

Toward Equitable Urban Sustainability: A Mixed Methods Inquiry into Energy-Food-Industry Nexus in India's Emerging Cities

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Abstract

India's rapid urbanization, pivotal to its "Vision 2047" ambitions, places immense stress on the Energy-Food-Industry (EFI) nexus, particularly in emerging cities which are the engines of future economic growth. These cities face a critical challenge: fostering development without exacerbating inequity and environmental degradation. This study investigates the interdependencies and trade-offs within the EFI nexus in three emerging Indian cities: Pune (Maharashtra), Coimbatore (Tamil Nadu), and Jaipur (Rajasthan). Employ a sequential mixed-methods approach, this research first quantitatively assesses urban sustainability performance through a composite index (derived from 25 indicators across energy access, food security, and industrial productivity). Subsequently, it qualitatively explores governance and equity dimensions via 45 semi-structured interviews with policymakers, industry representatives, and community leaders. Quantitative results reveal a "nexus penalty"—cities optimizing one sector (e.g., industrial growth in Coimbatore) often do so at the expense of another (e.g., peri-urban food security). Pune demonstrates higher integration but struggles with energy equity in informal settlements. Qualitative analysis uncovers three dominant themes: 1) Siloed governance impedes synergistic policy, 2) Informal sector actors are central to nexus flows yet excluded from planning, and 3) Technological solutions are prioritized over equitable distribution. Synthesizing these findings, the paper proposes a novel, tiered policy roadmap for national, state, and Urban Local Body (ULB) levels, advocating for a "Just Nexus" framework. This framework is essential for aligning India's urban trajectory with the Sustainable Development Goals (SDGs) and achieving the inclusive development envisioned for 2047.

Keywords: Urban Sustainability, Energy-Food-Industry Nexus, Mixed-Methods, India, Emerging Cities, Equitable Development, SDGs, Vision 2047.

Introduction

By 2047, the centenary of its independence, India envisions itself as a developed nation. This vision, "Vision 2047," is inextricably linked to the trajectory of its urbanization. With over 40% of its population projected to live in cities by 2030, and a significant portion of this growth occurring in "emerging cities"—those with populations between 1 and 5 million—the management of urban systems is a national priority [1]. These cities are critical hubs for economic activity, yet they are epicenters of profound socio-ecological challenges, particularly concerning the interconnected systems of Energy, Food, and Industry (the EFI Nexus). The EFI nexus presents a complex web of interdependencies in the Indian urban context. Industrial growth (the 'I') demands reliable energy (the 'E'), while the cultivation, transport, and processing of food (the 'F') are energy intensive. Conversely, energy production can compete with food production for land and water resources. This nexus is not merely a technical challenge; it is fundamentally a governance and equity issue. The urban poor often bear the brunt of nexus failures, facing energy poverty, food insecurity, and the health impacts of polluting industries, all while being central contributors to these systems through informal labor [2].

Existing policy frameworks, such as the Smart Cities Mission, AMRUT, and the National Food Security Act, often address these sectors in isolation.

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This siloed approach leads to policy contradictions and inefficiencies, undermining progress toward the Sustainable Development Goals (SDGs), especially SDG 11 (Sustainable Cities and Communities), SDG 7 (Affordable and Clean Energy), and SDG 2 (Zero Hunger) [3].

This research addresses a critical gap by moving beyond sector-specific analyses to investigate the EFI nexus as an integrated, socio-ecological system in India's emerging cities. It poses two central research questions:

1. What are the quantitative performance and interdependencies within the Energy–Food–Industry nexus across selected emerging Indian cities?
2. How do governance structures and socio-economic equity considerations influence the functionality and sustainability of this nexus?

By employing a mixed-methods approach, this study aims to provide a holistic understanding of the nexus, culminating in a actionable policy roadmap. The findings are intended to guide policymakers at all levels toward fostering an urban development model that is not only sustainable but also equitable, a prerequisite for realizing the aspirations of Vision 2047.

Literature Review

The concept of the Water-Energy-Food (WEF) nexus has gained significant traction in global sustainability discourse since the Bonn 2011 Conference. It emphasizes the interconnectedness of these resource systems and advocates for integrated governance to manage trade-offs and synergies [4]. However, in the specific context of India's rapid industrialization and urban energy transitions, reframing this as an Energy–Food–Industry (EFI) nexus is more salient, as it directly centers the engine of urban economic growth and its dual role as a driver of and solution to sustainability challenges.

1. The Indian Urban EFI Nexus: Key Interlinkages

- **Energy for Food and Industry:** The industrial sector is the largest consumer of electricity in India. Irregular power supply forces industries to rely on expensive and polluting diesel generators, increasing their carbon footprint and operational costs [5]. The food system—from cold storage warehouses to micro-enterprises—is also heavily dependent on unreliable energy, leading to significant post-harvest losses.
- **Food for Energy and Industry:** The controversial use of agricultural land and water for biofuel production exemplifies the food-energy competition. Furthermore, the location of food markets and the affordability of nutritious food are critical for sustaining a healthy industrial workforce.
- **Industry for Energy and Food:** While a major polluter, industry is also a key player in the renewable energy transition through corporate procurement and rooftop solar installations. The food processing industry, a major subsector, sits at the direct intersection of all three nexus elements.

2. Indian Policy Landscape and Identified Gaps

Several national policies implicitly address nexus components but lack integrative force. The **Smart Cities Mission** focuses on technology-driven solutions but has been critiqued for its limited engagement with equity and the informal sector [6]. The **Industrial Corridor projects** (e.g., Delhi-Mumbai Industrial Corridor) prioritize industrial efficiency but often underplay their regional impact on water and food systems. The **National Food Security Act (NFSA)** focuses on distribution, with less emphasis on the energy inputs or urban spatial planning required for resilient food systems. The literature reveals a clear gap: while quantitative modeling of nexus flows is advancing [7], there is a paucity of research that integrates this quantitative assessment with a qualitative, governance-centric analysis, particularly with a focus on equity in the context of India's dynamic and diverse emerging cities. This study seeks to fill this gap by combining metrics-based city profiling with an in-depth inquiry into the institutional and social dimensions of the EFI nexus.

Methodology

A sequential mixed-methods design was employed to provide a comprehensive analysis [8]. This involved a quantitative phase of data collection and analysis, followed by a qualitative phase designed to explain and elaborate on the quantitative findings.

1. Quantitative Phase: Composite Index Development and Analysis

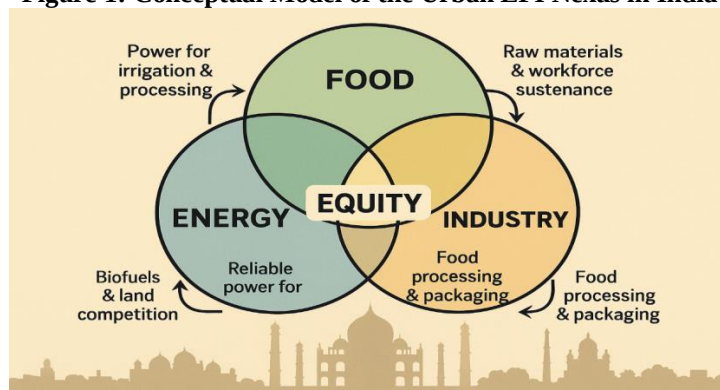
- **Case Selection:** Three cities were selected to represent diverse economic and geographical contexts:
 - **Pune, Maharashtra:** A major IT and manufacturing hub with rapid peri-urban transformation.
 - **Coimbatore, Tamil Nadu:** A traditional engineering and textile manufacturing center with active renewable energy adoption.
 - **Jaipur, Rajasthan:** A tourism and handicraft-based economy facing water scarcity and transitioning to solar power.
- **Data Collection:** Secondary data (2018-2023) was collected from municipal reports, state statistical abstracts, DISCOM reports, and Census data.
- **Indicator Framework:** A composite EFI Sustainability Index was constructed from 25 normalized indicators across three dimensions:

- **Energy:** Per capita electricity consumption, % renewable in mix, reliability of supply, access to LPG in slums, public transport coverage.
- **Food:** Percentage of population living in food deserts, market density, price volatility of staples, post-harvest losses, nutritional status of children.
- **Industry:** Industrial GDP contribution, MSME density, water consumption per industrial unit, compliance with green norms, formal/informal employment ratio.
- **Analysis:** Indicator scores were aggregated using a weighted sum approach to generate a comparative sustainability profile for each city.

2. Qualitative Phase: Stakeholder Interviews and Thematic Analysis

- **Participants:** 45 semi-structured interviews were conducted (15 per city) with a purposively selected sample: Municipal Commissioners, city planners, leaders of Industry Associations, small-scale food vendors, informal waste-pickers, and community representatives from low-income neighbourhoods.
- **Data Collection & Analysis:** Interviews, conducted in local languages and transcribed, focused on perceptions of nexus interlinkages, governance challenges, and experiences of equity. The data was analyzed using a reflexive thematic analysis approach [9] to identify recurring patterns and themes.

Figure 1: Conceptual Model of the Urban EFI Nexus in India



(A diagram showing three overlapping circles for Energy, Food, and Industry. In the center, the word "EQUITY" is highlighted. Arrows show bidirectional flows: "Power for irrigation & processing" from Energy to Food; "Biofuels & land competition" from Food to Energy; "Reliable power for production" from Energy to Industry; "Renewable tech & waste-for-energy" from Industry to Energy; "Raw materials & workforce sustenance" from Food to Industry; "Food processing & packaging" from Industry to Food. The diagram is set against a silhouette of an Indian city.)

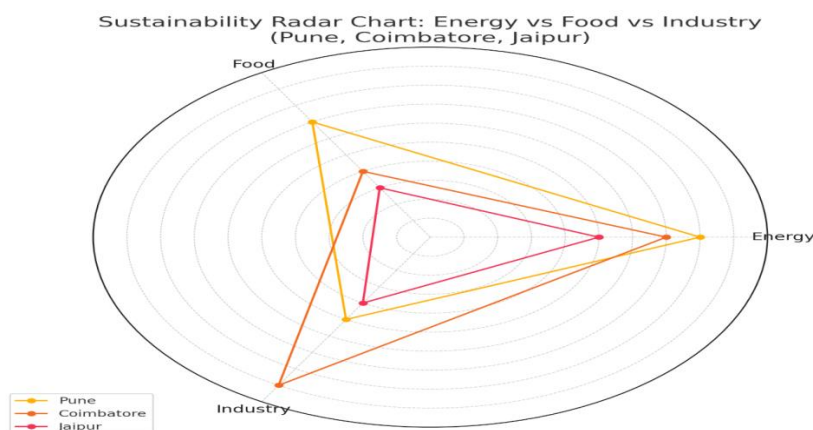
Results & Discussion

1. Quantitative Profiling: The Nexus Trade-offs

The composite EFI Sustainability Index scores were **Pune (0.68)**, **Coimbatore (0.61)**, **Jaipur (0.55)**. A deeper dive into the sub-dimensions reveals critical trade-offs.

Figure 2: Sustainability Score Comparison Chart (Radar Chart)

City	Energy	Food	Industry
Pune	8	6	8
Coimbatore	7	4	9
Jaipur	5	3	4



(A radar chart with three axes: Energy, Food, and Industry Sustainability. Three lines plot the scores for Pune, Coimbatore, and Jaipur. Pune's plot is the most balanced, though its Food score is lower than its Energy and Industry scores. Coimbatore's plot shows a very high Industry score but a low Food score. Jaipur's plot is the smallest and most uneven, with low scores across all three, especially Food.)

- **Coimbatore's "Industrial Efficiency" Paradox:** Coimbatore scored highest on industrial sustainability due to high productivity and growing renewable energy adoption. However, this came at the cost of the lowest food sustainability score. Interviews later revealed that industrial water extraction has depleted local aquifers, negatively impacting peri-urban agriculture.
- **Pune's "Integrated but Unequal" Profile:** Pune displayed the most balanced profile, a result of stronger city-level planning. However, disaggregated data showed a 35% gap in reliable energy access between formal settlements and informal bastis, a clear equity deficit.
- **Jaipur's "Resource Constrained" Status:** Jaipur scored lowest overall, reflecting its water-scarce context and less diversified industrial base. Its high industrial water consumption per unit output indicates inefficiency, which directly competes with both agricultural and domestic water needs.

2. Qualitative Insights: The Governance and Equity Chasm

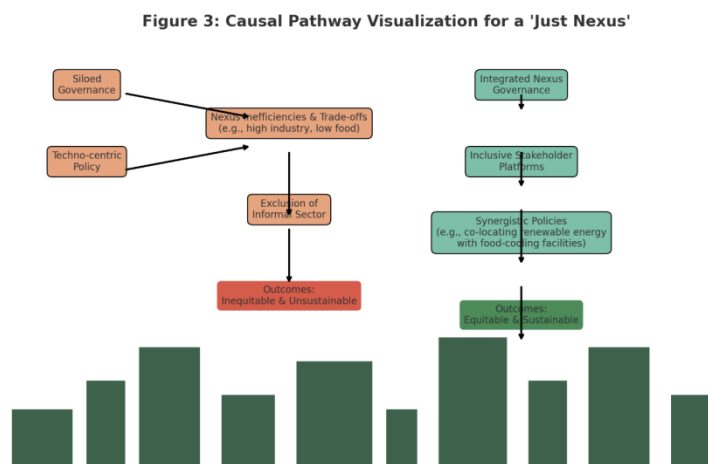
Thematic analysis of interview data provided context for the quantitative scores, highlighting three overarching themes:

- **Theme 1: Siloed Governance and Policy Incoherence.** A municipal official from Pune stated, "My mandate is solid waste management. I cannot dictate how the energy department procures power or how the town planning department zones industrial areas." This siloed mentality was universal. The "Smart City" SPV (Special Purpose Vehicle) in Jaipur was found to be operating in parallel to the traditional municipal corporation, creating confusion and duplication.
- **Theme 2: The Centrality and Invisibility of the Informal Sector.** The informal sector is the linchpin of the nexus. Informal waste-pickers are key to material and energy recovery; street vendors are crucial for urban food security. Yet, they are systematically excluded from formal planning. A street vendor leader in Coimbatore noted, "The city wants clean streets, so they push us out. But where will the factory workers get their affordable meals?"
- **Theme 3: Technological Fixation over Institutional Reform.** Policymakers overwhelmingly framed solutions in technological terms—smart grids, solar parks, AI-based logistics. While important, this focus often sidelined more complex institutional reforms related to land tenure, regulatory harmonization, and participatory governance, which are prerequisites for equitable outcomes.

3. Synthesis: Visualizing the Causal Pathway

The mixed-methods integration allows us to propose a causal pathway for achieving equitable outcomes.

Figure 3: Causal Pathway Visualization for a "Just Nexus"



(A flow diagram: "Siloed Governance" and "Techno-centric Policy" lead to "Nexus Inefficiencies & Trade-offs" (e.g., high industrial score, low food score).

This, combined with "Exclusion of Informal Sector," leads to "Outcomes: Inequitable & Unsustainable." The proposed solution pathway shows "Integrated Nexus Governance" and "Inclusive Stakeholder Platforms" leading to "Synergistic Policies" (e.g., co-locating renewable energy with food-cooling facilities), which finally lead to "Outcomes: Equitable & Sustainable.")

The findings demonstrate that the current urban development model, even in its more "sustainable" forms, is generating inequity. The pursuit of industrial growth and renewable energy, without integrated food system planning and explicit inclusion of the informal workforce, creates winners and losers.

Policy Roadmap

To steer India's emerging cities toward an equitable EFI nexus, a multi-tiered, actionable policy roadmap is proposed.

1. National and State Level

- **Mandate "Nexus Impact Assessments":** Integrate a compulsory EFI Nexus Impact Assessment into the environmental clearance process for all new industrial parks and large urban infrastructure projects.
- **Revise Urban Development Schemes:** Amend guidelines for schemes like the Smart Cities Mission 2.0 to require cities to submit integrated EFI management plans as a condition for funding.
- **Foster Data Ecosystems:** Create a national urban data portal with standardized, city-level EFI indicators to enable benchmarking and transparent monitoring.

2. Urban Local Body (ULB) Level

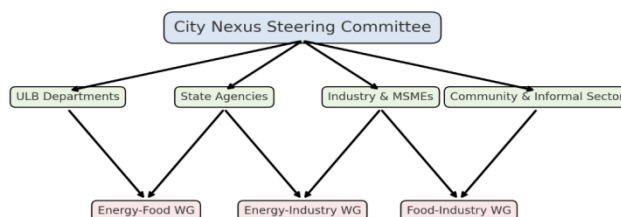
- **Establish an Inter-Departmental Nexus Cell:** Create a permanent cross-departmental committee within the ULB, with a mandate to identify and resolve policy conflicts between energy, food, and industry-related departments.
- **Develop Nexus-Zones:** Pilot designated "Nexus-Zones" where policies are co-located. For example, an industrial zone could be mandated to source a percentage of its energy from rooftop solar, with a portion of the power dedicated to running nearby cold-storage facilities for local farmers.
- **Formalize Informal Sector Linkages:** Integrate informal waste-pickers into solid waste management systems with fair compensation. Designate vending zones with essential services (water, energy) to secure urban food distribution.

3. Stakeholder Engagement

- **Create Multi-Stakeholder Platforms:** Institute regular forums that include ULB officials, industry representatives, formal and informal sector unions, and community-based organizations to co-design solutions.

Figure 4: Governance Integration Framework

Figure 4: Governance Integration Framework



(An organizational chart showing a "City Nexus Steering Committee" at the top, with representatives from "ULB Departments," "State Agencies," "Industry & MSMEs," and "Community & Informal Sector." Below it, arrows point to three collaborative working groups: "Energy-Food WG," "Energy-Industry WG," and "Food-Industry WG," each tasked with developing integrated projects.)

Conclusion

This research demonstrates that the path to urban sustainability in India's emerging cities lies not in optimizing sectors in isolation, but in consciously managing the interlinkages of the Energy–Food–Industry nexus through a lens of equity. The mixed methods approach unequivocally shows that the current "siloe" governance model is generating sub-optimal and unequal outcomes, creating a "nexus penalty" that undermines both well-being and economic resilience. The proposed "Just Nexus" framework and the accompanying policy roadmap provide a tangible starting point for systemic change. By moving from technological fixes to institutional integration and from the exclusion to the inclusion of the informal sector, Indian cities can unlock synergies that simultaneously advance economic productivity, environmental sustainability, and social justice. As India marches toward its Vision 2047, the ability of its emerging cities to navigate the complex EFI nexus equitably will be a defining metric of its success. This paper argues that a deliberate, integrated, and inclusive approach is not merely an option but an imperative for a sustainable and equitable urban future.



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