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Energy, Trade, and Technology in Tamil Nadu and India: A Critical Study of the Supply Chain Ecosystem, Future Trajectories, and Socioeconomic Implications for the Middle Class and the Marginalised (2001–2025)

T. Vasantha Kumaran^{1*} and S. Thirunavukkarasu²

Abstract

This study critically examines the intersecting domains of energy, international trade, and technological transformation in Tamil Nadu and India over the quarter-century from 2001 to 2025. Focusing specifically on the supply chain ecosystem as an integrating analytical lens, the paper traces how structural shifts in energy generation, particularly the rise of renewable sources, have reshaped industrial production patterns, influenced trade competitiveness, and disrupted legacy supply arrangements. Drawing on official government data, peer-reviewed scholarship, and sectoral reports, the analysis situates Tamil Nadu's trajectory within the broader arc of India's economic modernisation while probing the distributional consequences of this transformation for the middle class, the rural poor, and historically marginalised communities. The paper argues that without deliberate policy intervention addressing energy access inequities, labour market disruption, and the concentration of technology-driven gains, the promise of India's emerging supply chain leadership risks deepening rather than alleviating existing socioeconomic fault lines.

Keywords: Energy landscape, Renewable energy, Supply chain ecosystem, Middle class, Marginalised, Socioeconomic indicators

JEL Classification: Q42, F14, O33, L60, O18, D31

¹ Retired Professor of Geography, University of Madras, Chennai, India.

² President, Centre for Development Economics Studies and Former Principal and HoD of Economics, Ramakrishna Mission Vivekananda College (Autonomous), Chennai, India.

*Corresponding author Email: thangavelukumaran@gmail.com

1. Introduction

Few subnational economies in the developing world capture as vividly as Tamil Nadu the tensions and possibilities inherent in rapid economic transition. Simultaneously one of India's wealthiest and most industrialised states, Tamil Nadu is also home to millions whose livelihoods remain anchored in agriculture, artisanal manufacturing, and the informal economy (Figure 1). Over the twenty-five years since 2001, the state has navigated a succession of transformations, from wind energy pioneer to automotive powerhouse, from textile exporter to emerging semiconductor destination that mirror, often in amplified form, the broader trajectories of the Indian economy itself. Understanding these transitions requires moving beyond sector-specific narratives and examining the deeper structural architecture: the supply chain ecosystem through which energy, goods, and technology-embodied capital flow, combine, and generate value.

India: Political Map — Tamil Nadu Highlighted

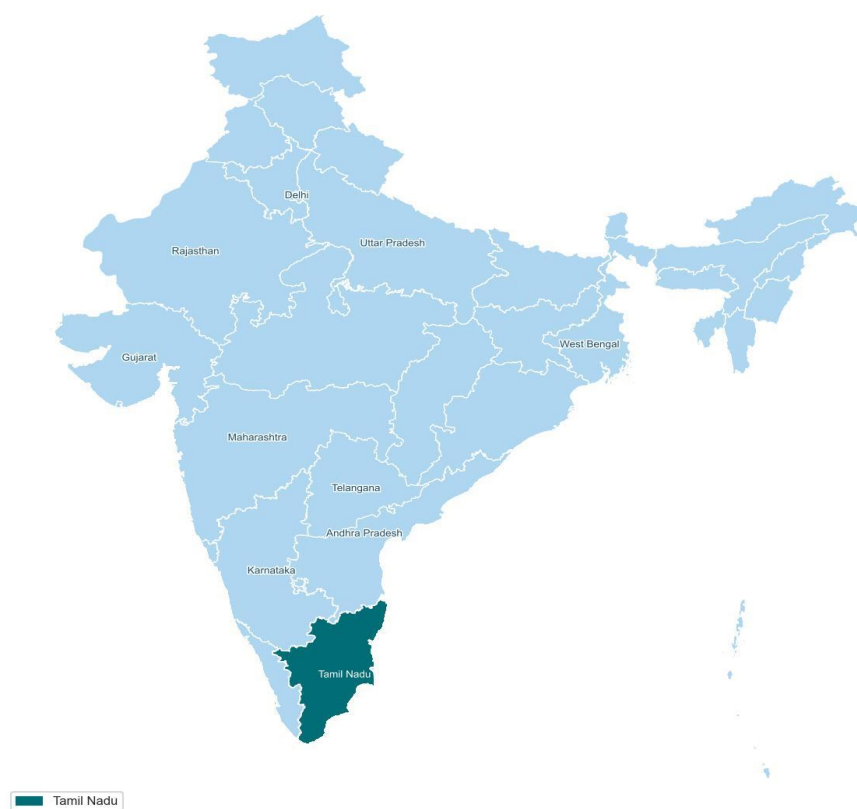


Figure 1. India's political geography with Tamil Nadu demarcated.
Source: GADM / SimplyGIS shapefiles.

*Figure 1. India's political geography with Tamil Nadu demarcated in teal.
Source: GADM / SimplyGIS shapefiles; author cartography.*

The supply chain, once treated as a technical backroom concern of logistics managers, has in the post-pandemic decade become a central preoccupation of development economists, industrial policymakers, and geopolitical strategists alike. The COVID-19 pandemic of 2020–21, the disruption of global semiconductor supply following the Wuhan outbreak, the Russia-Ukraine conflict's effects on fertiliser and energy prices, and the intensifying rivalry between

the United States and China over technological dominance have collectively elevated supply chain resilience to a first-order policy priority. For India—and especially for Tamil Nadu, whose export basket is deeply integrated with global value chains—these external shocks have forced a hard reckoning with structural dependencies that had hitherto attracted insufficient scrutiny.

This paper adopts a political economy framework that treats energy, trade, and technology not as isolated policy domains but as mutually constitutive elements of an evolving supply chain ecosystem. Three substantive questions organise the analysis. First, how have India's and Tamil Nadu's energy transitions between 2001 and 2025 reshaped the cost structure and reliability of industrial supply chains? Second, what have been the principal trade and technology dynamics driving the competitiveness of Tamil Nadu's industries during this period, and what structural vulnerabilities do these dynamics reveal? Third, and most critically, where are India and Tamil Nadu heading, and what do the emerging trajectories imply for the welfare of the middle class, the rural poor, and marginalised communities such as Dalits, Adivasis, and women workers in the informal sector?

The paper proceeds through seven substantive sections. Section 2 examines the energy landscape over the study period. Section 3 analyses trade dynamics and global value chain integration. Section 4 surveys technology and innovation. Section 5 synthesises these threads through the lens of the supply chain ecosystem; Section 6 projects forward trajectories. Section 7 examines distributional implications. A brief conclusion follows, preceded by a comprehensive reference list of references.

2. The Energy Landscape: From Thermal Dependence to Renewable Ambition

2.1 India's Evolving Generation Mix

At the turn of the millennium, India's electricity system was one defined above all by coal. Thermal generation, predominantly coal-fired, with a small contribution from gas and oil, accounted for roughly 75 to 80 per cent of total electricity produced. Hydroelectricity contributed approximately 15 per cent, nuclear power a modest three per cent, and renewables barely registered in the national accounts. The consequence was an energy system that was simultaneously carbon-intensive, geographically concentrated, and chronically inadequate: peak deficits routinely exceeded ten per cent of demand throughout the first decade of the 2000s, and large portions of rural India had no reliable grid connection whatsoever (Central Electricity Authority [CEA], 2005; Tongia, 2003).

The trajectory thereafter was shaped by two overlapping imperatives (Figure 2). The first was the sheer scale of demand growth. India's electricity consumption rose from approximately 380 billion units (BU) in 2001 to over 1,600 BU by 2023–24, driven by urbanisation, industrialisation, rising household appliance ownership, and the gradual electrification of rural areas under flagship schemes such as Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY, 2005) and its successor Saubhagya (2017) (Government of India [GoI], 2018; Kale, 2014). The second imperative was the worsening economics of coal, compounded by growing awareness of India's climate commitments. The Jawaharlal Nehru National Solar Mission (JNNSM) of 2010 set the initial target of 20 GW of solar capacity by 2022; this was subsequently revised upward, first to 100 GW and later embedded within a broader 500 GW renewable target for 2030 articulated at COP26 in Glasgow (Ministry of New and Renewable Energy [MNRE], 2022; Shrimali et al., 2013).

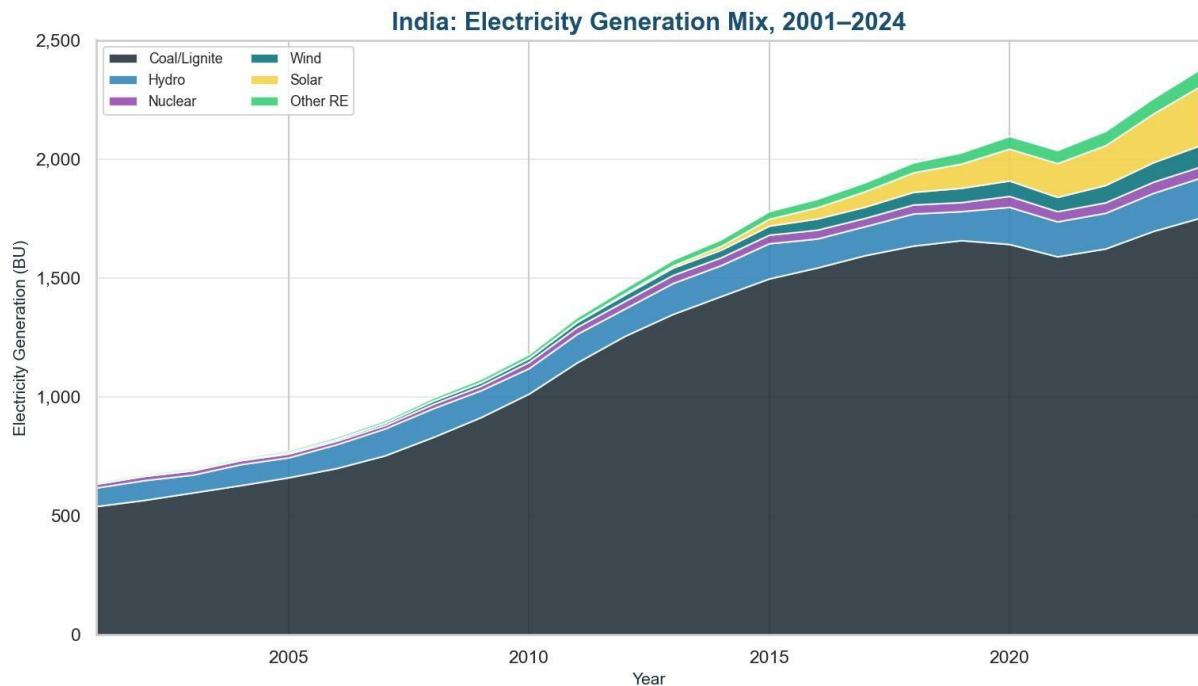


Figure 2. India's electricity generation mix (billion units) by source, 2001–2024.

Source: CEA Annual Reports (2001–2024); author compilation.

The results, as depicted in Figure 2, are striking in their asymmetry. Coal's absolute contribution continued to grow in volume terms, from around 541 BU in 2001 to over 1,755 BU in 2023–24, as base load demand outpaced renewable additions. Yet coal's share of total generation fell from over 75 per cent to approximately 71 per cent over the same period, as solar power surged from near-zero to more than 250 BU. The speed of solar's rise was remarkable by any international comparison: from less than 0.1 BU in 2012 to more than 250 BU by 2024, driven by precipitous reductions in module costs—from approximately USD 4.00 per watt-peak in 2010 to under USD 0.20 per watt-peak by 2023 (International Renewable Energy Agency [IRENA], 2023; Ram et al., 2023). Wind power, which had begun its Indian journey somewhat earlier, added steadily but faced headwinds in the second half of the decade as the best onshore sites were exhausted and the transition to an auction-based procurement model created transient uncertainty (Bridge et al., 2013; Chaudhary et al., 2019).

2.2 Tamil Nadu: A Pioneer under Pressure

Tamil Nadu occupies a singular position in India's energy history. The state became the nation's leading wind energy producer in the 1990s, when Muppandal in Tirunelveli district emerged as the site of one of Asia's largest wind farms. By the early 2000s, Tamil Nadu accounted for over 40 per cent of India's total installed wind capacity (TANGEDCO, 2005; Rao, 2010). This early mover advantage delivered real industrial benefits: energy-intensive industries such as textiles, engineering goods, and later automobile manufacturing could access captive and group captive wind power arrangements that reduced their electricity costs substantially relative to grid tariffs, conferring a competitive edge in export markets (Kale, 2014; Pillai & Banerjee, 2009).

India: Installed Renewable Energy Capacity by State (2023–24)

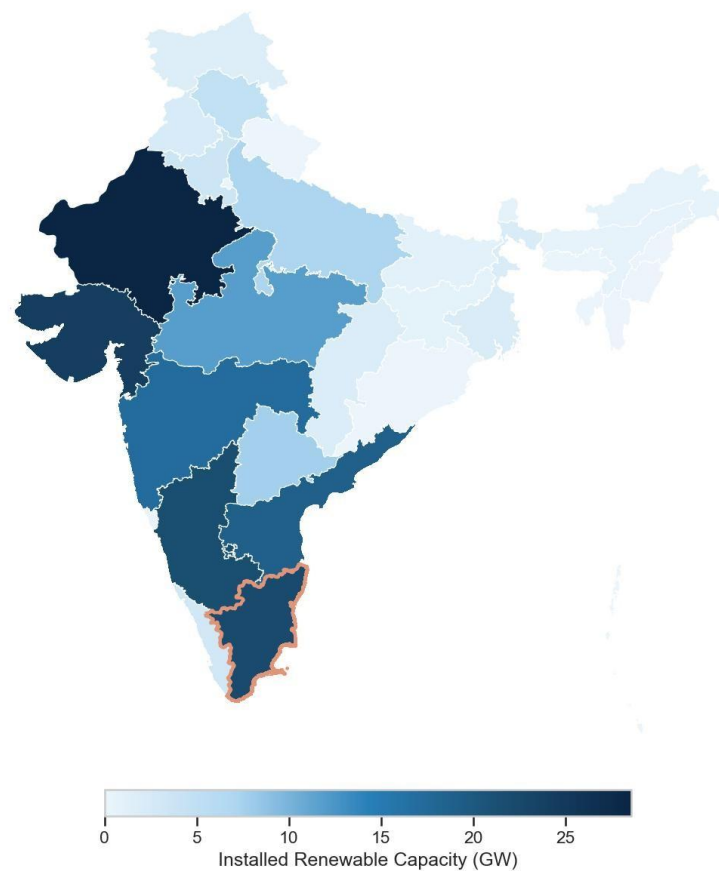


Figure 3. State-wise installed renewable energy capacity (GW) as of 2023-24, with Tamil Nadu outlined.

Source: MNRE Annual Report 2023-24; author cartography.

Figure 3 illustrates the current national landscape, in which Rajasthan and Gujarat have overtaken Tamil Nadu in total renewable installed capacity, chiefly through the deployment of utility-scale solar in their vast desert tracts, while Tamil Nadu retains its position as the dominant wind energy producer and has been aggressively building solar capacity since 2015. As of 2023–24, Tamil Nadu's total installed renewable capacity stood at approximately 22 GW, comprising roughly 10 GW of wind and 12 GW of solar, placing it third nationally (MNRE, 2024). Figure 4 traces this dual trajectory, illustrating how the state's renewable portfolio has diversified even as wind capacity approached a natural plateau in onshore installations.

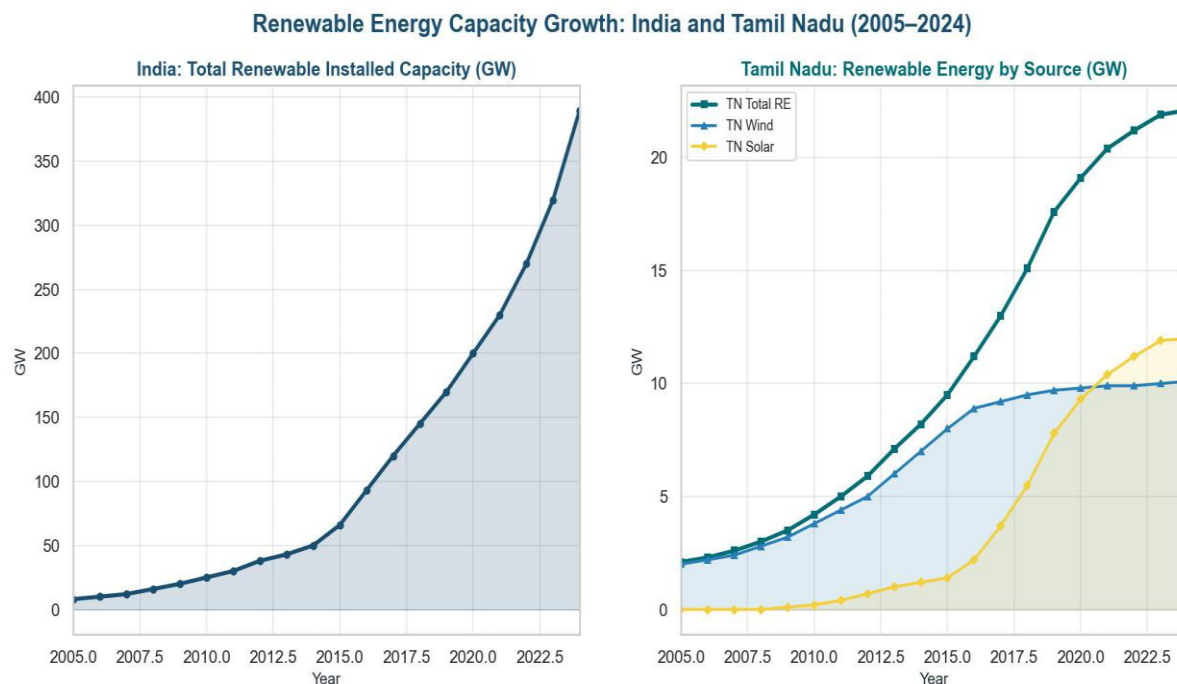


Figure 4. Installed renewable energy capacity (GW): India (left) and Tamil Nadu by source (right), 2005–2024.

Source: MNRE Annual Reports; TANGEDCO; author compilation.

Yet Tamil Nadu's energy story is not uniformly positive. The state has faced recurring distribution losses averaging 14 to 18 per cent, a highly subsidised agricultural tariff that has driven the Tamil Nadu Generation and Distribution Corporation (TANGEDCO) into persistent financial distress, and an ageing thermal fleet at Mettur, Tuticorin, and Ennore that has struggled to meet base load demand reliably (Prayas Energy Group, 2019; Srinivasan & Geetha, 2018). The financial losses of TANGEDCO—cumulatively exceeding INR 1.5 lakh crore by 2022—have constrained investment in grid modernisation and renewable integration, raising questions about the long-term reliability of the system that powers Tamil Nadu's globally integrated industries. The challenge of integrating large shares of variable renewable energy into a grid still largely designed for dispatchable coal and hydro generation is a technical and economic problem that the state government has acknowledged but not yet resolved at the scale the transition demands (CEA, 2023; Prayas Energy Group, 2019).

3. Trade Dynamics: Integration, Vulnerability, and Realignment

3.1 India's Trade Trajectory

India's integration into the global trading system accelerated markedly after 1991, but it was the period from 2001 to 2025 that consolidated the country's emergence as a significant participant in world merchandise and services trade. Total merchandise exports rose from approximately USD 44.9 billion in 2001–02 to USD 422 billion in 2021–22 and USD 447 billion in 2022–23, before moderating to approximately USD 437 billion in 2023–24 amid a global demand slowdown (Directorate General of Commercial Intelligence and Statistics [DGCI&S], 2024; Ministry of Commerce and Industry, 2024). Services exports—driven overwhelmingly by information technology and IT-enabled services—grew from around USD 16 billion in 2001 to over USD 340 billion by 2023, providing India with the critical current account offset that insulated it from the full impact of its merchandise trade deficit (Reserve

Bank of India [RBI], 2024). Figure 6 maps these merchandise export trajectories alongside Tamil Nadu's estimated contribution.

Three features of this export trajectory deserve emphasis. First, India's export basket has evolved from one dominated by textiles and agricultural commodities at the turn of the millennium toward one increasingly shaped by engineering goods, pharmaceuticals, chemicals, and electronic products. By 2022–23, engineering goods alone accounted for approximately 26 per cent of merchandise exports, petroleum products for roughly 21 per cent, and pharmaceuticals for around 6 per cent (DGCI&S, 2024).

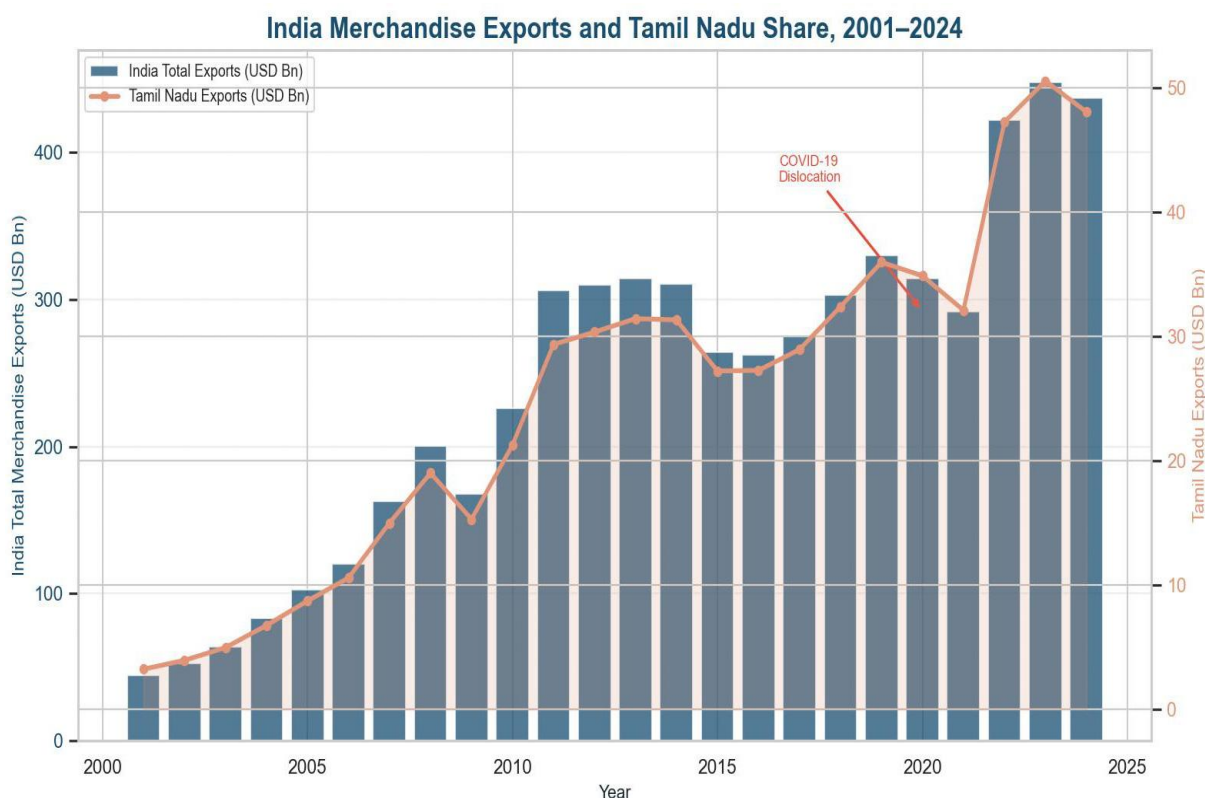


Figure 5. India's merchandise exports (USD Bn) and Tamil Nadu estimated exports, 2001–2024.

Source: DGCI&S; Ministry of Commerce; TNPC; author compilation.

Second, despite this diversification, India has struggled to penetrate the higher-value segments of global value chains that characterise Chinese and East Asian exports. India's share of world merchandise exports remained stubbornly at approximately 1.8 to 1.9 per cent through most of the 2010s, rising to approximately 2.2 per cent only after the COVID-19 disruptions created new sourcing diversification incentives for global buyers (World Trade Organization [WTO], 2024). Third, the COVID-19 pandemic of 2020–21 inflicted severe but ultimately short-lived damage on merchandise exports, which fell to USD 292 billion in 2020–21 before recovering sharply, demonstrating both the vulnerability and the underlying resilience of India's export base.

3.2 Tamil Nadu's Export Profile and Global Value Chain Integration

Tamil Nadu consistently accounts for approximately 10 to 11 per cent of India's total merchandise exports, making it one of the top three export-intensive states alongside Maharashtra and Gujarat. The state's export basket is distinguished by its unusual diversity: automobiles and automobile components from the Chennai-Oragadam-Sriperumbudur

corridor; leather and leather goods from Vellore, Ranipet, and Chennai; engineering goods and machinery from Coimbatore; readymade garments and knitwear from Tirupur, Erode, and Karur; and IT services from Chennai's extensive technology parks (Tamil Nadu Industrial Development Corporation [TIDCO], 2023; Tamil Nadu Planning Commission, 2022).

The automobile sector merits particular attention. Tamil Nadu is India's leading automobile manufacturing hub, contributing roughly 30 per cent of the country's total automotive output, including vehicles produced by Hyundai, Ford (until 2021), BMW, Daimler, Renault-Nissan, and a constellation of major component suppliers. This cluster's emergence was itself a supply chain achievement: over two decades, Chennai developed the logistics infrastructure, trained workforce, and supplier ecosystem necessary to produce export-grade vehicles at competitive costs (Barnes & Lorentzen, 2004; Saripalle, 2012). By 2023, the Tamil Nadu automotive sector exported components and vehicles worth approximately USD 7 billion, with electric vehicles beginning to feature significantly as Ola Electric, Hyundai's EV variants, and new entrants committed to the state's emerging EV ecosystem (TIDCO, 2023).

Figure 6 illuminates a structural weakness that underlies Tamil Nadu's and India's trade integration: high import dependence in critical sectors. Electronics, which India has targeted for domestic production through Production Linked Incentive (PLI) schemes since 2020, remains over 70 per cent import-dependent by value of components. Capital goods import dependence hovers around 62 per cent, reflecting India's persistently underdeveloped machine-tool and precision engineering sector.

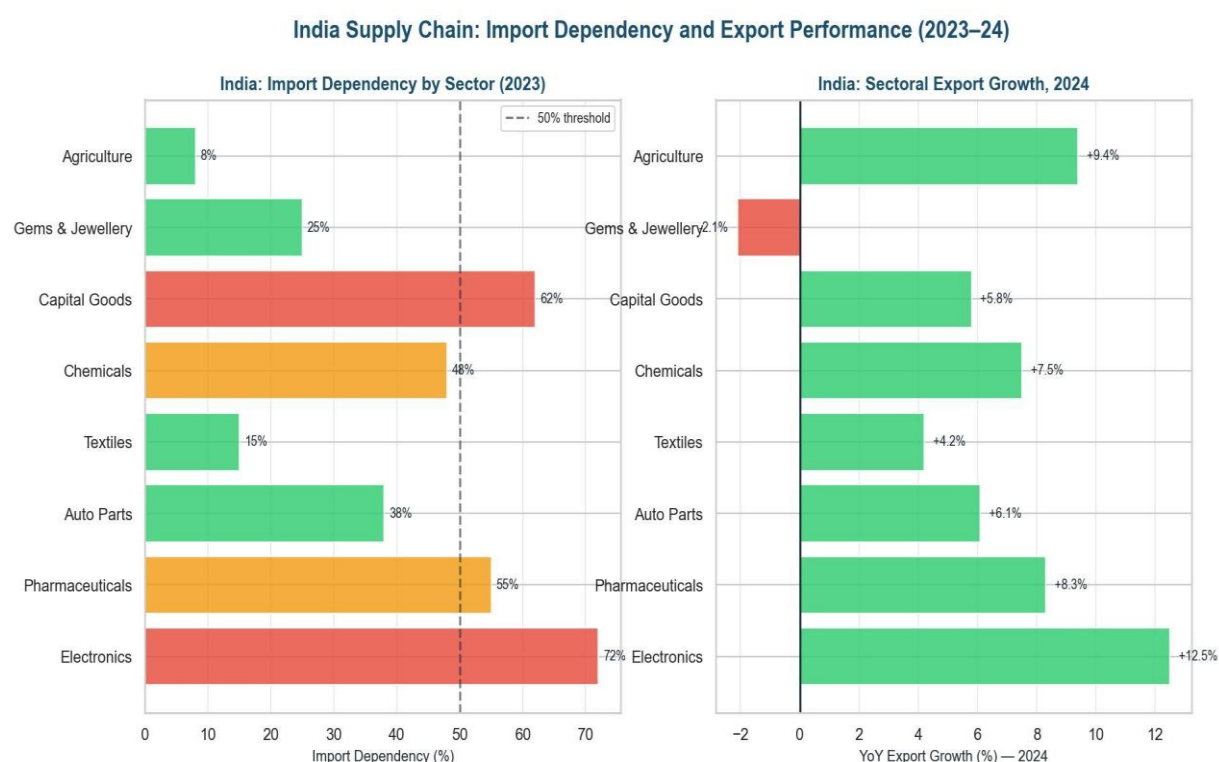


Figure 6. India's sectoral import dependency (%) and export growth (%), 2023-24.

Source: DGCI&S; DPIIT; author compilation.

Even pharmaceuticals, where India is a globally significant finished formulation exporter, depends on China for 65 to 70 per cent of its active pharmaceutical ingredient (API) requirements, a vulnerability underscored dramatically during the early months of the COVID-

19 pandemic (Pradhan, 2017; Yeravdekar & Tata, 2020). These import dependencies translate directly into supply chain fragility, which became viscerally apparent when pandemic-related factory shutdowns in China and Vietnam simultaneously disrupted production across India's automotive, electronics, and pharmaceutical sectors in 2020 and again in 2021 (Kumar & Agarwal, 2021).

4. Technology and Innovation: The Digital Layer of the Supply Chain

4.1 Information Technology and Digital Infrastructure

The information technology sector has been transformative for both Tamil Nadu and India in ways that extend far beyond its direct employment and export contributions. Chennai emerged in the early 2000s as India's third IT hub after Bangalore and Hyderabad, housing global delivery centres for Infosys, TCS, Wipro, Cognizant, and dozens of multinational IT services firms. By 2023, the Chennai IT/ITES sector employed approximately 500,000 professionals and generated export revenue estimated at USD 17 billion (Figure 7), approaching Hyderabad's scale and representing a near-fortyfold increase from USD 400 million in 2001 (NASSCOM, 2024; Software Technology Parks of India [STPI], 2023).

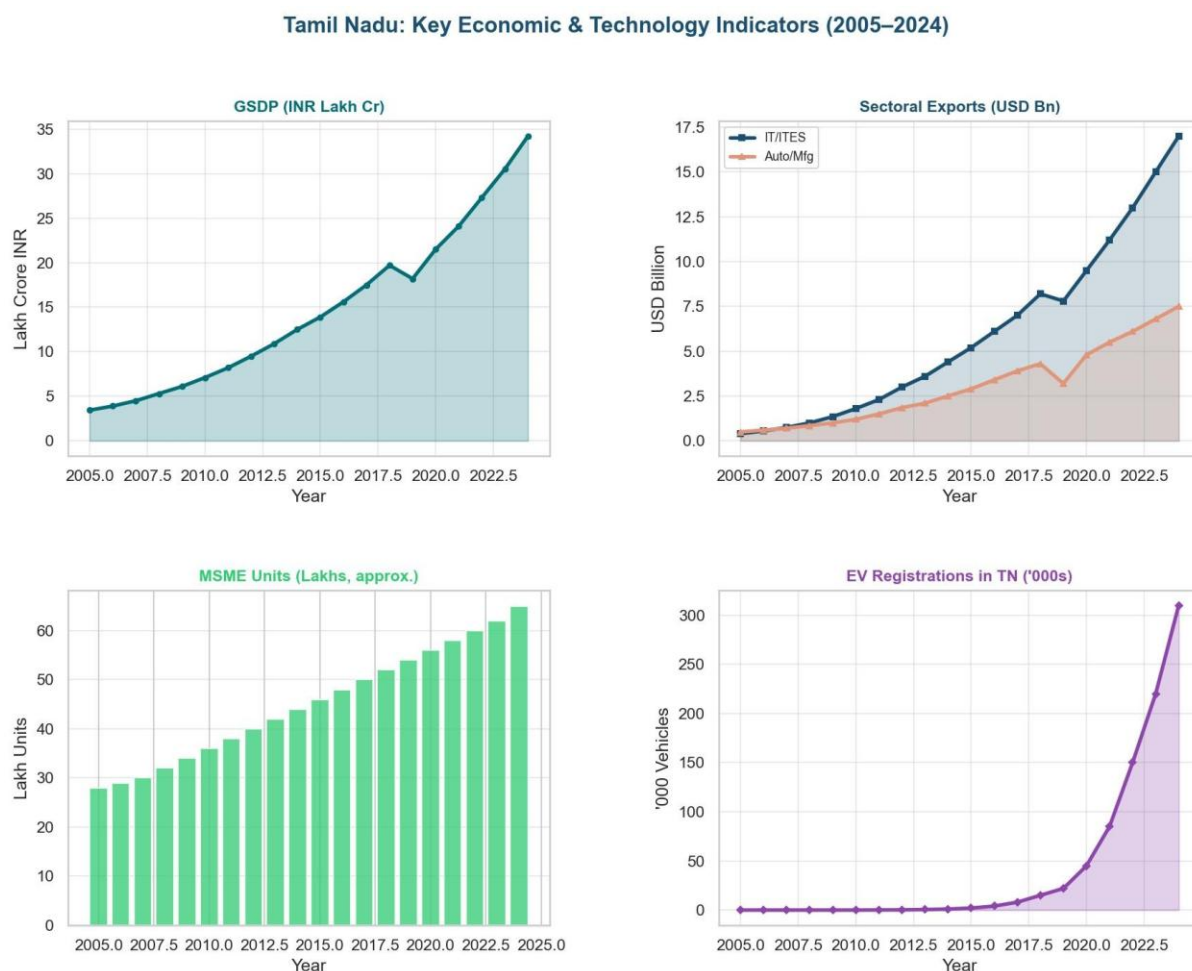


Figure 7. Tamil Nadu economic and technology indicators: GSDP, sectoral exports, MSME units, and EV registrations, 2005–2024. Source: CSO; DPIIT; TNPC; VAHAN; author compilation.

The significance of this sector for supply chains extends beyond the services it directly provides. India's IT industry has been the primary vehicle through which global enterprise resource planning (ERP) systems, logistics management software, and e-commerce platforms were implemented across Indian manufacturing firms, fundamentally changing inventory management, demand forecasting, and supplier coordination. The Digital India initiative launched in 2015 amplified this effect by building out the digital infrastructure, broadband connectivity, digital identity (Aadhaar), payment systems (UPI), that enabled micro and small enterprises to participate in digital supply chains for the first time (Heeks, 2017; Ninan, 2015; Rao, 2018).

4.2 Manufacturing Technology: From Automobiles to Semiconductors

Tamil Nadu's manufacturing technology trajectory over the study period traverses three distinct phases. The first phase (approximately 2001–2010) was characterised by the deepening of the automotive cluster, as successive waves of supplier investment from Japan, South Korea, Germany, and the United States built out the tier-2 and tier-3 supply base around Chennai. Assembly plants adopted Toyota Production System methods, lean manufacturing principles diffused through the supplier network, and quality management certifications (ISO/TS 16949, IATF 16949) became table stakes for component suppliers (Saripalle, 2012). The second phase (approximately 2010–2020) saw diversification into electronics assembly, with Foxconn, Flextronics, and Pegatron establishing facilities in the state, initially assembling smartphones and subsequently moving up the value chain toward printed circuit board assemblies. The third phase (2020 onwards) has been marked by India's ambition to develop a domestic semiconductor ecosystem, with Tamil Nadu positioning itself aggressively through land allocation in Oragadam, fiscal incentives under the Tamil Nadu Semiconductor Policy 2023, and partnerships with the central government's USD 10 billion India Semiconductor Mission (Government of Tamil Nadu, 2023; Invest India, 2024).

The emergence of electric vehicles as a major technology frontier has added a new dimension. Figure 8 shows EV registrations in Tamil Nadu growing from negligible volumes before 2018 to over 310,000 units by 2024, driven by two-wheelers and three-wheelers from manufacturers including Ola Electric, TVS, and Bajaj (VAHAN, 2024). The EV transition, however, is not simply an automotive story: it is a profound supply chain restructuring, as the lithium-ion battery, currently 90 per cent sourced from China and Japan, replaces the internal combustion engine and its associated supplier ecosystem (Luthra et al., 2020; Tyagi & Agarwal, 2021). For the thousands of machined-component suppliers in Coimbatore and Chennai who produce engine blocks, crankshafts, and fuel system components, the EV transition is an existential challenge that threatens to render their entire product portfolio obsolete over a ten-to-fifteen-year horizon.

5. The Supply Chain Ecosystem: Corridors, Clusters, and Vulnerabilities

The concept of the supply chain ecosystem, as developed by Adner and Kapoor (2010) and elaborated in the context of emerging markets by Taglioni and Winkler (2016), emphasises the interdependencies between focal firms, complementary asset providers, logistics infrastructure, regulatory institutions, and knowledge networks that together determine whether a geographic cluster can sustain competitive advantage in global value chains. Applying this framework to India and Tamil Nadu reveals a picture of considerable achieved capability coexisting with deep structural fragilities.

Figure 8 depicts India's National Industrial Corridor Programme, which since its launch in 2011 has sought to create world-class industrial infrastructure along dedicated freight corridors connecting major metropolitan centres. The Delhi-Mumbai Industrial Corridor

(DMIC), the first and largest of these, aims to create integrated industrial townships equipped with continuous power supply, high-speed logistics connectivity, and plug-and-play infrastructure for manufacturing firms. Tamil Nadu features prominently in the programme through the Chennai-Bengaluru Industrial Corridor (CBIC), which seeks to integrate the automotive, aerospace, and electronics clusters of Bengaluru and Hosur with Chennai's port and IT infrastructure, and the proposed Chennai-Kanyakumari Industrial Corridor (CKIC), designed to develop processing industries and renewable energy-intensive manufacturing along the state's southern coast (National Industrial Corridor Development Corporation [NICDC], 2024).

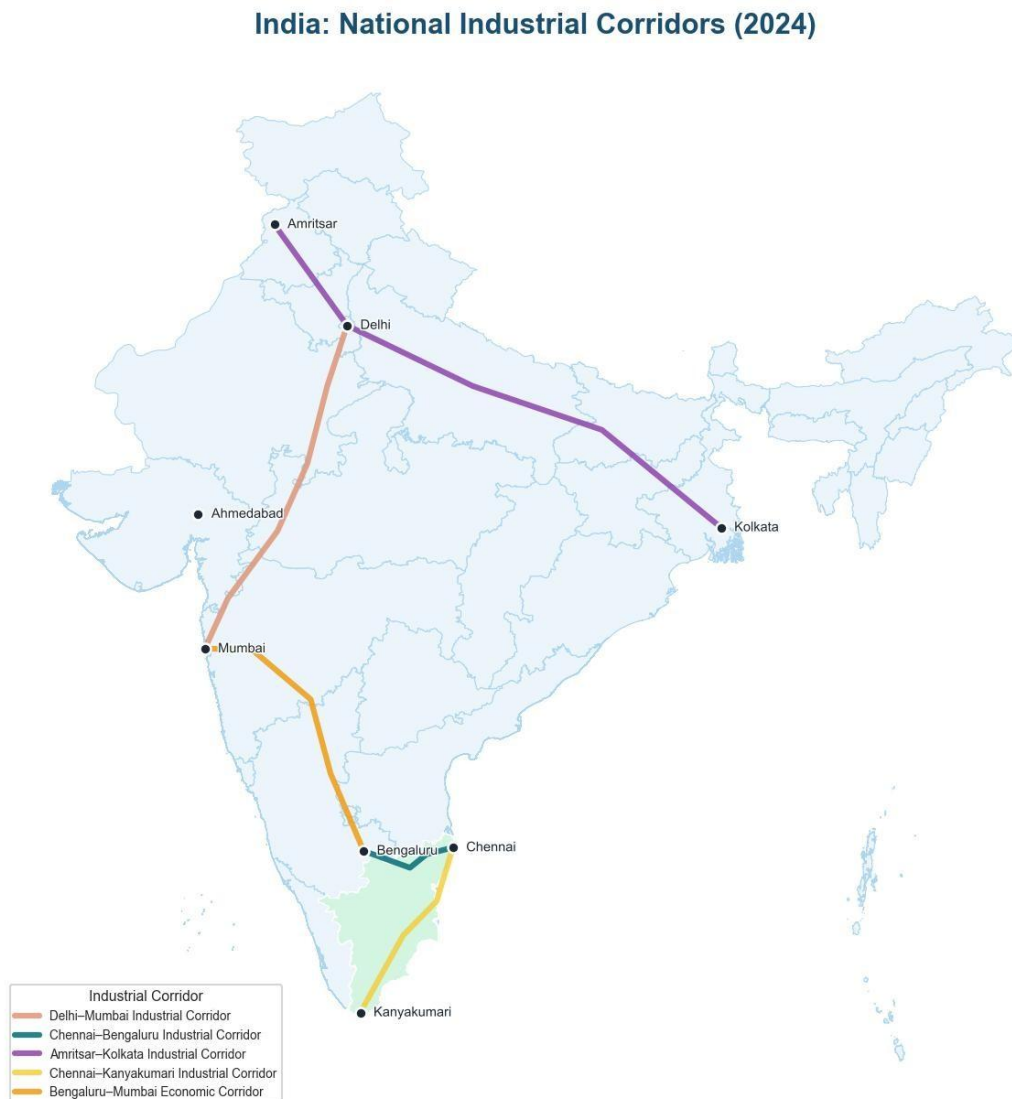


Figure 8. India's national industrial corridor network.

Source: NICDC; Ministry of Commerce and Industry; author cartography.

Figure 9 maps Tamil Nadu's district-level industrial and energy clusters, illustrating the spatial concentration of economic activity. The Chennai-Kancheepuram-Thiruvallur triangle hosts the automotive and IT clusters; Coimbatore anchors precision engineering, textile, and MSME economy; Tirupur functions as the global capital of knitwear; and the southern belt from Tirunelveli to Ramanathapuram is the wind energy heartland transitioning toward solar. This spatial clustering has generated agglomeration economies but has also produced spatial

inequalities: northern and central Tamil Nadu have captured the lion's share of industrial investment, while much of the delta region, Thanjavur, Nagapattinam, Thiruvarur, remains dependent on agriculture and remittances, with limited participation in the supply chains that drive Tamil Nadu's headline growth statistics (Tamil Nadu Planning Commission, 2022).

Tamil Nadu: Industrial and Energy Cluster Map (2024)

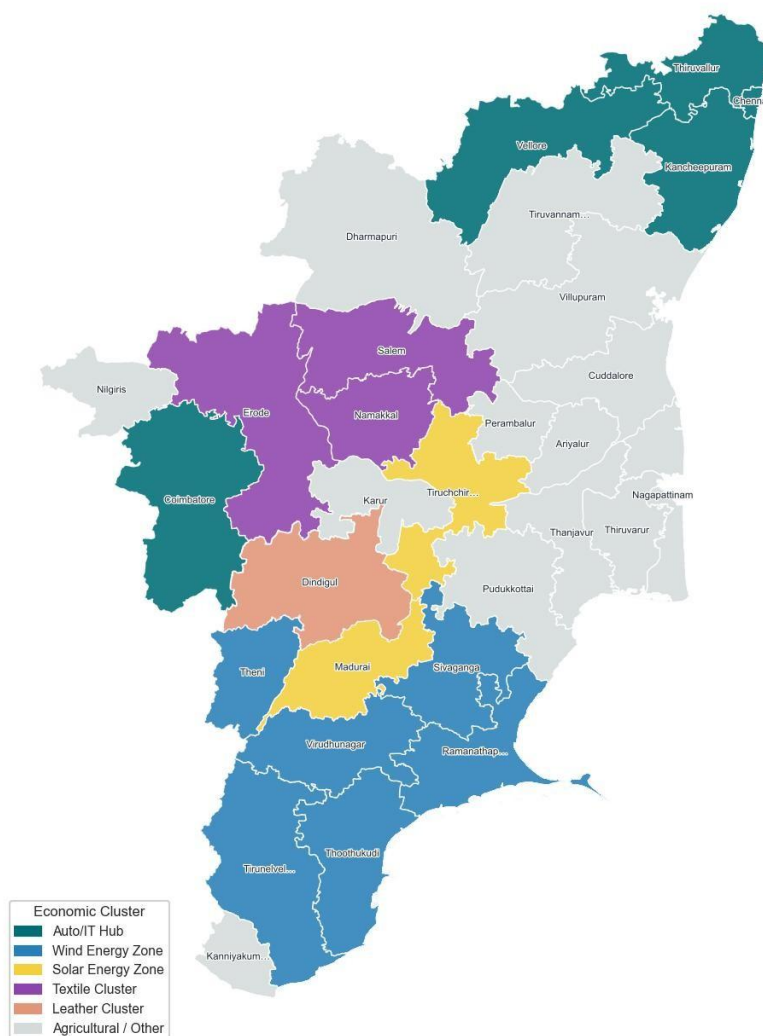


Figure 9. Tamil Nadu district-level economic and energy clusters, 2024.

Source: TANGEDCO; DPIIT; author classification based on literature.

The MSME sector, which Figure 7 shows growing from approximately 28 lakh registered units in Tamil Nadu in 2005 to over 65 lakhs by 2024, forms the connective tissue of these supply chains. Micro and small enterprises in Coimbatore's pump and motor manufacturing cluster, in Ambur's footwear industry, in Salem's steel re-rolling sector, and in Sivakasi's printing and fireworks industries function as the crucial tier-2 and tier-3 suppliers that large firms depend upon for just-in-time production (Mathew et al., 2016; Pillai & Banerjee, 2009). The vulnerability of this MSME layer was exposed with particular clarity during the COVID-19 lockdowns of 2020: without the working capital buffers and digitised supply chain systems of larger corporates, many MSMEs faced simultaneous demand collapse, supply disruption, and labour migration as workers returned to their villages, in many cases permanently (Bhattacharya & Bhattacharya, 2020; Kumar & Agarwal, 2021).

6. Where Are We Heading? Emerging Trajectories and Strategic Imperatives

6.1 The Energy Transition Horizon

India has committed to achieving net-zero emissions by 2070 and to obtaining 50 per cent of its electricity from non-fossil sources by 2030. These commitments, endorsed at COP26 and reflected in India's updated Nationally Determined Contribution (NDC), imply a massive acceleration of renewable deployment, from approximately 190 GW of non-hydro renewables installed in 2024 to 500 GW by 2030 (Ministry of Environment, Forest and Climate Change [MoEFCC], 2022). For Tamil Nadu, this trajectory opens significant opportunities: the state's coastal location enables offshore wind development, where MNRE has awarded exploration blocks in the Gulf of Mannar and Palk Strait; green hydrogen production using surplus renewable energy represents a potential new industry; and the integration of battery energy storage into the TANGEDCO grid could finally resolve the intermittency constraints that have limited deeper renewable penetration (Government of Tamil Nadu, 2023; IRENA, 2023).

However, the energy transition also poses formidable supply chain challenges. The manufacturing of solar panels, wind turbines, batteries, and electrolyzers requires minerals such as lithium, cobalt, nickel, and rare earths, whose global supply chains are geographically concentrated and geopolitically contested. India currently has negligible domestic production of most of these critical minerals, and its renewable energy supply chain is heavily dependent on Chinese-manufactured components, a vulnerability that the India-China border tensions since 2020 have made increasingly uncomfortable (Gielen, 2021; Gulati et al., 2022). The government's nascent critical minerals strategy, announced in 2023, represents a beginning rather than a solution to a challenge that will define the economics of India's energy transition for the coming two decades.

6.2 Trade Realignment: China+1 and India's Window

The global trend toward supply chain diversification away from China, often described as the China+1 or friend-shoring strategy, presents India with a potentially historic opportunity. Companies such as Apple (through Foxconn and Tata Electronics), Samsung, and Micron have either invested in or committed to major Indian production facilities, and Tamil Nadu has captured a significant share of this investment through its established electronics infrastructure. India signed a free trade agreement with the United Arab Emirates in 2022, finalised a trade deal with Australia, and advanced negotiations with the United Kingdom and the European Union, seeking to secure preferential market access for its expanding manufactured goods exports (Sinha & Sinha, 2022). The Production Linked Incentive scheme, extended to fourteen sectors including mobile phones, pharmaceuticals, textiles, food processing, and solar modules, disbursed approximately INR 55,000 crore in incentives by 2023–24 and claims to have generated incremental sales of over INR 10 lakh crore (Ministry of Finance, 2024).

6.3 Technology Disruption: Artificial Intelligence and Automation

Perhaps the most consequential, and least well understood, trajectory is the accelerating deployment of artificial intelligence, robotics, and digital platform technologies across supply chains. The widespread adoption of large language models in business process outsourcing, customer service, and software development threatens to hollow out segments of India's IT and BPO sector that have been the primary vehicle of middle-class employment creation over the past two decades (Accenture, 2023; WEF, 2023). Simultaneously, advanced robotics and cobots are reducing the labour cost advantage that makes Indian manufacturing competitive: an automotive welding robot that costs USD 30,000 in 2024 and operates continuously will, over a five-year horizon, undercut even the lowest Indian manufacturing wage rates for repetitive assembly tasks (Autor et al., 2022; NITI Aayog, 2022).

7. Hardships for the Middle Class, the Poor, and the Marginalised

7.1 The Squeezed Middle

India's middle class, estimated at 300 to 600 million individuals depending on the income threshold applied, with Tamil Nadu contributing approximately 25 to 30 million to this count, has been the principal beneficiary of the growth generated by IT services, automotive manufacturing, and export-led industries over the study period (Desai & Vanneman, 2015; Pew Research Center, 2021). Yet this class faces a mounting array of pressures that threaten to erode the gains of the past two decades. As illustrated in Figure 10, the divergence between average domestic electricity tariffs and real wage growth has widened appreciably since 2015, as tariff revisions, delayed for years by politically motivated subsidies to agricultural consumers, were eventually implemented in compressed form, creating sudden cost shocks for urban and semi-urban households. Combined with the broader inflationary pressures from essential commodities, wheat, rice, edible oil, and above all LPG and petrol, these energy costs have squeezed discretionary income for middle-income households whose nominal wage growth has consistently underperformed inflation in the post-pandemic period (CMIE, 2024; Krishnamurthy & Puri, 2022).

The technology disruption documented in Section 6.3 poses a deeper structural threat to the middle class. The information technology and business process management sectors have been the primary employers of college-educated youth from Tamil Nadu's urban and semi-urban towns, a pathway that lifted millions from lower-middle-class origins into a stable, aspirational lifestyle. As artificial intelligence automates the routine coding, data processing, and customer interaction tasks that form the bulk of entry-level IT employment, the wage premium for basic engineering and commerce graduates is likely to compress sharply.



Figure 10. Socioeconomic dimensions of the transition: (A) energy tariff vs real wages; (B) commodity price inflation; (C) automation risk by sector; (D) energy access disparities.
 Source: NSO; PPAC; ILO; NITI Aayog; author compilation.

NASSCOM estimated in 2023 that up to 25 per cent of existing IT roles could be substantially transformed by generative AI within five years, with roles in testing, basic coding, data entry, and tier-1 customer support most at risk (NASSCOM, 2023). The implications for Tamil Nadu, where the Chennai IT sector employs over 500,000 workers with a disproportionately high share from first-generation professionals, are profound.

7.2 Energy Poverty and the Rural Poor

Despite the remarkable progress achieved under Saubhagya, which connected approximately 26 million households to the grid between 2017 and 2019, electricity access statistics obscure the quality and reliability of supply experienced by poor rural households (Balachandran et al., 2021; GoI, 2018). A household in rural Bihar or Odisha that receives two to four hours of grid supply per day with frequent outages is counted as electrified in official statistics but cannot run a refrigerator, a productive enterprise, or an air cooler during the increasingly severe heat waves that climate change is bringing to the Gangetic Plain. Figure 10, panel D, illustrates the significant gaps that persist in both electricity reliability and clean cooking fuel access across India's lower-income states, with Tamil Nadu, at over 99 per cent household electrification, standing in sharp contrast to Jharkhand or Madhya Pradesh. These

gaps are not merely inconveniences; they represent structural constraints on human capability development, productivity, and health, particularly for women who bear the disproportionate burden of indoor air pollution from biomass cooking (Greenstone & Hanna, 2014; Rao et al., 2019).

For Tamil Nadu's poor, energy vulnerability takes a different but equally pressing form. The state's agricultural sector, dependent on diesel-powered pumpsets and increasingly erratic monsoons, has seen input costs rise faster than farm-gate prices for most of the study period. The Cauvery water dispute with Karnataka has added water insecurity to the energy and market price insecurities facing the delta farmers of Thanjavur, Nagapattinam, and Thiruvavur. The promise of free electricity for agricultural consumers, a policy maintained by successive Tamil Nadu governments, has paradoxically contributed to groundwater depletion, TANGEDCO's financial distress, and the perpetuation of a production structure ill-suited to the water-scarce conditions that climate projections indicate for the coming decades (Bassi et al., 2023; Pattnaik & Lahiri-Dutt, 2020).

7.3 Marginalised Communities: Dalits, Women Workers, and Informal Labour

The gains from Tamil Nadu's and India's energy-trade-technology transition have been distributed along lines that closely track pre-existing social hierarchies. Dalit communities, which constitute approximately 20 per cent of Tamil Nadu's population and a similar proportion nationally, remain significantly underrepresented in the formal industrial employment and IT sectors that have driven economic growth, concentrated instead in agriculture, manual sanitation, brick kilns, and construction, sectors that are simultaneously among the most physically hazardous and the most vulnerable to automation and climate disruption (Harriss-White, 2003; Jodhka & Shah, 2010; Shah et al., 2006). The much-celebrated IT sector, while formally caste-blind in its recruitment, has in practice been shaped by access to quality engineering education that reproduces social stratification through the mechanism of preparatory coaching costs and social networks (Upadhyay & Vasavi, 2008).

Women workers in Tamil Nadu's garment and textile industries, concentrated in Tirupur, Erode, and Coimbatore, represent a distinct category of vulnerability. The Sumangali scheme, subsequently reformed but still influential in shaping labour practices in spinning mills, attracted young women from rural districts with promises of a lump sum payment at the end of a contract period, effectively constituting bonded labour conditions criticised extensively in international supply chain audits (Mezzadri, 2016; Ruwanpura & Wrigley, 2011). Even in the reformed post-Sumangali landscape, women garment workers face a persistent combination of low wages, inadequate social protection, and vulnerability to trade demand volatility that leaves them ill-equipped to absorb the cost shocks documented in Figure 10, panel B. The automation of fabric cutting, sewing, and packaging—gradually advancing with the deployment of robotic sewing systems and AI-driven quality control—threatens to displace precisely the workers who have the least capacity to reskill and transition into alternative employment (Barrie, 2020; ILO, 2019).

The informal economy, estimated to employ between 80 and 90 per cent of India's workforce and a somewhat lower but still dominant share in Tamil Nadu, presents perhaps the most intractable dimension of the socioeconomic challenge. Informal workers are, by definition, outside the formal supply chain structures that governments and corporations manage; they are simultaneously indispensable to those structures as sub-contracted piece-rate workers, home-based workers, and street vendors supplying the consumption needs of formal sector employees. The pandemic demonstrated with brutal clarity how thin the margin of survival is for this population: within weeks of the March 2020 lockdown, millions of migrant workers—including a significant Tamil Nadu contingent working in construction across

southern and western India—began walking home, having lost both income and temporary shelter simultaneously (Bhattacharya & Bhattacharya, 2020; Raha & Bhattacharya, 2021). The formal supply chain's recovery after 2021 was rapid; the recovery of the informal workers who sustained it was far slower and, for many, incomplete.

8. Conclusion: Navigating the Triple Transition

The twenty-five years from 2001 to 2025 have seen Tamil Nadu and India traverse a triple transition in energy, trade, and technology that has created economic dynamism and distributional tension in equal measure. The energy system has diversified substantially, with renewables now comprising a meaningful share of total generation; trade integration has deepened, with India establishing a credible if incomplete position in global manufacturing value chains; and technology, digital platforms, automation, and artificial intelligence are reshaping the production, logistics, and service functions that constitute the supply chain ecosystem. These transitions have generated aggregate gains in GDP, exports, employment, and human development indicators that are real and significant.

Yet the analysis in this paper reveals that aggregate progress obscures distributional divergences that threaten social cohesion and long-run economic sustainability. The middle class faces income stagnation relative to rising energy, housing, and education costs, compounded by an emerging threat to the IT employment base that has been its primary economic anchor. The rural poor, particularly in agrarian districts of Tamil Nadu and in India's lower-income states, continue to experience energy poverty in its full sense, unreliable, expensive, and polluting, while bearing a disproportionate share of the environmental costs of fossil-fuel dependent industrialisation. Marginalised communities face not merely inadequate participation in the gains of the transition but active displacement risks as automation targets precisely the low-skill, labour-intensive sectors in which they are concentrated.

The path forward requires three broad categories of intervention that must operate simultaneously rather than sequentially. Energy policy must be redesigned to ensure that the transition to renewables does not entrench energy access inequality: this means reforming electricity tariff structures to eliminate the regressive cross-subsidisation that finances agricultural free power through higher industrial tariffs, investing in decentralised and mini-grid solutions for last-mile rural access, and using green hydrogen and energy storage to ensure reliability as variable renewables expand. Trade and industrial policy must attend not only to aggregate export competitiveness but to the domestic supply chain depth that reduces import dependency and creates linkages to MSME suppliers and informal workers. And technology governance must proactively address the distributional consequences of artificial intelligence and automation through anticipatory retraining programmes, portable social protection for informal workers, and competitive policy frameworks that prevent the concentration of AI-driven productivity gains in the hands of a narrow corporate elite.

Tamil Nadu, with its combination of industrial depth, educational infrastructure, renewable energy leadership, and a civil society tradition of demanding accountable governance, is better positioned than most Indian states to navigate this transition successfully. Whether it does so in a manner that genuinely includes the middle class, the poor, and the marginalised will be the definitive test of its development achievement over the next quarter-century.

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