

Structural Pathways and Directional Spillovers: A Network Framework for SDG Prioritisation

Keywords: centrality, clustering, SDG indicator, synergy, trade-off

Extended Abstract

Motivation. The Sustainable Development Goals (SDGs) were conceived as an integrated development framework in which progress in one domain influences outcomes in others. Empirical research documents both reinforcing synergies and constraining trade-offs among SDG indicators. However, most quantitative studies rely on undirected contemporaneous correlations and goal-level aggregation, neglecting directionality, spillover magnitude, and the coexistence of positive and negative outward effects [3, 4].

This raises a central policy question: *How can policymakers identify interventions that generate strong positive downstream spillovers while explicitly accounting for directional asymmetry and embedded trade-offs?* This question is particularly important in resource-constrained settings, where prioritisation must maximise systemic impact while avoiding redundancy. We develop a direction-sensitive, indicator-level network framework to identify high-impact and structurally diversified entry points for SDG implementation in India.

Approach and Methodology. We construct a directed weighted SDG interlinkage network from country-specific time series using statistically significant lagged correlations between ordered pairs (X_{t-1}, Y_t) ($p < 0.05$). When both directions are significant, only the dominant relationship is retained. The network is defined as

$$G = (V, E, W),$$

where V denotes indicators and $W = \{w_{ij}\}$ spillover weights.

Indicators are classified by the balance of their outgoing effects:

$$S_{i-out}^+ = \frac{\sum_{j \neq i} \max(w_{ij}, 0)}{\sum_{j \neq i} |w_{ij}|}, \quad S_{i-out}^- = \frac{\sum_{j \neq i} |\min(w_{ij}, 0)|}{\sum_{j \neq i} |w_{ij}|}.$$

Indicators with $S_{i-out}^+ \geq 0.5$ are synergy-dominated.

Systemic influence is measured using Opsahl weighted out-centrality [1],

$$C_{i-out} = \sqrt{k_{i-out} S_{i-out}},$$

which balances the breadth and intensity of positive spillovers. To reduce redundancy, we construct a strong positive network retaining $w_{ij} \geq 0.9$ and apply flow-based clustering [2] to identify coherent propagation pathways. The indicator dominated by synergy with the highest-centrality of each cluster is selected to ensure diversified structural coverage.

Results. The Indian SDG network comprises 79 indicators connected through 2,643 significant lagged interlinkages, of which 56.4% are positive and 43.6% negative. Although reinforcing spillovers slightly dominate, trade-offs remain structurally embedded.

Using outward balance classification, 52 indicators are synergy-dominated and 27 trade-off-dominated. Health (SDG 3) and Innovation (SDG 9) contain the largest share of synergy-dominated indicators, while indicators under SDGs 12 and 13 are outward trade-off-dominated.

Ranking by weighted out-centrality identifies vaccination coverage, lower secondary completion, poverty headcount ratio, under-five mortality, sustainable nitrogen management, electricity access, and governance measures as the most influential positive spillover sources. However, clustering shows that top-ranked indicators are concentrated within a single socio-developmental subsystem, implying potential redundancy if selected simultaneously.

Cluster-based prioritisation yields a diversified portfolio spanning vaccination coverage (socio-developmental pathway), academic publication output (innovation–digital pathway), and the Statistical Performance Index (institutional pathway), alongside isolated synergy-dominated indicators. This strategy maximises structural coverage while reducing overlap in downstream effects.

Conclusions and Outlook. Three conclusions follow. First, SDG interlinkages in India are highly directional and structurally diverse, extending beyond goal boundaries. Second, trade-offs remain embedded even within a predominantly synergistic system, underscoring the need for coordinated policy design. Third, high-impact interventions are organised along structural pathways, making diversification across subsystems essential to avoid redundancy.

Methodologically, this study integrates outward balance classification, weighted centrality, and flow-based clustering into a unified prioritisation framework that is scalable to other national contexts. Future work will extend this framework using causal inference methods, dynamic simulations, and cross-country comparisons to further refine structurally informed SDG prioritisation.

References

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