelines, and grievance redress mechanisms. This legal pluralism grants governments wide discretion in choosing acquisition pathways. The choice of legal route thus becomes an instrument of both project acceleration and political control, shaping patterns of efficiency and contestation across energy sectors.

Coal — Centralized Monopoly and Legacy Statutes: In coal mining, the LARR framework is routinely bypassed through the "strategic industries" exemption, with projects overwhelmingly executed under the Coal Bearing Areas (Acquisition and Development) Act, 1957 (CBA Act). Gazette notifications confirm that the CBA Act remains the dominant legal vehicle for land acquisition in the coal sector. As stated in its preamble, the CBA is: *"An Act to establish in the economic interest of India greater public control over the coal mining industry and its development by providing for the acquisition by the State of unworked land containing or likely to contain coal deposits or of rights in or over such land, for the extinguishment or modification of such rights accruing by virtue of any agreement, lease, licence or otherwise, and for matters connected therewith."*[13]

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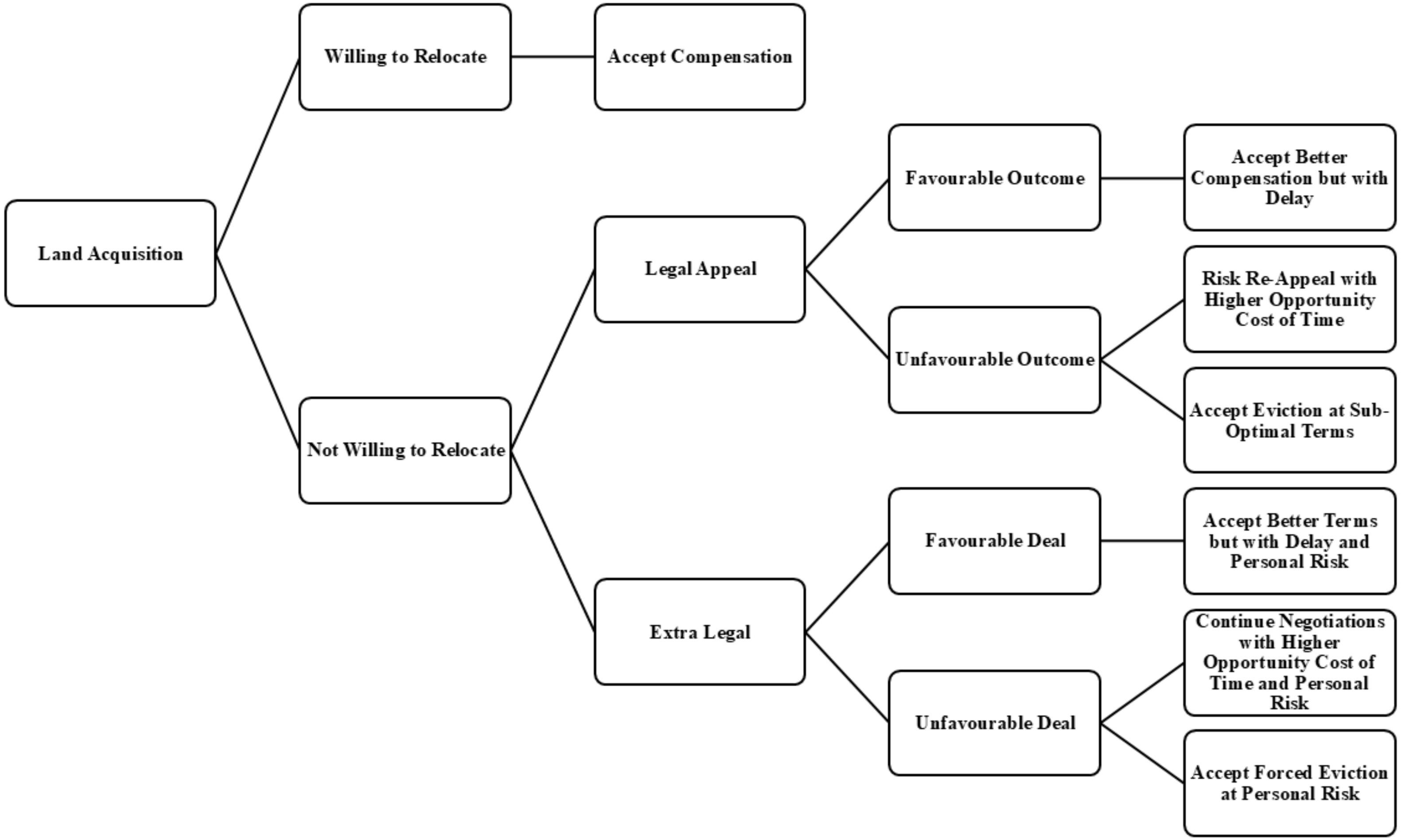
[12] These include sector-specific laws for industrial corridors, mining, highways, and renewable energy, each with distinct standards for consent, compensation, and rehabilitation.

[13] See the text of the Act here: `https://www.indiacode.nic.in/bitstream/123456789/`

Figure 8: **Land Acquisition Decision Tree**



Note: The graph depicts a simplified decision framework for actors navigating land acquisition processes. Source: Author's analysis based on a review of land acquisition statutes and data collected from court filings and civil society organizations.

This statute grants sweeping powers to the central government, allowing it to issue a preliminary notice to acquire any land “likely” to contain coal and to vest ownership absolutely in the state after only a brief objection period. Section 9A confers “special powers in case of urgency” to bypass the consent of landowners or village councils, while the Act *does not* require Social and Environmental Impact Assessments or provide any statutory framework for rehabilitation and resettlement (R&R) to project-affected persons. Section 12 further states: *“The competent authority may, by notice in writing, require any person in possession of any land acquired under this Act to surrender or deliver possession of the land within such period as may be specified in the notice, and if a person refuses or fails to comply with any such notice, the competent authority may enter upon and take possession of the land, and for that purpose may use or cause to be used such force as may be necessary.”*

The CBA Act also sidesteps the enhanced compensation provisions of LARR, relying on vague valuation guidelines that invite disputes over adequacy. Grievance redress is confined to the Appellate Tribunal and High Courts, bypassing local civil courts and thereby narrowing avenues for appeal, raising transaction costs, and prolonging resolution timelines. While these provisions expedite land acquisition for public sector undertakings, they embed deep structural asymmetries in bargaining power by centralizing authority, stripping away procedural safeguards, and enabling coercive possession. The result is a legal architecture that privileges rapid resource extraction over participatory governance, systematically constraining the capacity of local communities—especially in Scheduled Areas—to organize and resist.

Yet, this centralizing logic collides with the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (FRA), in coal-rich forest districts of eastern India with large Indigenous populations. The FRA’s recognition of customary land and forest rights introduces overlapping jurisdictions that frequently spark litigation, grassroots mobilization, and political contestation. Resistance is intensified not only by the ecological degradation and forced displacement linked to coal mining, but also by the chronic failure of state agencies to uphold statutory protections—illustrating how legal pluralism, when fused with extractive imperatives, entrenches the social inequities at the core of energy development.

Hydropower — Institutional Fragmentation and Conditional Bargaining: Land acquisition for hydropower projects in India is institutionally fragmented, governed by a patchwork of central and state-level mechanisms and implemented by a diverse set of actors, including state irrigation departments, central public sector undertakings (PSUs) such as the National Hydroelectric Power Corporation (NHPC), and private developers. Projects not classified as “critical infrastructure,” are typically managed by state governments or joint ventures, with land acquired either under the LARR Act or respective state statutes, depending on jurisdiction, project classification, and implementing agency. This multiplicity of legal channels creates openings for litigation and bargaining, especially when LARR’s procedural safeguards—such as Social and Environmental Impact Assessmentsand consent provisions—are formally triggered.

In practice, however, the application of LARR remains uneven. Many state

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governments invoke "public purpose" exemptions, apply urgency clauses, or rely on legacy state laws to bypass participatory safeguards. Implementation challenges include outdated cadastral records, inter-agency coordination failures, and bureaucratic inertia. In hilly and tribal districts, where land is often recorded as state or forest property, acquisition can proceed without full consent or compensation, despite statutory protections under FRA or PESA. This combination of legal ambiguity, overlapping mandates, and discretionary exemptions constrains community participation while preserving limited, case-specific bargaining spaces. As a result, hydropower projects operate within an institutional environment that is both procedurally complex and strategically malleable, producing variable outcomes in terms of delay, contestation, and community benefit-sharing.

Solar — Private Development and Silent Dispossession: The solar sector follows a markedly different trajectory, with most projects circumventing formal LARR procedures entirely. Land access is typically facilitated through state industrial policies and sector-specific agencies—such as Solar Park Implementing Agencies—which aggregate parcels via leasing, pooling, or Special Purpose Vehicles (SPVs) that hold land on behalf of private developers (Burman, 2023). Solar projects frequently rely on long-term leases of government or revenue land classified as "wasteland" or "non-cultivable," as well as on pooled private plots, neither of which requires formal landowner consent or mandatory SIA when classified outside agricultural or inhabited categories.

Compensation frameworks are correspondingly thin, often limited to nominal lease payments with minimal or no provisions for livelihood restoration. Rehabilitation and Resettlement (RR) obligations are weakly enforced or absent, justified by the claim that communities are "not displaced" in the legal sense, even when customary access to grazing grounds and common resources is lost. Grievance redress remains largely ad hoc, forcing affected groups to resort to petitions or litigation in the absence of structured dispute-resolution mechanisms.

These arrangements replicate many of the inequities historically associated with large-scale development, but under a decentralized, market-oriented guise. Legal ambiguities surrounding common lands and the absence of explicit protections for pastoralists and landless households exacerbate procedural opacity. In states such as Rajasthan, Gujarat, and Karnataka, these mechanisms have enabled rapid solar deployment while simultaneously generating patterns of silent displacement and eroding community safeguards (Jain, 2022). A recent survey indicates that nearly 50% of renewable energy projects in India are affected by local conflicts, with disputes over common property resources being the most significant driver. An estimated 20% of these projects have been stalled entirely due to such conflicts (Land Conflict Watch, 2025).

In sum, India's energy-sector land acquisition regimes reflect deep institutional heterogeneity. While the LARR framework exists as a formal unifying statute, its practical application is fragmented across sector-specific laws, procedural loopholes, and state-level policy innovations. Coal mining under the CBA Act is characterized by centralized state control and the systematic bypassing of participatory safeguards; hydropower acquisition occurs in a multi-agency environment where overlapping mandates and legal ambiguity shape variable contestation dynamics; and solar expansion is largely enabled by extra-LARR administrative mechanisms that facilitate speed but institutionalize new forms of silent dispossession.

B: Litigation Over Compensation and Procedural Lapses: Poor or delayed compensation remains one of the most persistent drivers of local resistance to large-scale infrastructure projects in India. Under the LARR Act, compensation is calculated using the highest of three benchmarks: (a) the minimum land value notified under the Indian Stamp Act for registration purposes, (b) the average sale price for comparable land transactions in the preceding three years, or (c) consent-based agreements in the case of public-private partnerships (PPPs) or purely private projects. With multipliers, in rural areas, total compensation can be up to four times the notified market value.[14]

A systematic review of all land acquisition-related cases decided by the Supreme Court of India between 1950 and 2015 found that compensation disputes accounted for nearly two-thirds of the cases, with procedural lapses making up most of the remainder (**?**). Courts awarded higher compensation in more than 90% of the cases where the market value was contested, with final awards averaging seven times the initial amount set by the acquiring authority. However, these legal remedies were accompanied by severe delays: the median resolution time for compensation disputes exceeded 20 years, underscoring the systemic inefficiency and uncertainty of India's land acquisition framework.

Publicly available data on compensation payments remains sparse. A report by the Comptroller and Auditor General revealed that, in several coal mining projects, compensation remained unpaid even five years after physical possession of land had been taken. To assemble sector-specific trends, I draw on Parliamentary debates where Members of Parliament request project-level details from relevant ministries. Although this method is laborious, it yields rare insights into compensation practices across sectors.

Three notable patterns emerge from this analysis:

1. *Rising compensation levels post-LARR:* Compensation amounts have increased steadily over time, reflecting both inflation adjustments and the growing bargaining power of affected communities. Inflation-adjusted payments in the power sector projects were, on average, 22% higher in the 2020s compared to the 2020s. Following the enactment of the LARR Act, the increase was particularly sharp.[15] While these trends reflect the combined impact of statutory multipliers, mandatory SIAs, and heightened legal awareness, they have also raised acquisition costs, prompting developers to bypass or remain outside the purview of LARR altogether, such as in case of coal mining.

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[14] In addition to the base land value, the Act provides for the valuation of immovable assets such as trees, buildings, and crops, alongside comprehensive Rehabilitation and Resettlement (RR) entitlements. The total amount is adjusted with a multiplier linked to the distance from urban centers, plus a solatium of up to 100% to account for the involuntary nature of the acquisition.

[15] Similar patterns are observable in other sectors, but data gaps prevent comprehensive cross-sector analysis. For instance, the average compensation paid by the National Highways Authority of India (NHAI) rose from 5.8 million INR per acre in 2014–15 to 11.4 million INR per acre in 2016–17.

2. *Systematic under-compensation in tribal areas:* Compensation for land acquired in Scheduled (tribal) areas is substantially lower than in non-tribal regions. Based on my analysis of power generation projects, tribal lands received, on average, 38% less compensation than adjacent non-tribal lands. Even when compensation is paid, it rarely translates into sustainable livelihood restoration. In the mining sector, tribal families eligible for compensation fail to claim it—primarily due to disputes over title or inheritance (46%), absence of ownership records (33%), and outdated documentation (21%). This disparity reflects structural inequities in land titling, undervaluation of customary holdings, and the limited bargaining power of tribal communities when negotiating with state or private developers.

3. *Poor rehabilitation records:* Ad-hoc rehabilitation packages frequently fall short of restoring livelihoods or social security for displaced households. Even where land-for-land or job-for-land promises are made, delivery is inconsistent and contingent on project-specific discretion. In major power projects during the Eleventh and Twelfth Five-Year Plans, only about 8% of displaced tribal families secured employment, despite the widespread perception that R&R packages guarantee at least one job per affected household. In practice, such commitments are often informal and conditional, as reflected in the NTPC's R&R policy—first articulated in 1978 and reiterated in 2000—which states: *"Although no commitment for employment was given by NTPC to land losers, based on the availability of vacancy and suitability of candidates, employment has been provided to land losers and other rehabilitation benefits have been extended as per extant RR Policy and as decided by the State Government."*

C: Mistrust and Extra-Legal Conflict: A critical yet under-theorized consequence of land acquisition failures in India is the erosion of institutional trust and the rise of extra-legal resistance. The persistent patterns of under-compensation, inadequate rehabilitation, and structural inequities in land acquisition—particularly in Scheduled Areas—have a cumulative effect that extends beyond material loss. They corrode the legitimacy of state institutions, weaken the social contract, and fuel deep-seated mistrust among affected populations. When communities experience repeated failures in compensation delivery, livelihood restoration, and grievance redress, opposition to projects shifts from transactional bargaining to entrenched resistance, often spilling over into extra-legal forms of protest.

The recurring pattern of "foregone compensation"—where payments are withheld due to unresolved bureaucratic hurdles such as absentee landownership, disputed titles, or state apathy—has been well documented.[16] Such scenarios erode the

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[16] A striking example is the Visakhapatnam Steel Plant, where land was acquired decades ago but compensation remained unpaid—fueling long-standing protests and legal disputes (Ramachandraiah, 2011). Similarly, in certain Special Economic Zones (SEZs), acquisitions occurred at highly concessional rates of 1 per acre ostensibly for industrial development but were later diverted—often illegally—to high-end real estate ventures. In recent years, similar patterns have emerged in the context of solar energy development, such as in Rajasthan, where utility-scale solar parks have been facilitated through concessional land transfers to private developers, while affected communities report minimal compensation and opaque valuation processes.

credibility of the state and generate long-term grievances among affected communities. For instance, in Hasdeo Arand (Chhattisgarh) and the Hirakud Dam project (Odisha), local populations have mobilized not only against physical displacement but also against the state's persistent failure to fulfill compensation commitments (Fernandes, 2008). These episodes reinforce the widespread perception that large-scale infrastructure projects disproportionately serve external stakeholders—such as private developers or central agencies—while systematically dispossessing local communities without meaningful redress.

This breakdown of trust manifests in both legal and extra-legal opposition. While land-related disputes dominate formal justice delivery, India is witnessing a growing wave of extralegal resistance. According to independent estimates, over 900 active land conflicts currently affect more than 2.5 million people and have stalled infrastructure investments worth over \$200 billion (Land Conflict Watch, 2025). The apathy of the Indian state towards land conflicts is underscored by the fact that, despite constructing over 5,000 large dams since independence, India has yet to develop a centralized repository of displaced people.

Historically, the Left Wing Extremist (Maoist) insurgency, which gained traction from the 1960s through the early 2000s, emerged in part as a response to land alienation and state-led resource extraction in the tribal belt of eastern and central India (Banerjee, 2006). Districts rich in coal, bauxite, and forest resources became flashpoints for armed resistance, as communities excluded from formal grievance mechanisms turned to insurgency as a mode of protest. Although the insurgency has waned in recent years, the underlying grievances around land, displacement, and exclusion remain potent. In this context, land acquisition uncertainty should not be viewed merely as a logistical challenge—it represents a systemic political and economic risk. By failing to institutionalize fair compensation, effective grievance redress, and participatory mechanisms, the Indian state inadvertently fuels cycles of conflict and undermines long-term investment viability.

6.3 Investment Uncertainty and the Future of Energy in India

Development-induced displacement generates a form of localized NIMBYism, which reconfigures the geography of capital investment. Regions marked by prior contestation become tagged as "high-risk," deterring future public and private investments and closely mirroring a subnational variant of the "resource curse" (Bebbington et al., 2008). As (Flyvbjerg, 2009) argued, unresolved land conflicts cascade into fiscal stress, repeated cost overruns, and, in many cases, complete project abandonment—exemplifying the "Iron Law of Megaprojects": over budget, over time, over and over again, where repeated delivery failures erode the credibility of the state and shrink the capacity of planning institutions.[17]

The consequences of land-related constraints are especially visible in India's energy sector. Despite an estimated 145 GW of technically feasible hydropower poten-

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[17] For example, the Nandigram protests in West Bengal in 2007 against proposed industrial land acquisition led to project cancellation and eroded the public image of the state in terms of ease of doing business.

tial, only about 47 GW had been developed as of 2023—reflecting a realization rate of less than one-third. Between 2000 and 2020, India added just 400–500 MW of new hydropower capacity per year on average, falling well short of national targets. Data from the Central Electricity Authority (CEA) show that more than half of India's large dam projects remain delayed or incomplete—many for over a decade—due to land acquisition disputes, environmental clearance hurdles, and entrenched local resistance.

Coal mining faces a parallel set of challenges. Although India holds over 350 billion metric tons of total coal reserves—with forest-rich eastern states like Jharkhand, Odisha, and Chhattisgarh accounting for nearly 70%—the expansion of mining capacity has faced resistance. Delays of three to five years owing to land disputes and ecological clearances have become routine, raising investor risk premiums and deterring private capital in what has historically been a state-dominated sector.

Even in the relatively nascent solar energy sector—often praised for its speed and efficiency—land acquisition is emerging as a binding constraint. Large, contiguous tracts of flat, unshaded land—typically located in semi-arid regions—are under growing pressure from private land brokers, competing land uses, and local communities. India's commitment to achieving 500 GW of non-fossil fuel capacity by 2030 under its net-zero pledge will require an estimated 50–75 million acres of land for solar and wind installations, depending on spatial efficiency and storage assumptions Chakraborty (2023). However, mounting land-use conflicts driven by poor consultation, inadequate compensation, and the loss of commons are increasingly slowing the pace of new project approvals.

Building on the comparative data in Figure 1, India would need to increase its per capita energy consumption by 40–60% to reach upper middle income status. However, the persistent pattern of under-realization underscores that land governance—rather than purely technical or financial constraints—will be a decisive factor in shaping the country's energy security. While India possesses abundant natural resources across coal, hydro, and solar, unresolved land conflicts risk locking it into a high-carbon trajectory. The coal sector, in particular, continues to benefit from implicit land subsidies through the ongoing use of the Coal Bearing Areas Act (1957), which enables rapid acquisition for state-owned enterprises while bypassing the consent and rehabilitation safeguards mandated by the LARR Act. This not only distorts the cost competitiveness of coal relative to renewables but also exposes millions to the risk of internal displacement, perpetuating a cycle of dispossession without adequate compensation or rehabilitation.

7 Conclusion

This study develops a scalable and empirically grounded framework for estimating the social costs of infrastructure development in India, with a focus on displacement arising from coal, hydropower, and solar energy projects. By combining archival Gazette notifications with high-resolution satellite-based population grids, it offers one of the first systematic attempts to quantify and compare displacement effects across energy sectors. The findings reveal stark sectoral differences in the scale and nature of displacement, persistent institutional weaknesses in compensation and rehabilitation, and the emergence of spatial inequalities in infrastructure outcomes.

The results underscore that India's energy transition is not constrained solely by capital availability, technological feasibility, or resource endowments, but equally by the political economy of land governance. Where acquisition processes are opaque, compensation is inadequate, and rehabilitation remains poorly implemented, infrastructure projects face heightened social resistance, prolonged delays, and cost escalation. These dynamics weaken investor confidence and risk locking the country into a high-carbon development pathway by privileging sectors—such as coal—where land acquisition laws remain more permissive.

Sustaining investment momentum while safeguarding social legitimacy will require targeted reforms that strengthen land records, ensure fair and timely compensation, institutionalize robust rehabilitation and resettlement frameworks, and embed meaningful community participation in planning. Without such measures, the very populations intended to benefit from infrastructure expansion may become its most enduring opponents.

Beyond its empirical contributions, the data architecture developed here provides a foundation for further inquiry into the distributional and political consequences of large-scale infrastructure. It can be leveraged to explore heterogeneity in displacement across caste, gender, and tenure regimes; to assess compliance with statutory safeguards; and to evaluate the spatial justice implications of climate transition investments. As India moves toward its ambitious renewable energy and net-zero targets, integrating social safeguards into energy planning will not only mitigate conflict but also enhance the resilience and legitimacy of the transition itself.

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Appendix

Table A1: **Installed Power Station Capacity in India (in GW)**

	Fossil					**Non-Fossil**				
Sector	**Coal**	**Lignite**	**Gas**	**Diesel**	**Total**	**Nuclear**	**Large Hydro**	**Renewable**	**Total**	**Total**
Central	69.1	3.6	7.2	–	80.0	8.8	16.5	1.6	26.9	107.0
State	71.9	1.2	7.0	0.3	80.3	–	27.5	2.6	30.1	110.4
Private	71.7	1.8	5.9	0.3	79.7	–	3.9	174.6	178.5	258.2
All India	212.7	6.6	20.1	0.6	240.1	8.8	47.9	178.8	235.5	**475.6**
Percentage (%)	44.7	1.4	4.2	0.1	50.5	1.9	10.1	37.6	49.5	100.0

Note: Renewable includes solar, wind, biomass, and small hydro. Source: Compiled from the Central Electricity Authority's May 2025 monthly report.

Table A2: **Performance of Hydro Projects by Decade and Project Type**

		Major Projects						**Medium Projects**					
Decade	Variable	Count	Min	Median	Mean	Max	SD	Count	Min	Median	Mean	Max	SD
1950s	Completion Time (Years)	36	5.0	16.5	23.2	51.0	15.6	24	5.0	10.0	12.8	34.0	6.9
	Cost Overrun (%)	36	-73.1	-17.9	17.2	492.0	106.5	24	-59.3	-22.2	-10.6	200.6	52.4
	Potential Benefit (th-hc/cr)	36	0.8	3.4	7.4	71.6	13.4	24	0.5	1.9	3.6	14.9	4.2
	Realized Benefit (th-hc/cr)	36	0.5	3.5	7.9	85.7	15.9	24	0.5	2.1	4.4	21.4	5.7
1960s	Completion Time (Years)	43	5.0	33.0	32.3	51.0	13.0	11	5.0	16.0	20.7	56.0	15.3
	Cost Overrun (%)	43	-69.8	95.9	200.4	1339.3	288.0	11	-99.1	33.4	84.6	416.3	163.4
	Potential Benefit (th-hc/cr)	43	0.2	3.1	4.1	16.2	3.3	11	0.4	2.7	3.2	6.7	2.0
	Realized Benefit (th-hc/cr)	43	0.1	1.2	2.0	7.3	1.8	11	0.3	2.1	6.5	44.4	12.7
1970s	Completion Time (Years)	28	6.0	28.5	28.5	43.0	8.7	46	2.0	24.0	24.2	43.0	9.4
	Cost Overrun (%)	28	-69.0	213.9	208.8	803.6	226.9	46	-31.5	157.9	262.9	3181.4	473.1
	Potential Benefit (th-hc/cr)	28	0.0	1.7	2.1	7.5	2.0	46	0.1	1.6	2.2	10.4	2.0
	Realized Benefit (th-hc/cr)	28	0.0	0.5	1.2	7.7	2.1	46	0.0	0.6	0.8	3.3	0.8
1980s	Completion Time (Years)	7	17.0	27.0	27.7	37.0	7.9	21	15.0	22.0	22.2	32.0	5.9
	Cost Overrun (%)	7	-34.2	19.1	42.5	221.5	88.3	21	-15.8	198.5	205.6	589.0	186.5
	Potential Benefit (th-hc/cr)	7	0.2	0.4	0.4	0.7	0.2	21	0.3	1.3	1.6	5.4	1.2
	Realized Benefit (th-hc/cr)	7	0.1	0.3	0.3	0.7	0.2	21	0.2	0.5	0.6	2.0	0.5
1990s	Completion Time (Years)	7	10.0	15.0	17.4	31.0	7.4	9	10.0	25.0	20.6	25.0	5.8
	Cost Overrun (%)	7	-52.6	-25.0	-11.5	67.7	40.8	9	-55.5	-2.5	54.3	456.7	161.1
	Potential Benefit (th-hc/cr)	7	0.0	0.4	4.1	25.7	9.5	9	0.1	0.2	0.4	1.4	0.4
	Realized Benefit (th-hc/cr)	7	0.0	0.5	8.3	54.1	20.2	9	0.1	0.3	0.2	0.5	0.1
2000s	Completion Time (Years)	2	5.0	5.0	5.0	5.0	0.0	3	15.0	15.0	15.0	15.0	0.0
	Cost Overrun (%)	2	-19.2	-9.0	-9.0	1.2	14.4	3	-37.0	-25.8	-27.6	-20.1	8.6
	Potential Benefit (th-hc/cr)	2	0.2	0.2	0.2	0.2	0.0	3	0.2	0.2	0.2	0.2	0.0
	Realized Benefit (th-hc/cr)	2	NA	NA	NA	NA	NA	3	0.2	0.2	0.2	0.3	0.0

Note: Projects delayed are calculated based on completion timelines compared to the original timelines based on the Five-Year plans. Cost overruns and benefits estimates are inflation-adjusted based on WPI estimates from the Reserve Bank of India. Source: Author's calculation using project-level data from the Water Resource Information System (WRIS).

Data Appendix

A1: Using NLP Pipeline on Gazette Notifications

I develop a novel spatio-temporal dataset of coal mining projects in India using an NLP pipeline applied to historical `Gazette Notifications`.

1. **Data Acquisition:** I collected Gazette Notifications from two primary sources. First, I downloaded 179,890 GNs hosted on the official Government of India portal (egazette.nic.in), covering the period from 1937 to 2023. However, after careful review, I found that the digital archives on this official site are incomplete and contain significant gaps—especially for older records and sector-specific acquisitions. To overcome these limitations, I accessed a more comprehensive repository of approximately 370,000 GNs available on the Internet Archive (archive.org). These two sources together form the raw corpus from which project-specific land acquisition events were extracted.

2. **Training Corpus and NLP Modeling:** Using metadata from the official portal, I identified and labeled approximately 15,000 land acquisition notifications. A binary classifier built with `scikit-learn` and `spaCy`—utilizing TF-IDF features and logistic regression—was trained to detect acquisition-related GNs. This yielded 21,081 relevant GNs, including 800 notifications specific to coal mining.[18]

3. **Text and Table Extraction:** I employed `Tesseract OCR` to digitize non-machine-readable PDFs, followed by text extraction using `pdfminer.six` AND `PyMuPDF`. Named Entity Recognition (NER) models trained via `spaCy` extracted entities like acquiring agencies, land types, and notification dates. For tabular data, such as land measurements, I used `camelot` and `pdfplumber` depending on table formats.[19]

4. **Spatio-Temporal Structuring:** Project mentions were consolidated into a time-stamped, geo-referenced dataset. Place names were standardized using gazetteers and geocoded to subdistrict polygons from the SHRUG database. Duplicate GNs (due to multi-stage legal processes) were resolved using fuzzy string matching and spatial proximity heuristics.

5. **Validation:** I validated spatial mappings against an independent spatial dataset from ABC (2020), observing a 93% overlap. Discrepancies largely arose from incomplete records, OCR/NLP errors, or georeferencing mismatches. The Gazette-based dataset tends to capture the full legally acquired land, which often exceeds the operational footprint observed via remote sensing.

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[18] Coal mining projects, while fewer in number, represent significant land acquisitions compared to linear infrastructure.

[19] OCR pre-processing steps included de-skewing, denoising, and contrast enhancement to improve recognition accuracy. The Internet Archive collection contains OCR-processed scanned documents, crucial for older records missing in official digital archives.

A2: Using Historical Satellite Imagery for Solar Projects

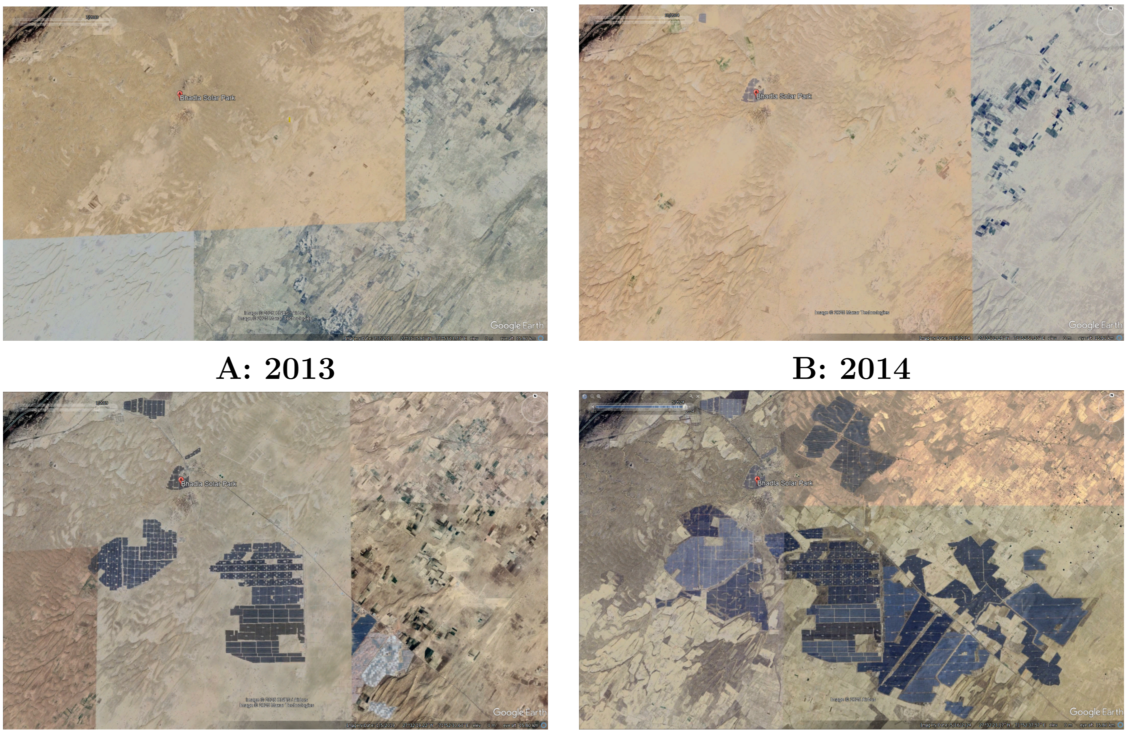
To validate commissioning timelines for solar parks, I used *Google Earth Engine (GEE)* via the `earthengine-api` and `geemap` Python libraries. GEE provides direct access to **Landsat** (5, 7, 8), **Sentinel-2**, and MODIS datasets.

I retrieved satellite imagery as follows:

1. Authenticate using `ee.Authenticate()` and initialize with `ee.Initialize()`.
2. Define the Area of Interest (AOI) using latitude-longitude bounds.
3. Filter an `ee.ImageCollection` by date range (`filterDate`) and spatial bounds (`filterBounds`).
4. Select relevant bands (e.g., Red, NIR, SWIR).
5. Export images to `Google Drive` with `ee.batch.Export.image.toDrive()`.

Figure A1 presents satellite imagery for a selected solar park, demonstrating identification of project commissioning.[20]

Figure A1: **Bhadla Solar Park (2013–2024)**



A: 2013 **B: 2014**

C: 2019 **D: 2024**

Note: Satellite imagery composites generated using Google Earth Engine. Panels illustrate India's largest solar PV installation park, Bhadla in Rajasthan.

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[20] I appreciate the research assistance of Nabiha Fatima to complete manual inspection of over 1,000 spatial polygons.