DOI: 10.1478/AAPP.104S1A4

AAPP | Atti della Accademia Peloritana dei Pericolanti
Classe di Scienze Fisiche, Matematiche e Naturali
ISSN 1825-1242

Vol. 104, No. S1, A4 (2026)

RESOURCE OPTIMIZATION AND WASTE MANAGEMENT OF FOSSO IMPERATORE INDUSTRIAL PARK: A MULTI-CRITERIA DECISION-MAKING APPROACH

CARLOTTA D'ALESSANDRO [a*], ANTONIO LICASTRO [b], ROBERTA ARBOLINO [b], GIUSEPPE IOPPOLO [a] AND GRAZIA CALABRÒ [a]

ABSTRACT. This paper presents a multi-criteria decision-making approach for evaluating resource optimization and waste management strategies at Fosso Imperatore Industrial Park (IP) in Southern Italy. Despite the recognized potential of Industrial Symbiosis (IS) for implementing Circular Economy (CE) principles in industrial settings, practical implementation faces barriers including economic constraints, information asymmetry, and regulatory challenges. Through application of the Analytic Hierarchy Process (AHP), this study evaluates four alternative strategies: enhanced external processing, internal material exchanges, centralized processing facility development, and a hybrid phased implementation. Data collected through direct engagement with 15 stakeholders, representing different interests within the industrial ecosystem, show that the main focus is on economic considerations, particularly operational costs, followed by environmental benefits, technical feasibility, and social acceptance factors, respectively. Internal Material Exchanges emerged as the preferred strategy, performing strongly on economic feasibility and social acceptance criteria. Incremental approaches building on existing capabilities and targeting "quick win" opportunities offer the most promising implementation pathway for initiating circular transitions. These findings can be seen as practical guidance for resource optimization in IPs. Implementation strategies should prioritize bilateral exchange opportunities with favorable economics and minimal technical barriers, supported by simple information-sharing mechanisms that can gradually evolve toward more sophisticated platforms.

1. Introduction

Industrial development contributes to environmental degradation through increased natural resource consumption and pollution. The effects of this environmental challenge become clear when considering historical CO_2 concentrations, which have significantly risen since pre-industrial levels (Ahmed *et al.* 2022). These environmental trends highlight the urgent need for approaches to sustainable development that address interrelated dimensions of environmental preservation, social equity, and economic viability.

The Circular Economy (CE) concept has emerged as a tangible approach to achieve sustainability goals by decoupling economic growth from resource consumption through

closed-loop systems. This framework has attracted increasing academic attention and corporate interest, with companies recognizing its potential value for both operations and stakeholders (Ellen MacArthur Foundation 2013). Within this context, Industrial Symbiosis (IS) represents a key operational approach for translating CE principles into practice by facilitating mutually beneficial exchanges of waste and by-products between different organizations (Lombardi and Laybourn 2012).

Industrial Parks (IPs) provide ideal settings for implementing IS and CE principles due to their geographic concentration of diverse industrial activities. IPs can be understood as urban subsystems with specific metabolic patterns of resource flows and waste generation (Ioppolo *et al.* 2014). As designated areas equipped with essential infrastructure for industrial operations, IPs serve as catalysts for economic growth while simultaneously creating both environmental challenges and sustainability opportunities (Barrera *et al.* 2021). The effectiveness of an IP's supply chain fundamentally depends on the successful implementation of IS networks, highlighting the critical connection between industrial organization and sustainable development practices (Zeng *et al.* 2017).

The predominance of linear economic models creates certain barriers to establishing circular approaches (Korhonen, Honkasalo, and Seppälä 2018). Common obstacles include information asymmetry between potential exchange partners, lack of trust, regulatory constraints, and economic considerations that prioritize short-term gains over long-term sustainability benefits (Barreiro-Gen and Lozano 2020). Additionally, technical expertise limitations and uneven resource distribution patterns may impede the development of viable symbiotic relationships (Zhang *et al.* 2015).

Addressing these challenges requires interventions across multiple dimensions. Information exchange mechanisms can help identify symbiotic opportunities, while specialized intermediaries could overcome regulatory barriers (Mirata and Emtairah 2005; Domenech and Davies 2011). Economic incentives, collaborative governance structures, and technical innovations offer additional pathways for enabling resource recovery and circular transitions (Chertow 2007). Selecting and prioritizing these interventions requires an evaluation framework that integrates diverse stakeholder perspectives and multiple assessment criteria similar to approaches used for evaluating urban metabolism through standardized indicators (D'Amico *et al.* 2020, 2021).

This paper presents a Multi-Criteria Decision Making (MCDM) approach using the Analytic Hierarchy Process (AHP) to evaluate resource optimization and waste management strategies for Fosso Imperatore IP. This builds on established approaches for territorial evaluation like the Territory Balanced Scorecard (Ioppolo, Saija, and Salomone 2012), adapting them specifically for IS contexts. The AHP methodology decomposes complex decision problems into hierarchical structures, facilitating pairwise comparisons between criteria and alternatives while maintaining consistency in evaluation (Saaty 1980).

The AHP has been used across socio-economic research domains. Applications span renewable energy selection (Ahmad and Tahar 2014; Y. Wang, Xu, and Solangi 2020), sustainable supply chain management (Luthra *et al.* 2017; Brandenburg *et al.* 2014), and sustainability assessment in industrial contexts (Singh *et al.* 2007; Cinelli, Coles, and Kirwan 2014). Specific to IPs, AHP has guided high-tech industry selection (Chen and Huang 2004), eco-industrial park site selection (Nuhu *et al.* 2022; Arabsheibani, Kanani Sadat, and Abedini 2016), and IS partner prioritization (Yazici, Alakas, and Eren 2023).

However, its application to waste management in industrial contexts remains limited, with existing studies focusing primarily on municipal landfill siting (G. Wang *et al.* 2009; Şener *et al.* 2010) rather than IS strategies. This gap reinforces the novelty of applying AHP to evaluate CE transitions in IPs. Hence, the research addresses three primary questions: (1) What criteria are most significant for evaluating waste management strategies in the context of IS? (2) Which strategies provide the optimal balance of benefits across multiple criteria? (3) How can stakeholder perspectives be incorporated into the decision-making process?

The paper is structured as follows: the next section outlines the materials and methods, describing the Fosso Imperatore case study, data collection procedures, and the AHP methodology application. The results section presents the derived criteria weights, alternative evaluations, and sensitivity analysis outcomes. The discussion examines the implications of these findings for IS implementation and waste management policy in Italian IPs. Finally, the conclusion summarizes key insights and provides recommendations for future research and practice.

2. Materials and Methods

2.1. Case Study Area Description. The Fosso Imperatore IP, located in Nocera Inferiore in the Campania region of Southern Italy, serves as the focal point for this analysis. Managed by a consortium of 25 firms (Co.I.F.IM.), it spans approximately 144,846 square meters and collectively employs around 1,000 workers with an annual turnover exceeding 300 million euros. The strategic location of the park, with direct access to infrastructure networks and proximity to the Caserta-Roma highway, provides excellent accessibility for industrial operations.

Companies within the park operate across three main macro-sectors: Manufacturing, Recycling, and Services. The Manufacturing sector exhibits the greatest diversity, encompassing metalworking, metal construction, machinery manufacturing, aerospace components, food industry, packaging, and window manufacturing. The Services sector includes software development, logistics, graphic arts, and machinery maintenance, while the Recycling sector comprises two specialized firms. This diverse industrial composition creates potential for symbiotic relationships across different sectors, making Fosso Imperatore suitable for assessing resource optimization strategies (Chertow 2000).

2.2. Data Collection and Processing. The research centered on direct engagement with stakeholders at the IP through structured meetings and interviews with company managers. These interactions provided information on waste management challenges, operational constraints, and potential opportunities for resource optimization. Rather than emphasizing computational modeling of waste flows, the research prioritized gathering qualitative inputs directly from decision-makers who would ultimately implement any selected strategies.

The interviews explored current waste management practices, perceived barriers to implementing circular approaches, and receptiveness to various intervention strategies. Participants provided assessments regarding the relative importance of different decision criteria and the performance of alternative strategies against these criteria.

Supplementary data on waste quantities, company characteristics, and existing certifications (ISO 9001, ISO 14001, ISO 45001) were collected to provide contextual understanding but served primarily to support rather than drive the decision-making process. Stakeholder

priorities and preferences, rather than purely technical optimization, would ultimately determine the success of any resource management strategy.

2.3. Analytic Hierarchy Process Methodology. The Analytic Hierarchy Process (AHP) methodology, developed by Saaty (Saaty 1980), was selected to evaluate alternative waste management strategies for Fosso Imperatore IP. AHP facilitates decision-making in complex multi-criteria contexts by decomposing problems into hierarchical levels: goal, criteria, sub-criteria, and alternatives. This methodology incorporates both quantitative and qualitative factors, integrates diverse stakeholder perspectives, and maintains consistency through pairwise comparisons (Al-Thani and Al-Ansari 2021).

The AHP implementation consisted of six steps: (1) formulating the decision hierarchy with resource optimization as the goal; (2) identifying evaluation criteria from literature review and stakeholder inputs; (3) defining alternative strategies; (4) conducting pairwise comparisons to establish relative importance; (5) calculating priority weights using the eigenvalue method and checking consistency ratios; and (6) performing sensitivity analysis to assess ranking robustness (Saaty 2008).

Pairwise comparisons used Saaty's fundamental scale (1–9, where 1 indicates equal importance and 9 extreme importance). Participants judged the relative importance of criteria and evaluated alternative performance. Quantifiable metrics were informed by actual IP data, while qualitative assessments relied on expert judgment from company managers, consortium representatives, and waste management specialists (Behzadian *et al.* 2010).

2.4. Criteria Selection and Hierarchy Development. The criteria selection process aimed to develop a holistic yet manageable set of factors that capture key dimensions of resource optimization and waste management. Drawing on the literature (Korhonen, Honkasalo, and Seppälä 2018; Kirchherr, Reike, and Hekkert 2017) and stakeholder consultations, four primary criteria clusters were established: economic feasibility, environmental benefits, technical feasibility, and social acceptance. Such approach aligns with established frameworks for evaluating sustainability indicators in industrial contexts (D'Amico *et al.* 2020).

The economic feasibility criterion encompassed three sub-criteria: initial investment requirements (capital expenditure), operational costs (ongoing expenses), and return on investment period (time required to recover investment costs). Environmental benefits were assessed through waste diversion rates (percentage of waste redirected from disposal), emissions reduction (CO_2 equivalent savings), and resource conservation (virgin material offset). Technical feasibility included sub-criteria of implementation complexity (technical difficulty), infrastructure requirements (physical facilities needed), and technology readiness (maturity level). Social acceptance addressed business willingness (company receptiveness), community support (local population attitudes), and regulatory alignment (consistency with existing frameworks).

Furthermore, to understand preference variations across stakeholder types, separate AHP analyses were conducted for each subgroup. Individual pairwise comparison matrices were aggregated using the geometric mean method within each stakeholder category (manufacturing companies, recycling companies, technical experts, and consortium representatives).

2.5. Alternative Strategies Definition. Four waste management strategies were formulated for evaluation.

Enhanced external processing optimizes the current external waste management paradigm through improved collection efficiency, transportation logistics, and market access. While requiring minimal operational changes, it limits local value capture opportunities.

Internal material exchanges establish direct IS relationships between park companies for company-to-company waste transfers. This targets immediate opportunities requiring minimal transformation, utilizing waste directly as inputs without intermediate processing.

Centralized processing facility creates dedicated infrastructure within the park to collect, process, and redistribute waste materials. Despite addressing regulatory and technical barriers, it requires significant initial investment and coordination.

Hybrid phased implementation combines elements of the previous alternatives, starting with accessible opportunities and progressively building complex symbiotic relationships. It balances immediate benefits with long-term transformation through flexible timelines responsive to market conditions.

These alternatives represent different strategic approaches for comparative evaluation through the AHP framework (Kuznetsova, Zio, and Farel 2016).

2.6. Data Analysis. The priority weights derived from pairwise comparisons were aggregated using the geometric mean method to incorporate multiple stakeholder perspectives into a single set of priorities. Consistency ratios were calculated for each set of comparisons, with values below 0.1 considered acceptable (Saaty 1980). For comparisons exceeding this threshold, participants were asked to reconsider their judgments to improve consistency.

Global priority scores for alternatives were computed by multiplying the local priority of each alternative with respect to each criterion by the corresponding criterion weight, then summing these weighted scores. The resulting global priorities provided a comprehensive evaluation of each alternative, considering all criteria simultaneously.

Sensitivity analysis was conducted by systematically varying the weights of individual criteria and observing the resulting changes in alternative rankings. This process helped identify threshold values at which ranking reversals occurred, providing insights into the robustness of the results and the critical factors influencing strategy selection (T. Wang *et al.* 2021).

Additionally, stakeholder subgroup analysis was performed to examine variations in priorities across different participant categories (e.g., companies, local authorities, technical experts). This step aimed to help identify areas of consensus and divergence, providing valuable information for building stakeholder alignment around implementation strategies (Saaty 2008).

3. Results

Fifteen stakeholders participated in the AHP evaluation: 8 company managers (3 manufacturing, 2 recycling, 3 services), 3 consortium representatives, 2 technical experts, and 2 local authority representatives. Company managers constituted the largest stakeholder category.

TABLE 1. Criteria and Sub-criteria Weights

Main Criteria	Sub-criteria	Local Weight	Global Weight
Economic Feasibility	Initial investment	0.243	0.103
(0.423)	Operational costs	0.572	0.242
	Return on investment period	0.182	0.078
Environmental Benefits	Waste diversion rate	0.412	0.088
(0.214)	Emissions reduction	0.294	0.063
	Resource conservation	0.294	0.063
Technical Feasibility	Implementation complexity	0.483	0.115
(0.238)	Infrastructure requirements	0.317	0.075
	Technology readiness	0.200	0.048
Social Acceptance	Business willingness	0.623	0.078
(0.125)	Community support	0.130	0.016
	Regulatory alignment	0.247	0.031

The pairwise comparisons produced clear patterns in stakeholder priorities. Economic feasibility received the highest weight (0.423), with operational costs standing out as the primary concern across all criteria (global weight: 0.242). Technical feasibility came second (0.238), mainly due to implementation complexity concerns. Environmental benefits (0.214) and social acceptance (0.125) received lower priorities, though within social factors, business willingness stood out.

Different stakeholder groups showed predictable variations in priorities (Table 2). Manufacturing companies gave more weight to economics than recycling companies, who emphasized environmental benefits more strongly. Technical experts maintained a balance between environmental and economic aspects, while local authorities assigned the highest importance to social acceptance, consistent with their community-focused responsibilities. This comes as no surprise as it reflects their need to balance community concerns with economic development pressures.

TABLE 2. Stakeholder Subgroup Analysis of Main Criteria Weights

Stakeholder Group	Economic Feasibility	Environmental Benefits	Technical Feasibility	Social Acceptance
Manufacturing (n=3)	0.472	0.183	0.223	0.122
Recycling (n=2)	0.376	0.273	0.241	0.110
Services (n=3)	0.398	0.205	0.267	0.130
Consortium Reps (n=3)	0.413	0.167	0.293	0.127
Technical Experts (n=2)	0.328	0.324	0.258	0.090
Local Authority (n=2)	0.321	0.298	0.201	0.180

Internal Material Exchanges ranked first among the four strategies (Table 3), offering a favorable mix of economic feasibility and social acceptance through practical "quick

win" opportunities, such as, metal shavings from metalworking operations (approximately 40–50 tons annually) directly usable by other metal fabricators within the park; plastic packaging waste from the food sector transferable to plastic processing companies without preprocessing (estimated 150–200 tons annually); and organic waste from food industry operators suitable for direct composting or anaerobic digestion (roughly 500 tons combined annually). Enhanced External Processing came second thanks to its technical feasibility, while the Centralized Processing Facility, though strong on environmental metrics, ranked last due to economic and technical limitations.

TABLE 3. Alternative Strategies Performance Scores and Rankings

Alternative Strategy	Econ. Feas.	Envir. Ben.	Tech. Feas.	Social Accept.	Global Priority	Rank
Enhanced External Processing	0.287	0.153	0.348	0.219	0.268	2
Internal Material Exchanges	0.332	0.246	0.304	0.383	0.317	1
Centralized Processing Facility	0.149	0.403	0.152	0.178	0.198	4
Hybrid Approach	0.232	0.198	0.196	0.220	0.217	3

Stakeholder preferences aligned with their operational contexts (Table 4). Company managers overall favored strategies requiring minimal disruption to current operations, while recycling companies within this group showed greater openness to infrastructure-intensive solutions. Technical experts, despite recognizing environmental advantages of certain options (notably assigning the highest environmental sub-score to the Centralized Processing Facility), ultimately prioritized implementability. This pattern suggests that practical considerations outweigh theoretical benefits across all stakeholder groups.

TABLE 4. Stakeholder Subgroup Analysis of Alternative Strategy Preferences[a]

Stakeholder Group	Enhanced External	Internal Material	Central. Process.	Hybrid Approach
Company Managers (n=8)	0.323	0.364	0.147	0.166
of which: Recycling (n=2)	0.218	0.253	0.268	0.261
Consortium Reps (n=3)	0.245	0.302	0.205	0.248
Technical Experts (n=2)	0.238	0.293	0.216	0.253
Overall (n=15)	0.268	0.317	0.198	0.217

[a]Technical experts' environmental sub-scores notably favored Centralized Processing (0.454), though their overall preferences prioritized implementability.

3.1. Sensitivity Analysis. The sensitivity analysis confirmed that Internal Material Exchanges maintains its top position under reasonable variations in criteria weights (Table 5).

TABLE 5. Sensitivity Analysis: Threshold Values for Ranking Reversal

Criterion	Base Wt.	Threshold	Change Required Effect
Economic Feas.	0.423	0.318	−0.105: Internal Material Exchanges and Enhanced External Processing swap
Environmental Ben.	0.214	0.427	+0.213: Centralized Processing Facility becomes highest ranked
Technical Feas.	0.238	0.379	+0.141: Enhanced External Processing becomes highest ranked
Social Acceptance	0.125	0.347	+0.222: Gap between Internal Material Exchanges and other alternatives increases

Major shifts would be needed to change the rankings—specifically, decreasing economic importance or greatly increasing environmental weight could make other strategies preferable. This stability supports the recommendation while highlighting when alternative approaches might become more suitable.

4. Discussion

The prioritization of economic considerations, particularly operational costs, shapes implementation pathways at Fosso Imperatore. Economic viability functions as the entry point for circular initiatives, as they must deliver tangible operational cost advantages to gain traction among stakeholders (Korhonen, Honkasalo, and Seppälä 2018).

Internal Material Exchanges ranked first because they build on existing capabilities without requiring new infrastructure or complex coordination. This preference for incremental transition aligns with early-stage IS development patterns (Chertow 2007). Enhanced External Processing ranked second due to path dependency, where familiar approaches with minor improvements appear more viable than transformative alternatives.

This economic orientation creates a paradox: while providing pragmatic entry points, it may limit optimal resource outcomes (Zhang *et al.* 2015). The substantial weighting change needed to elevate the Centralized Processing Facility (from 0.214 to 0.427 for environmental criteria) quantifies this preference gap. Incremental approaches risk efficiency improvements that fail to achieve optimal resource management (Korhonen, Honkasalo, and Seppälä 2018).

Stakeholder variations require differentiated engagement. Manufacturing firms favor minimal operational changes, while recycling companies accept greater environmental investments. Implementation strategies should adapt messaging, accordingly, emphasizing cost savings for manufacturers while focusing on environmental performance for recycling firms and technical specialists.

The low weight for social acceptance (0.125) risks perpetuating industrial convenience over community integration (Barreiro-Gen and Lozano 2020). Within this category, business willingness dominated (0.623), treating community support and regulatory alignment as secondary considerations.

Implementation should begin with bilateral exchanges offering immediate economic benefits, targeting operational cost reductions rather than capital subsidies, while tailoring engagement to specific stakeholder concerns. These principles build on existing motivations rather than attempting to reshape them.

Policy implications include limited effectiveness of environmental regulations without operational cost incentives. Reducing regulatory complexity for symbiotic exchanges while maintaining protections could address key barriers. The priority variations within this single IP indicate that flexible, locally adapted frameworks outperform standardized approaches.

Digital platforms received theoretical support during interviews but lower practical priority in the AHP results, consistent with previous findings (Álvarez and Ruiz-Puente 2017). These tools should support rather than replace direct material exchanges, starting with basic information sharing.

Ultimately, it should be noted that these findings likely apply to IPs across Southern Europe sharing similar characteristics: SME predominance, diverse sectoral composition, and limited internal processing infrastructure. However, local regulatory frameworks and stakeholder priorities necessitate context-specific adaptation of both the methodology and implementation strategies.

Study limitations include the small sample (n=15), potential self-selection bias toward environmentally engaged participants, manufacturing overrepresentation, and absence of citizen groups. Another limitation pertains to the absence of detailed cost-benefit data for the evaluated alternatives. While stakeholders prioritized economic feasibility, the assessment relied on qualitative perceptions rather than quantitative financial analysis. The lack of specific data on investment requirements, operational costs, and potential savings prevents determination of actual economic distances between alternatives. This constraint reflects the early planning stage of symbiosis implementation at Fosso Imperatore, where detailed feasibility studies have not yet been conducted. Consequently, the economic "distance" between alternatives cannot be quantified in monetary terms, limiting the definition of trade-offs between options. The static nature of AHP methodology cannot capture the dynamic evolution of IS networks, where partnership configurations and material flows change over time. Future research should integrate dynamic modeling approaches (system dynamics or agent-based models) with comprehensive economic feasibility studies incorporating actual investment costs, operational expenses, and projected returns. Longitudinal studies tracking implementation outcomes would validate whether initial stakeholder preferences translate into successful symbiotic relationships. Additionally, future research should compare multiple IPs across Italian regions to identify contextual success factors.

5. Conclusion

This study applied the Analytic Hierarchy Process to evaluate resource optimization strategies for Fosso Imperatore IP. The analysis confirms that economic viability, particularly operational costs, drives stakeholder decisions in CE transitions. Internal Material Exchanges ranked as the preferred strategy due to its balance of economic feasibility and implementability through existing industrial relationships. The findings support an incremental approach to IS in Southern Italian contexts. Rather than pursuing transformative

infrastructure projects, initial efforts should focus on bilateral material exchanges with clear economic benefits.

This pragmatic pathway aligns with stakeholder priorities while creating foundations for more ambitious circular initiatives over time. Policy interventions should address operational cost barriers through targeted incentives and reduced regulatory complexity for material exchanges. The significant priority variations among stakeholders within a single IP underscore the need for flexible, locally adapted implementation frameworks rather than standardized approaches.

Future research should compare IPs across Italian regions to identify contextual success factors, develop dynamic models capturing evolving symbiotic relationships, and detail specific governance mechanisms for implementing material exchange networks. As resource constraints intensify, decision support frameworks like AHP provide essential tools for navigating the complex transition from linear to circular industrial systems.

Acknowledgments

Thanks to the Project "CE IPsa: A development model for Circular Economy between Industrial Parks and surroundings areas" CUP J53D23016630001 – codice identificativo P20227NFA4.

References

Ahmad, S. and Tahar, R. M. (2014). "Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia". *Renewable Energy* **63**, 458–466. DOI: 10.1016/j.renene.2013.10.001.

Ahmed, F., Ali, I., Kousar, S., and Ahmed, S. (2022). "The environmental impact of industrialization and foreign direct investment: empirical evidence from Asia-Pacific region". *Environmental Science and Pollution Research* **29**, 29778–29792. DOI: 10.1007/s11356-021-14681-4.

Álvarez, R. and Ruiz-Puente, C. (2017). "Development of the tool SymbioSyS to support the transition towards a circular economy based on industrial symbiosis strategies". *Waste and Biomass Valorization* **8**, 1521–1530. DOI: 10.1007/s12649-016-9748-1.

Arabsheibani, R., Kanani Sadat, Y., and Abedini, A. (2016). "Land suitability assessment for locating industrial parks: a hybrid multi criteria decision-making approach using Geographical Information System". *Geographical Research* **54**(4), 446–460. DOI: 10.1111/1745-5871.12182.

Barreiro-Gen, M. and Lozano, R. (2020). "How circular is the circular economy? Analysing the implementation of circular economy in organisations". *Business Strategy and the Environment* **29**(8), 3484–3494. DOI: 10.1002/bse.2590.

Barrera, G. A. F., Durany, X. G. i, Pons, J. R., and Erazo, J. G. G. (2021). "Trends in global research on industrial parks: A bibliometric analysis from 1996–2019". *Heliyon* **7**(8), e07778. DOI: 10.1016/j.heliyon.2021.e07778.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., and Aghdasi, M. (2010). "PROMETHEE: A comprehensive literature review on methodologies and applications". *European Journal of Operational Research* **200**(1), 198–215. DOI: 10.1016/j.ejor.2009.01.021.

Brandenburg, M., Govindan, K., Sarkis, J., and Seuring, S. (2014). "Quantitative models for sustainable supply chain management: Developments and directions". *European Journal of Operational Research* **233**(2), 299–312. DOI: 10.1016/j.ejor.2013.09.032.

Chen, C.-J. and Huang, C.-C. (2004). "A multiple criteria evaluation of high-tech industries for the science-based industrial park in Taiwan". *Information & Management* **41**(7), 839–851. DOI: 10.1016/j.im.2003.10.002.

Chertow, M. R. (2000). "Industrial symbiosis: literature and taxonomy". *Annual Review of Energy and the Environment* **25**(1), 313–337. DOI: 10.1146/annurev.energy.25.1.313.

Chertow, M. R. (2007). ""Uncovering" industrial symbiosis". *Journal of Industrial Ecology* **11**(1), 11–30. DOI: 10.1162/jiec.2007.1110.

Cinelli, M., Coles, S. R., and Kirwan, K. (2014). "Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment". *Ecological Indicators* **46**, 138–148. DOI: 10.1016/j.ecolind.2014.06.011.

D'Amico, G., Arbolino, R., Shi, L., Yigitcanlar, T., and Ioppolo, G. (2021). "Digital technologies for urban metabolism efficiency: Lessons from urban agenda partnership on circular economy". *Sustainability* **13**(11), 6043. DOI: 10.3390/su13116043.

D'Amico, G., Taddeo, R., Shi, L., Yigitcanlar, T., and Ioppolo, G. (2020). "Ecological indicators of smart urban metabolism: A review of the literature on international standards". *Ecological Indicators* **118**, 106808. DOI: 10.1016/j.ecolind.2020.106808.

Domenech, T. and Davies, M. (2011). "The role of embeddedness in industrial symbiosis networks: Phases in the evolution of industrial symbiosis networks". *Business Strategy and the Environment* **20**(5), 281–296. DOI: 10.1002/bse.695.

Ellen MacArthur Foundation (2013). *Towards the Circular Economy*. Tech. rep. Ellen MacArthur Foundation.

Ioppolo, G., Heijungs, R., Cucurachi, S., Salomone, R., and Kleijn, R. (2014). "Urban Metabolism: Many open questions for future answers". In: *Pathways to Environmental Sustainability: Methodologies and Experiences*. Springer, pp. 23–32. DOI: 10.1007/978-3-319-03826-1_3.

Ioppolo, G., Saija, G., and Salomone, R. (2012). "Developing a Territory Balanced Scorecard approach to manage projects for local development: Two case studies". *Land Use Policy* **29**(3), 629–640. DOI: 10.1016/j.landusepol.2011.11.005.

Kirchherr, J., Reike, D., and Hekkert, M. (2017). "Conceptualizing the circular economy: An analysis of 114 definitions". *Resources, Conservation and Recycling* **127**, 221–232. DOI: 10.1016/j.resconrec.2017.09.005.

Korhonen, J., Honkasalo, A., and Seppälä, J. (2018). "Circular economy: the concept and its limitations". *Ecological Economics* **143**, 37–46. DOI: 10.1016/j.ecolecon.2017.06.041.

Kuznetsova, E., Zio, E., and Farel, R. (2016). "A methodological framework for Eco-Industrial Park design and optimization". *Journal of Cleaner Production* **126**, 308–324. DOI: 10.1016/j.jclepro.2016.03.025.

Lombardi, D. R. and Laybourn, P. (2012). "Redefining industrial symbiosis: Crossing academic-practitioner boundaries". *Journal of Industrial Ecology* **16**(1), 28–37. DOI: 10.1111/j.1530-9290.2011.00444.x.

Luthra, S., Govindan, K., Kannan, D., Mangla, S. K., and Garg, C. P. (2017). "An integrated framework for sustainable supplier selection and evaluation in supply chains". *Journal of Cleaner Production* **140**, 1686–1698. DOI: 10.1016/j.jclepro.2016.09.078.

Mirata, M. and Emtairah, T. (2005). "Industrial symbiosis networks and the contribution to environmental innovation: The case of the Landskrona industrial symbiosis programme". *Journal of Cleaner Production* **13**(10–11), 993–1002. DOI: 10.1016/j.jclepro.2004.12.010.

Nuhu, S. K., Manan, Z. A., Alwi, S. R. W., and Reba, M. N. M. (2022). "Integrated modelling approach for an eco-industrial park site selection". *Journal of Cleaner Production* **368**, 133141. DOI: 10.1016/j.jclepro.2022.133141.

Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Saaty, T. L. (2008). "Decision making with the analytic hierarchy process". *International Journal of Services Sciences* **1**(1), 83–98. DOI: 10.1504/IJSSCI.2008.017590.

Şener, Ş., Şener, E., Nas, B., and Karagüzel, R. (2010). "Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey)". *Waste Management* **30**(11), 2037–2046. DOI: 10.1016/j.wasman.2010.05.024.

Singh, R. K., Murty, H. R., Gupta, S. K., and Dikshit, A. K. (2007). "Development of composite sustainability performance index for steel industry". *Ecological Indicators* **7**(3), 565–588. DOI: 10.1016/j.ecolind.2006.06.004.

Al-Thani, N. A. and Al-Ansari, T. (2021). "Comparing the convergence and divergence within industrial ecology, circular economy, and the energy-water-food nexus based on resource management objectives". *Sustainable Production and Consumption* **27**, 1743–1761. DOI: 10.1016/j.spc.2021.04.008.

Wang, G., Qin, L., Li, G., and Chen, L. (2009). "Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China". *Journal of Environmental Management* **90**(8), 2414–2421. DOI: 10.1016/j.jenvman.2008.12.001.

Wang, T., Zhang, M., Springer, C. H., and Yang, C. (2021). "How to promote industrial park recycling transformation in China: An analytic framework based on critical material flow". *Environmental Impact Assessment Review* **87**, 106550. DOI: 10.1016/j.eiar.2020.106550.

Wang, Y., Xu, L., and Solangi, Y. A. (2020). "Strategic renewable energy resources selection for Pakistan: Based on SWOT-Fuzzy AHP approach". *Sustainable Cities and Society* **52**, 101861. DOI: 10.1016/j.scs.2019.101861.

Yazici, E., Alakas, H. M., and Eren, T. (2023). "Prioritizing of sectors for establishing a sustainable industrial symbiosis network with Pythagorean fuzzy AHP-Pythagorean fuzzy TOPSIS method: a case of industrial park in Ankara". *Environmental Science and Pollution Research* **30**(31), 77875–77889. DOI: 10.1007/s11356-023-26903-w.

Zeng, H., Chen, X., Xiao, X., and Zhou, Z. (2017). "Institutional pressures, sustainable supply chain management, and circular economy capability: Empirical evidence from Chinese eco-industrial park firms". *Journal of Cleaner Production* **155**, 54–65. DOI: 10.1016/j.jclepro.2017.04.005.

Zhang, Y., Zheng, H., Chen, B., Su, M., and Liu, G. (2015). "A review of industrial symbiosis research: theory and methodology". *Frontiers of Earth Science* **9**, 91–104. DOI: 10.1007/s11707-014-0436-8.

[a] Università degli Studi di Messina,
Dipartimento di Economia,
Messina, 98122, Italy

[b] Università degli Studi di Napoli "L'Orientale",
Dipartimento di Scienze Umane e Sociali (DiSUS),
Napoli, 80134, Italy

* To whom correspondence should be addressed | email: carlotta.dalessandro@unime.it

Paper contributed to the #ApplMath2025 International Workshop (9–11 June 2025).
Manuscript received 16 July 2025; published online 18 November 2026



© 2026 by the author(s); licensee *Accademia Peloritana dei Pericolanti* (Messina, Italy). This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/).