The Rise of the Indian Sustainability Start up Ecosystem: Mapping\ Network Dynamics and SDG Focused Investment Patterns

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Sruthi Kannan
Bhaskar Bhowmick
C.S. Kumar
IIT Kharagpur & Ramaiah University of Applied Sciences
(sruthisresearch@gmail.com)
(bhaskar@see.iitkgp.ac.in)
(kumar@mech.iitkgp.ac.in)
Mehakdeep Singh
The Indus Entrepreneurs
(mehakshokar17@gmail.com)

Startup ecosystems are globally recognized as engines of economic growth, innovation, and social impact, positioning them to drive substantial progress toward Sustainable Development Goals (SDGs). Studies highlight the role of high-centrality hubs in facilitating the flow of knowledge, resources, and funding within these networks. This research presents a social network and funding trend analysis of Indian sustainability startups founded and funded over the past two decades. By examining funding patterns and centrality metrics, we provide insights into influential network structures to support targeted policy interventions and foster an SDG-aligned startup ecosystem.

Keywords: Sustainability, Startup, SNA, Funding, SDG

1. Introduction

Supported by increased digital adoption, favorable government policies, and expanding venture capital inflows, the Indian startup ecosystem has matured over the past decade (NASSCOM, 2021). These developments align with global trends, where startup ecosystems are seen as engines of economic growth, innovation, and social impact (Mason & Brown, 2014). The relevance of SDGs in the context of startups has become more pronounced in achieving sustainable development. Startups, with their focus on disruptive innovation, are well-positioned to drive significant progress toward SDGs, particularly in emerging markets like India (Kolk, 2016). However, limited research exists on fundamental dimensions such as socio network structure, SDG aligned startup funding. This study attempts to bridge this gap with our explorations of the structural dynamics and the distribution of SDG-related funding within the sustainability startup ecosystem.

2. Literature Survey

The evolution of startup ecosystems largely depends on the network structures, investment landscapes, and policy environments that support entrepreneurship (Stam & Spigel, 2016). Network analysis in entrepreneurship research focuses on identifying central players and assessing the influence of hubs within ecosystems (Acs et al., 2015). Studies have shown that high-centrality locations attract more funding and facilitate faster growth due to better access to resources and talent (Feld, 2020). Hubs like Bengaluru, with high degrees of network centrality, emerge as critical nodes, facilitating the flow of knowledge, resources, and funding (Bala Subrahmanya, 2017; Mitra et al., 2023). Funding flows, however, are not uniform and vary greatly over time as well as in SDG alignment. This funding disparity reflects investor preferences and underscores the need for a more balanced approach to SDG alignment in startup investments (Walker et al., 2019).

City-level frameworks and conditions significantly impact the development of entrepreneurial ecosystems. Cities with well-established infrastructure, supportive policy environments, and robust financial markets are more likely to foster successful startup ecosystems (Audretsch & Belitski, 2017). Entrepreneurial ecosystems are dynamic and influenced by continuous interactions between entrepreneurs, institutions, and resources, shaping the development and success of ventures (Spigel & Harrison, 2018). Adaptability, self-organization, and feedback loops are crucial for sustaining ecosystem growth, highlighting mechanisms that drive ecosystems to evolve and thrive (Roundy et al., 2018). Empirical studies are needed to understand specific mechanisms driving ecosystem development, helping tailor policies and interventions effectively (Alvedalen & Boschma, 2017).

Regional characteristics such as industrial diversity, knowledge spillovers, and social capital significantly influence entrepreneurial activity (Feldman & Kogler, 2010). Leadership, culture, and accessible markets are critical for fostering a thriving entrepreneurial environment, offering practical insights into building and sustaining ecosystems (Isenberg, 2011). Ecosystems co-create value through collaborative networks, enhancing innovation and competitive advantage, with cooperation and collective efforts driving success (Pitelis, 2012). Strong interpersonal networks and mentorship support entrepreneurial growth, with case studies providing empirical evidence of their contribution to ecosystem vitality (Motoyama & Knowlton, 2016).

Interdisciplinary approaches and longitudinal studies are needed to capture the complexity of ecosystems, with a comprehensive research program advancing the study of entrepreneurial ecosystems (Wurth, Stam, & Spigel, 2022). Digital

platforms and co-working spaces facilitate entrepreneurial activity by lowering entry barriers and fostering collaboration, highlighting their transformative potential in ecosystem development (Autio et al., 2018). Education and research institutions play a critical role in nurturing entrepreneurial talent, with the interplay between human capital, knowledge, and new firm formation shaping regional entrepreneurial systems (Qian, Acs, & Stough, 2013). Context-specific strategies are necessary to address unique regional challenges, with tailored policies and interventions conceptualizing entrepreneurial ecosystems (Brown & Mason, 2017).

Current debates in entrepreneurial ecosystem research suggest future directions, with attention needed on policy interventions and the impact of global trends on local ecosystems (Cavallo, Ghezzi, & Balocco, 2019). Evolutionary dynamics of ecosystems, focusing on adaptation and change over time, highlight the importance of continuous learning and resilience (Mack & Mayer, 2016). Access to finance, supportive policies, and a collaborative culture are essential for ecosystem development, providing practical insights into environmental factors influencing success (Suresh & Ramraj, 2012). The evolving landscape of ecosystem research identifies key themes and trends, providing a bibliometric analysis of entrepreneurial ecosystems (Tripathi, Ojala, & Salo, 2019).

Regions with strong social safety nets and support systems experience higher levels of entrepreneurial activity, highlighting the positive impact of social protection on entrepreneurship (Vedula & Kim, 2019). Clustering has a positive impact on innovation and firm performance, providing theoretical perspectives and empirical evidence on the role of clusters in entrepreneurship (Rocha & Sternberg, 2005). Clusters enhance knowledge sharing, resource access, and collaborative innovation, contributing to ecosystem vitality through practical mechanisms supporting entrepreneurial activity (Li & Geng, 2012). National systems of entrepreneurship, emphasizing institutions, policies, and culture, influence entrepreneurial activity, providing a comprehensive overview of factors shaping entrepreneurship at the national level (Acs, Audretsch, Lehmann, & Licht, 2017). By probing the patterns of funding and mapping the network structures of the Indian sustainability startup ecosystem, we aim to accelerate policymaking to bridge gaps that can be addressed through the sustainable startup ecosystem.

3. Methodology

This study explores the Indian sustainability startup ecosystem by leveraging a dataset of 13750 entries from Tracxn on funding rounds of startups founded between 2000 to 2020, detailing startup and investor locations, funding levels, and SDG themes. Our study applied social network analysis tool NetworkX for calculating centrality measures like PageRank and betweenness centrality, alongside SciPy for trend analysis. Data preparation involved cleaning and standardizing information, particularly addressing missing values in categorical fields and ensuring consistent formats in funding data. Visualizations crafted with Matplotlib and Seaborn illustrated network structures, revealing primary hubs, while SDG mapping identified high-impact and underserved areas. Through these analyses, key nodes and growth trends emerged, with insights into how different hubs contribute to SDG-oriented outcomes. Our findings offer a foundation for strategic decision-making, pointing to areas of robust investment potential and highlighting gaps for further development across the sustainability ecosystem.

3.1 Data Preprocessing

The preprocessing phase was crucial for preparing the data for analysis. Missing values in categorical fields (e.g., SDG themes and investor locations) were imputed using mode imputation, filling gaps with the most frequent category. For numerical fields like funding amounts, missing data were imputed with the mean or median, depending on the data distribution. Additionally, formatting inconsistencies in funding amounts were standardized to a consistent currency and scale, ensuring comparability across the dataset. The cleaned data was then transformed to facilitate further analysis, ensuring that categorical variables were properly encoded and numerical variables normalized.

3.2 Social Network Analysis

Social network analysis (SNA) was employed to explore the relationships between startups, investors, and SDGs. This analysis was performed using NetworkX, a Python library designed for the creation, analysis, and visualization of network structures. We calculated key centrality measures including PageRank and betweenness centrality, to assess the importance of nodes (startups and investors) in the network. PageRank assigns a score to each node based on its connectedness within the network. The PageRank PR of a node ii is given by

$$PR(i) = (1-\alpha) + \alpha \sum_{j \in M(i)} \frac{PR(j)}{L(j)}$$

Where

- α is the damping factor (set to 0.85),
- M(i) is the set of nodes linking to node i,
- L(j) is the number of links from node j.
- Betweenness centrality measures how often a node appears on the shortest path between other nodes in the network. The betweenness centrality CC_B of a node v is defined as

$$C_B(v) = \sum_{S \neq v \neq t} \frac{\sigma(s,t|v)}{\sigma(s,t)}$$

Where

- σ(s,t) is the total number of shortest paths between nodes s and t,
- σ(s,t|v) is the number of shortest paths between s and t that pass through node v.

These centrality measures help identify the hubs in the ecosystem, i.e., key players (startups and investors) that are central to the flow of funding and innovation.

3.3 Trend Analysis and SDG Mapping

To assess trends in funding and startup growth, SciPy was used to perform statistical trend analysis. We utilized regression models to study the relationship between funding amounts and time, as well as to analyse the alignment of different SDGs with investment trends. Linear regression was used to model the relationship between funding amounts and time:

$$\gamma = \beta_0 + \beta_1 x + \epsilon$$

Where:

- γ is the funding amount,
- x is time,
- β_0 is the intercept,
- β_1 is the slope (representing the rate of change),
- ϵ is the error term.

Additionally, SDG mapping was used to categorize startups by their focus on specific SDGs. This mapping allowed us to analyze which SDGs have received the most investment and which have been underserved. By combining this with geographic and funding information, we identified areas with the highest potential for impact, as well as regions or sectors that may need more attention in terms of investment.

3.4 Visualization

To communicate the results effectively, data visualizations were created using Matplotlib and Seaborn. These visualizations illustrated the network structure, showing the relationships between startups, investors, and SDGs. Network graphs revealed the central nodes and hubs, while scatter plots and bar charts were used to depict funding trends over time and across different SDGs. These visualizations helped highlight patterns such as funding concentration in specific regions or industries, as well as emerging trends in sustainable development.

4. Finding and Analysis

The Indian sustainability startup ecosystem saw consistent and significant growth before 2020, peaking at around 80 startups with a total funding of approximately 100 billion USD, indicating high investor confidence and a thriving market. However, post-2020, there was a marked decline in both the number of startups and overall funding, signaling a shift toward maturation and market stabilization. This transition suggests a movement from an aggressive growth phase to a more cautious investment landscape, where investors increasingly prioritize sustainability and viability over rapid expansion. Our study examined the alignment of startups with singular as well as multi-faceted focus areas of SDGs. No Poverty and Sustainable Cities and Communities attracted the highest funding of close to 200B USD and demonstrated the strongest network influence. Most other SDGs fell below 50B USD funding level, indicating opportunities for growth through ecosystem support and investment initiatives

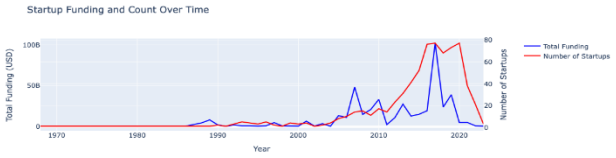

Figure 1 *Temporal Depiction of Funding of Sustainability Startups*

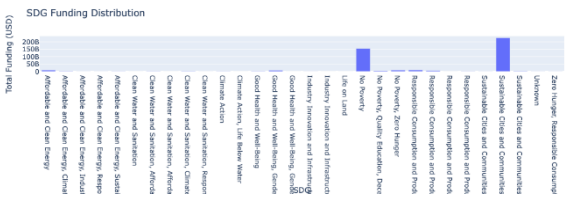

Figure 2 *Funding Distribution of Sustainability Startups*

In the social network analysis approach, degree centrality, betweenness centrality, closeness centrality, and PageRank centrality, offer unique insights into the structure and dynamics of a network, providing valuable understanding of influence,

reach and connectivity. Degree centrality is a measure of direct connections, while betweenness centrality provides the frequency of appearance on the shortest path, influencing how quickly or broadly information and innovation spread. Closeness centrality measures the average shortest path from a node to all other nodes in the network, and those with higher values have a strategic advantage in reachability of the ecosystem. PageRank assigns higher importance to nodes that are connected to other highly influential nodes, and entities with high PageRank are generally well- regarded or reputable within their community due to their connections with other important nodes.

Figure 3. *Social Network Analysis – Spread of Centrality Measures*

Bengaluru has emerged as the primary hub in the Indian sustainability startup ecosystem, with the highest PageRank (~0.15) and betweenness centrality (~0.55), indicating a central role in the network with approximately 200 connections and $1billion in funding. Secondary hubs, Delhi and Mumbai, exhibit moderate centrality (~0.25) and strong network influence, each accounting for around 100 connections and approximately $5 billion in funding. Meanwhile, emerging hubs like Gurgaon and Hyderabad demonstrate promising growth, though they currently have significantly lower network strength and centrality metrics, suggesting potential for future development within the ecosystem.

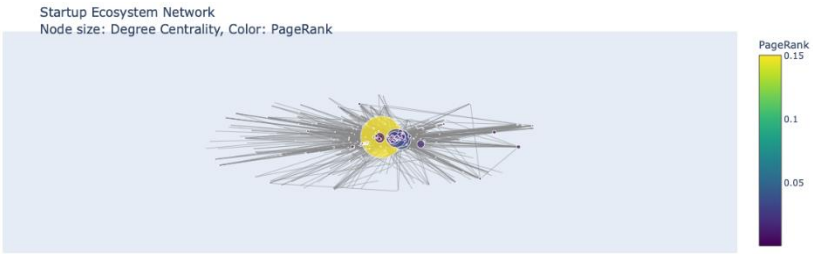

Figure 4. *Sustainability Startup Ecosystem: Node Size – Centrality, Colour – PageRank*

Our study also observed that the top investment corridors include Bengaluru-Stockholm and Bengaluru-Seoul, indicating a robust international network, especially within Asia and Europe, which warrants further research in this direction.

5. Conclusion

The Indian sustainability startup ecosystem is characterized by a growing network predominantly centered in Bengaluru, which plays a pivotal role in directing funding flows. This ecosystem demonstrates a strong alignment with high-impact SDGs, though there remains potential for growth through targeted support from government and private sectors by diversifying funding sources to promote innovation in underserved areas. The post-2020 funding decline highlights the market's sensitivity to economic shifts, emphasizing the necessity for adaptive strategies among startups. Policymakers should focus on creating resilient frameworks that equip startups with the tools to ensure sustainable growth of sustainability startups.

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