

Diagnosing Manufacturing Innovation Ecosystems: Profiles of Actors and Processes*

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Abstract

Manufacturing ecosystems are increasingly recognized as critical frameworks for understanding how diverse actors contribute to industrial innovation. While existing studies often emphasize structural mapping and actor typologies, less attention has been paid to functional contributions across different stages of the innovation process. This paper addresses this gap by applying a quantified Actor × Function Matrix to assess the roles of six institutional types (manufacturing SMEs, lead firms, industrial clusters, universities, incubators, and technology transfer offices) across five innovation functions: applied R&D, process innovation, manufacturing scale-up, technology deployment, and industrial demand. Two complementary perspectives are presented. The institutional analysis develops extended actor profiles that evaluate functionality, versatility, and systemic role, while the functional analysis aggregates contributions to reveal strengths, weaknesses, and systemic risks. The results indicate strong reliance on lead firms, concentration of R&D in academic and intermediary institutions, weak involvement of SMEs in upstream innovation, and insufficient articulation of industrial demand. These findings highlight structural asymmetries that limit the resilience and inclusiveness of manufacturing ecosystems.

Keywords: manufacturing innovation ecosystem, innovation ecosystems actors, Actor–Function Matrix.

Introduction

Production systems are under increasing pressure to continuously innovate, combining advanced technologies, scalable processes, and market needs. In this context, innovation ecosystems, comprising networks of companies, universities, and business support organizations, are essential for coordinating production, dissemination, and knowledge utilization (Baldwin et al., 2024). While much of the ecosystem literature attends to structural mapping, identifying who the actors are and how they interconnect (Ates et al., 2023; Dedehayir et al., 2018; Granstrand and Holgersson, 2020; Gu et al., 2021), less attention is paid to how these actors functionally contribute across stages of innovation, especially in manufacturing settings.

A number of recent studies point to emergent gaps in ecosystem research. Some researchers stress that the literature remains fragmented in how it conceptualizes actors' activities and their interplay. Others similarly argue that analytical structures must better capture dynamic contributions of actors over time (Coletto et al., 2024). In manufacturing ecosystems, such functional distinctions are even more critical yet under-explored. This gap is problematic, value lies not only in invention but in the alignment of upstream research with downstream deployment and market demand (Dai et al., 2024; Zhou et al., 2024). Without a clear understanding of each actor's functional role, ecosystems may develop imbalances or bottlenecks that reduce industrial competitiveness.

To address these limitations, this paper applies a quantified framework to analyze manufacturing innovation ecosystems. The analysis operationalizes the previously developed Actor \times Value Contribution Matrix (Helman, 2025), converting qualitative categories of contribution into a numerical scale. The framework is applied in two complementary ways. First, extended actor profiles are developed for six institutional types (SMEs, lead firms, clusters, universities, incubators, TTOs) in order to assess their functionality, versatility, and systemic role. Second, a functional analysis at the ecosystem level aggregates actor contributions across five core innovation processes: Applied R&D, Process Innovation, Manufacturing Scale-Up, Technology Deployment, And Industrial Demand. Through this dual lens, the study identifies both institutional strengths and systemic imbalances within manufacturing ecosystems.

Research Methodology

The analysis builds on the “*Manufacturing Innovation Ecosystem Actor \times Value Contribution Matrix*” which was developed in a previous study and published in (Helman, 2025). In the present research, the original qualitative categories of actor contributions were transformed into a quantitative scale to enable systematic comparison across actors and functions. Specifically, contributions coded as *Low* were assigned a value of 1, *Moderate* a value of 2, and *High* a value of 3. This modification allowed the matrix to be used not only for descriptive mapping but also for aggregated analysis, calculation of averages, and the identification of systemic risks within the manufacturing innovation ecosystem. The resulting Quantified Manufacturing Innovation Ecosystem Actor \times Function Matrix is presented in table below.

Tab. 1 Quantified Manufacturing Innovation Ecosystem Actor \times Function Matrix

Ecosystem Actor Type	Applied R&D	Process Innovation	Manufacturing Scale-up	Technology Deployment	Industrial Demand
Manufacturing SMEs	1	2	3	2	3
Lead Manufacturing Firms	2	3	3	3	3
Industrial Clusters / Hubs	2	2	2	2	2
Universities / Research Institutes	3	2	1	1	1
Incubators	1	1	2	3	1
Tech Transfer Offices	3	3	2	2	1

The modified matrix was applied in two complementary ways:

1. First, it served as the basis for the *extended actor profiles*, which assessed the functionality, versatility, and systemic role of each institution within the manufacturing innovation ecosystem. To visualize these profiles, radar charts were developed to illustrate the distribution of each actor contributions across the five innovation functions.
2. Second, the matrix was used for an *extended functional analysis* at the ecosystem level. In this stage, actor contributions were aggregated to assess the relative strength of applied R&D, Process Innovation, Manufacturing Scale-Up, Technology Deployment, and Industrial Demand. Each function was examined in terms of contributors, the systemic risks arising from concentration or imbalance, and the implications for manufacturing transformation.

These two applications of the matrix together provided a structured approach to identifying weaknesses and inequalities in the ecosystem. The actor-oriented analysis captured roles and complementarities, while the function-oriented analysis revealed how innovation processes are distributed and where bottlenecks may constrain industrial competitiveness.

Results

The results are presented in two complementary parts. The first part focuses on the institutional perspective by developing extended profiles of key actors in the manufacturing innovation ecosystem. This analysis combines radar chart visualizations with descriptive assessments to examine the functionality, versatility, and systemic roles of different stakeholders. The second part focuses on the functional perspective, analyzing the combined

contribution of all actors in five innovation processes. This dual approach makes it possible to identify both the strengths of individual actors and the systemic risks that emerge from imbalances between functions, thereby providing insights into the overall performance of manufacturing innovation systems.

Extended actors profile analysis – the institutions perspective

This chapter provides a comparative profile of key actors within the manufacturing innovation ecosystem, highlighting their functional strengths, versatility, and roles. By combining radar chart visualizations with analytical descriptions, the section illustrates how different stakeholder groups contribute to distinct stages of industrial innovation and shape the dynamics of ecosystem performance.

Manufacturing SMEs

- **Functionality:** SMEs show their strongest performance in *Manufacturing Scale-up* and *Industrial Demand*, reflecting their position as end users who implement external solutions and define operational requirements for production. Their contribution to *Applied R&D* remains low, forced by limited resources, weak uptake capacity, and poor collaboration with research institutions. While SMEs engage in *Process Innovation* and *Technology Deployment*, their impact is low compared to lead firms.
- **Versatility:** With an average score of 2.2, SMEs are characterized by a moderately balanced but uneven profile. They are clearly stronger in downstream and demand-driven functions than in upstream or translational activities. This asymmetry highlights their dependence on other ecosystem actors for innovation inputs.
- **Ecosystem role:** SMEs operate as *demand articulators and industrial adopters*, embedding new technologies into everyday production and validating their applicability in real conditions. They play a key role in disseminating and scaling innovation in supply chains, but their weak market position limits their ability to stimulate industrial upgrading on their own.

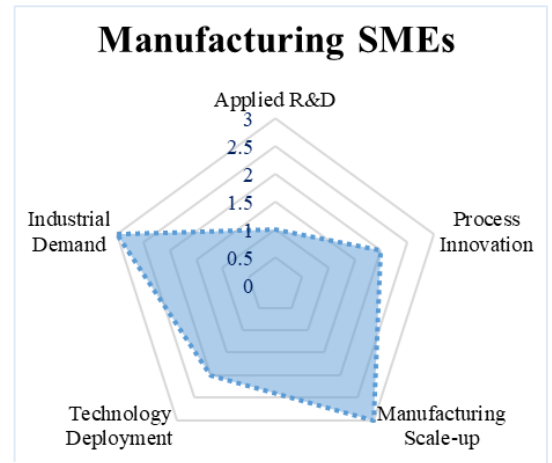


Fig. 1 Manufacturing SMEs profile

Lead Manufacturing Firms

- **Functionality:** Lead firms are consistently strong across all functions, particularly in *Process Innovation*, *Scale-up*, *Technology Deployment*, and *Demand*, owing to their advanced production capabilities, supply chain authority, and capacity for capital-intensive investments. Their role in *Applied R&D* is more moderate, as they often absorb and integrate external knowledge rather than generate it exclusively in-house.
- **Versatility:** With the highest average score (2.8), lead firms are the most versatile and robust actor in the ecosystem. They maintain strong involvement across both upstream and downstream innovation processes, positioning them as multi-functional anchors.
- **Ecosystem Role:** Lead firms serve as *industrial anchors and system integrators*. They set process and product standards, coordinate supplier upgrading, and create demand for new technologies through their production networks. By piloting large-scale deployments, they accelerate industrial transformation. However, their dominance also risks reinforcing dependency, potentially marginalizing smaller firms and reducing ecosystem diversity.

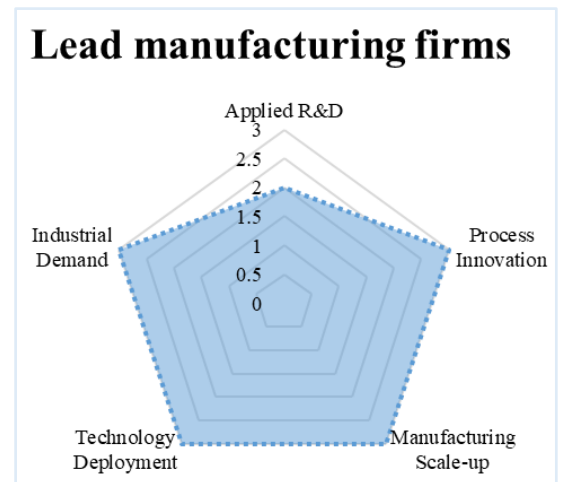


Fig. 2 Lead manufacturing firms profile

Industrial clusters / Hubs

- **Functionality:** Clusters demonstrate uniform, medium-level contributions across all innovation functions. They neither dominate nor underperform in any domain, underscoring their role as collective rather than individual performers. Their core strength lies in enabling shared infrastructure, resource pooling, and coordination of collaborative initiatives.
- **Versatility:** With an average score of 2.0, clusters are the most balanced actors in the system. Their lack of specialization means they do not dominate in innovation outcomes, yet their even contribution profile allows them to maintain relevance in multiple domains simultaneously.
- **Ecosystem Role:** Clusters act as *coordination platforms for manufacturing systems*, facilitating technology diffusion across SMEs, enabling process improvements through joint projects, and supporting supply chain integration. Their systemic importance lies in reducing fragmentation and transaction costs within industrial ecosystems. However, without targeted policy support or enhanced governance, their contribution risks remaining underutilized.

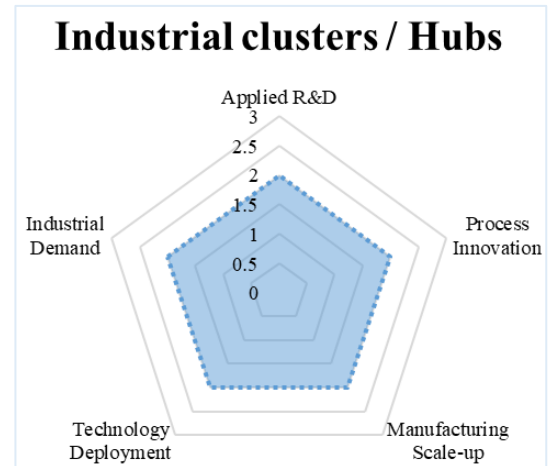


Fig. 3 Industrial clusters / Hubs profile

Universities / Research Institutes

- **Functionality:** Universities score highest in *Applied R&D*, providing fundamental and applied research outputs. However, their engagement in *Scale-up*, *Deployment*, and *Demand articulation* is limited, reflecting the persistent disconnect between academic research and industrial implementation.
- **Versatility:** Their average score (1.6) reveals a specialized and narrow profile. Universities focus primarily on upstream research while struggling to translate knowledge into applied contexts. Their limited engagement in deployment and industrial collaboration highlights systemic barriers in valorization.
- **Ecosystem Role:** Universities act as *sources of scientific and technical knowledge relevant to advanced manufacturing*. They generate prototypes and proof-of-concepts but struggle to connect with industrial production needs. Their weak involvement in deployment and demand articulation underscores a persistent translation gap between research and manufacturing practice.

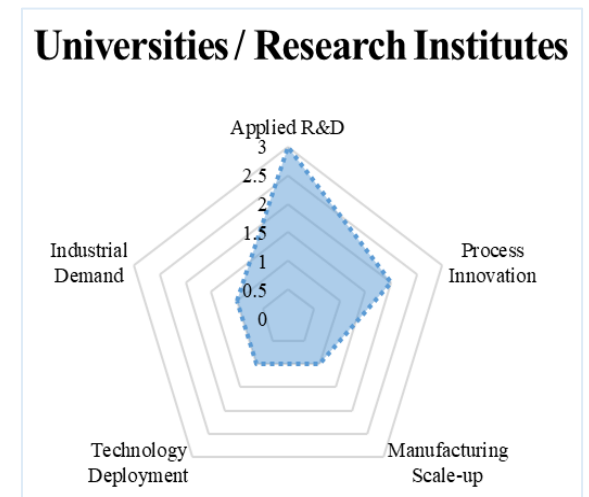


Fig. 4 Universities / Research Institutes profile

Incubators

- **Functionality:** Incubators contribute most strongly to *Technology Deployment*, providing environments for early-stage ventures to validate and adopt technologies. They also support *Scale-up*, though their involvement in *R&D*, *Process Innovation*, and *Demand articulation* is minimal. Their functional profile reflects a strong orientation towards early-stage commercialization.
- **Versatility:** With an average score of 1.6, incubators are highly specialized actors. Their contributions are concentrated in a narrow domain, leaving large parts of the innovation process outside their scope.
- **Ecosystem Role:** Incubators are *deployment enablers in early-stage industrial ventures*. They help validate technologies in pilot production environments and prepare startups for integration into manufacturing supply chains. While they accelerate technology adoption at the micro-level, their systemic influence remains limited without stronger industrial linkages.

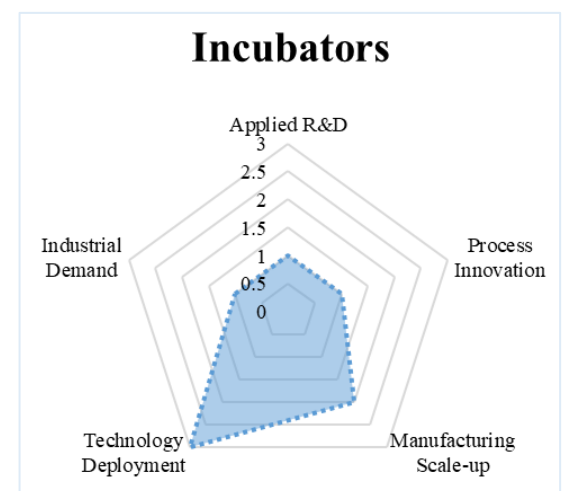


Fig. 5 Incubators profile

Tech Transfer Offices

- **Functionality:** TTOs perform strongest in *Applied R&D* and *Process Innovation*, supporting the translation of academic research into industrially relevant solutions. They contribute moderately to *Scale-up* and *Deployment*, but their role in *Demand articulation* remains weak, as they rarely engage directly with production environments.
- **Versatility:** With an average score of 2.2, TTOs demonstrate a relatively balanced profile. They combine upstream strength with moderate downstream involvement, positioning them as hybrid actors that span different stages of the innovation process.
- **Ecosystem Role:** TTOs act as *translators of research into industrial application*, bridging academic outputs with industrial practice. They facilitate the commercialization of manufacturing technologies, manage IP, and create linkages for industrial pilots. Their effectiveness in accelerating industrial upgrading depends on their integration with SMEs, clusters, and lead firms. Their contribution is crucial in reducing knowledge-transfer barriers, but their effectiveness depends on integration with firms and clusters that can carry innovations into large-scale production.

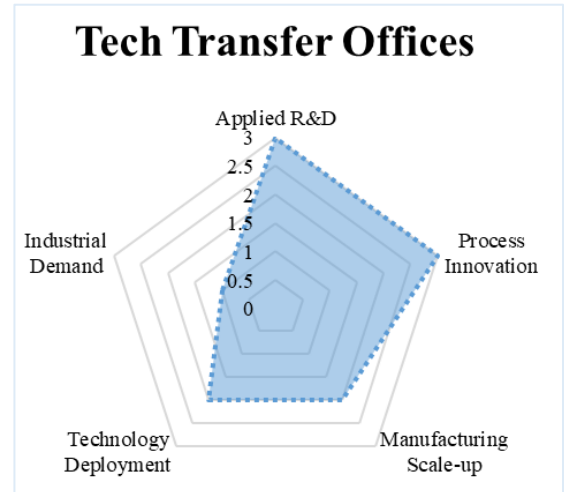


Fig. 6 Tech Transfer Offices profile

Extended functional analysis – the processes perspective

This section analyzes the manufacturing innovation ecosystem through five core processes: *Applied R&D*, *Process Innovation*, *Manufacturing Scale-Up*, *Technology Deployment*, and *Industrial Demand*. For each function, the analysis identifies strong, moderate, and weak contributors, highlights systemic risks arising from imbalances in actor engagement, and outlines the implications for industrial transformation. The functional perspective was used to reveal how uneven distribution of contributions across functions creates bottlenecks that shape the ecosystem's ability to generate, scale, and disseminate innovation in line with manufacturing competitiveness.

Applied R&D (average = 2.0)

Strong contributors: Universities and Technology Transfer Offices represent the most prominent actors, acting as principal providers of applied research and knowledge inputs.

Weak contributors: Manufacturing SMEs and incubators show consistently low engagement, reflecting structural barriers to in-house research capacity, limited access to R&D infrastructure, and a reliance on external knowledge.

Risk: The concentration of applied R&D capacity in academic and intermediary organizations creates an *asymmetry of innovation origins*, with limited industry-driven research. This risks reinforcing a “linear” innovation model, where knowledge flows one-way from academia to industry without sufficient feedback from production environments.

Implication for manufacturing: The competitiveness of manufacturing depends largely on joint applied research that is tailored to manufacturing challenges such as digital transformation, automation, green manufacturing, and advanced materials. Weak industrial involvement in R&D reduces the probability that new knowledge will meet manufacturing standards (scalability, robustness, cost-efficiency). Without mechanisms for joint industry–science R&D, the ecosystem risks producing outputs that remain at the laboratory stage, detached from industrial implementation and scaling.

Process Innovation (average = 2.17)

Strong contributors: Lead manufacturing firms and TTOs, both of which play central roles in upgrading industrial processes, standard-setting, and the diffusion of new manufacturing practices.

Moderate contributors: SMEs, clusters, and universities provide relevant but more incremental contributions.

Weak contributors: Incubators remain marginal in altering or improving established industrial processes.

Risk: The heavy reliance on lead firms for process innovation creates systemic dependency. If their innovation approach prioritizes global competitiveness over the modernization of local suppliers, smaller firms may be excluded from process.

Implication for manufacturing: Sustained competitiveness in manufacturing requires extensive modernization of processes throughout the supply chain. This includes digitalization, robotics integration, and sustainable production practices. If SMEs continue to lag behind in terms of transformation process, industrial ecosystems risk becoming dualistic, where large firms advance technologically while smaller firms stagnate, undermining systemic resilience.

Manufacturing Scale-up (average = 2.17)

Strong contributors: Lead firms and SMEs, which collectively represent the backbone of scaling new technologies into production environments.

Moderate contributors: Clusters and TTOs provide infrastructural and organizational support for scaling, though they lack direct production capabilities.

Weak contributors: Universities play only a minor role, underscoring the disconnect between laboratory prototypes and industrial scalability.

Risk: Scale-up capacity depends on strong SME–lead firm integration. Weak supplier–buyer linkages, fragmented production networks, or lack of pilot-line infrastructure can prevent prototypes from reaching industrial maturity. This creates bottlenecks in the innovation pipeline, delaying market entry.

Implication for manufacturing: Scaling is crucial to ensuring that technological advances translate into products suitable for industrial application. Failure at this stage is a common source of the “*valley of death*” in manufacturing innovation. Robust pilot plants, demonstration factories, and collaborative scaling programs are essential to reduce time-to-market and enhance global manufacturing competitiveness.

Technology Deployment (average = 2.17)

Strong contributors: Lead firms, which deploy technologies at scale, and incubators, which provide platforms for early-stage deployment within startups and emerging ventures.

Moderate contributors: SMEs, clusters, and TTOs contribute, though their role is more complementary than driving.

Weak contributors: Universities remain marginal in this stage.

Risk: The ecosystem is highly dependent on two types of institutions: large lead firms and niche incubators. This risks leaving a deployment gap in SMEs and across broader industrial supply chains. Without widespread dissemination, new technologies may remain limited to pilot applications or become monopolized by large, established companies.

Implication for manufacturing: Technology deployment determines whether innovation reshapes production systems at scale. Effective deployment requires inclusive adoption mechanisms across SMEs and clusters. Without them, ecosystems risk uneven technological upgrading, reinforcing disparities between advanced and lagging manufacturing actors.

Industrial Demand (average = 1.83 – the weakest function)

Strong contributors: Lead firms and SMEs, which are the main entities expressing market needs and industrial requirements.

Moderate contributors: Clusters play a secondary role in representing collective industrial demand.

Weak contributors: Universities, incubators, and TTOs contribute minimally to demand articulation, reflecting their weak integration into market-oriented feedback loops.

Risk: Demand is expressed almost exclusively by business actors, with limited involvement from academia and intermediaries. This weakens the capacity of research and innovation agendas to respond to real production challenges. The lack of structured foresight, demand forecasting, and policy-driven market creation reduces the ability of ecosystems to align knowledge creation with pressing manufacturing needs.

Implication for manufacturing: The weakness of industrial demand is a systemic barrier. Without effective feedback from industry into research and innovation, manufacturing ecosystems risk misalignment, developing technologies that are not market-relevant or fail to meet industrial adoption conditions. Strengthening demand through public procurement, industrial foresight exercises, and co-creation of innovation agendas with manufacturers is essential to ensure that innovation processes take into account key areas of such as decarbonization, resilience, and digital integration.

Conclusions

This study applied a quantified Actor × Function Matrix to analyze the dynamics of manufacturing innovation ecosystems from both institutional and functional perspectives. By converting qualitative assessments into numerical values, the framework enabled systematic comparison of actor contributions and ecosystem functions. The extended actor profiles revealed asymmetries: lead manufacturing firms demonstrated the most versatile role, acting as system integrators nearly for all functions; SMEs emerged as critical adopters and demand articulators but remained weak in upstream activities; universities and research institutes contributed strongly to applied R&D yet were poorly integrated into scaling and deployment stages; incubators showed a narrow specialization in early-stage deployment; and technology transfer offices occupied an intermediate position, bridging upstream research with moderate downstream involvement.

The functional analysis further demonstrated that process innovation, scale-up, and deployment were moderately well supported, whereas applied R&D remained concentrated in academic and intermediary actors, and industrial demand was the weakest function overall. These findings highlight systemic risks, including over-reliance on lead firms, insufficient mechanisms for translating research outputs into industrial practice, and a persistent gap in articulating demand signals across the ecosystem. Such imbalances constrain the ability of manufacturing systems to align knowledge generation with industrial transformation priorities.

Overall, the study shows that applying a functional perspective provides a clearer diagnosis of ecosystem strengths and weaknesses. The findings underscore the need for governance and policy measures that reduce dependency on dominant firms, strengthen collaborative R&D between industry and academia, and enhance demand articulation mechanisms. Addressing these gaps is essential for building more resilient, inclusive, and competitive manufacturing innovation ecosystems.

References

- Ates, A., Paton, S., Sminia, H. and Smith, M. (2023), “Crafting strategic responses to ecosystem dynamics in manufacturing”, *Technological Forecasting and Social Change*, Vol. 194, p. 122727, doi: 10.1016/j.techfore.2023.122727.
- Baldwin, C.Y., Bogers, M.L.A.M., Kapoor, R. and West, J. (2024), “Focusing the ecosystem lens on innovation studies”, *Research Policy*, Vol. 53 No. 3, p. 104949, doi: 10.1016/j.respol.2023.104949.
- Coletto, C., Caliarì, L., Bernardes-de-Souza, D. and Callegaro-de-Menezes, D. (2024), “Dynamics of actors in innovation ecosystems’ analytical structures”, *Innovation & Management Review*, Vol. 21 No. 4, pp. 244–259, doi: 10.1108/INMR-11-2022-0150.
- Dai, G., Zhang, L., Zhang, Q. and Mao, M. (2024), “Navigating tensions between value creation and capture in ecosystems”, *Journal of Business Research*, Vol. 170, p. 114333, doi: 10.1016/j.jbusres.2023.114333.

- Dedehayir, O., Mäkinen, S.J. and Roland Ortt, J. (2018), “Roles during innovation ecosystem genesis: A literature review”, *Technological Forecasting and Social Change*, Vol. 136, pp. 18–29, doi: 10.1016/j.techfore.2016.11.028.
- Granstrand, O. and Holgersson, M. (2020), “Innovation ecosystems: A conceptual review and a new definition”, *Technovation*, Vol. 90–91, p. 102098, doi: 10.1016/j.technovation.2019.102098.
- Gu, Y., Hu, L., Zhang, H. and Hou, C. (2021), “Innovation Ecosystem Research: Emerging Trends and Future Research”, *Sustainability, Multidisciplinary Digital Publishing Institute*, Vol. 13 No. 20, p. 11458, doi: 10.3390/su132011458.
- Helman, J. (2025), “Mapping functional roles in manufacturing innovation ecosystems”, *Proceedings of the 45th International Business Information Management Association Computer Science Conference (IBIMA) : Strategies, Innovation, and Human-Centric Practices in the Modern Organizations, Cordoba, Spain, 25-26 June 2025 / Ed. Khalid S. Soliman. [King of Prussia, PA] : International Business Information Management Association, Cop. 2025.*, pp. 2034–2039.
- Zhou, Y., Yan, W., Ji, S., Zhang, J.Z. and Wang, Q. (2024), “Co-creating value in manufacturing supply chains: unravelling the dynamics of innovation ecosystems”, *Enterprise Information Systems, Taylor & Francis*, Vol. 18 No. 8, p. 2365195, doi: 10.1080/17517575.2024.2365195.