INDUSTRIAL SYMBIOSIS AS A GREEN CORRIDOR FOR SMALL COMMUNITIES: THE ECONEXUS MODEL

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Keywords: ECONEXUS Project, Industrial Symbiosis, Green corridor, Circularity, Biochar

ABSTRACT

Sustainable actions to transform waste into resources are current concerns for local, national, regional and global communities. Practices for managing water, energy and material flows are concerns for local communities. These concerns are integrated within research that aims to achieve a technology transfer from research organizations to industry and to constitute a coherent model.The approach focuses on short and controlled pathways for resource circulation, enabled through technology transfer from research institutions to local industrial and community actors. The paper outlines the conceptual architecture of the ECONEXUS framework and its early- stage methodological structure, encompassing performance indicators for water recovery, energy balance, material and nutrient circularity, operational stability, and system adaptability. Preliminary insights from pilot case studies are used to explore system behaviour and module interactions under diverse operational conditions. Findings suggest that modular industrial symbiosis can sustain stable local resource loops and act as a decentralized logistics corridor for secondary resources. Although the research remains in its initial implementation phase, the framework shows promising applicability to rural, peri- urban, and mixed territories, including port- related contexts, advancing broader goals of smart and resilient logistics corridors.

1. INTRODUCTION

Life and metabolism of a community are shaped by water, energy, materials, and nutrients [1]. Many regions still treat these flows as separate systems, even when they are linked by simple physical and operational relations. We use the word al-tarābuṭ[1](الترابط) to denote systemic interconnections that enable coordinated resource flows and industrial symbiosis. Within the ECONEXUS framework it describes the cohesion emerging from distributed interactions rather than from centralized control.

The ECONEXUS project brings a comprehensive approach that connects communities with modular technologies and offers a way to organize these flows. Among the project objectives is the ability to create a close link between research organizations and small and medium-sized enterprises. Through this collaboration, a transfer of methods, tools, results is achieved that allow waste to become local resources [2], [3], [4]. Through project activities, complex processes for wastewater treatment are developed [5], [6], [7], [8]. These complex processes include electrodosing, electrochemical filtration and ozonation. Through these processes we want to reduce pollutants and recover useful materials. Another process converts vegetable residues into biochar and thermal energy [5]. These processes provide a wider range of choices for recovering local resources. Several of these modules are integrated in a pilot containerised station [7]. The studies allow us to test the recovery of nutrients [9], the removal of emerging pollutants [10], and the potential for small material loops. The work promotes national and European objectives concerning circularity and water quality [11]. Modern treatments are still lacking in many areas, and pre-treatment increases the loss of precious materials. ECONEXUS offers several workable options to close these gaps. We view industrial and urban symbiosis as a natural extension of this work [12], [13], [14]. When one process creates a stream that another process can use, the system becomes more coherent. Wastewater contains nutrients. Organic matter holds energy. Residues hold recovery potential. A modular station can stabilize these flows and reduce the pressure on central infrastructures. The idea is not the creation of a large treatment facility. The aim is a flexible structure that supports a green corridor for small communities and local industries [15], [16]. The work is situated within the conference themes through the flow followed by waste from its generation to its transformation into a resource. The project addresses the closed loop of logistics through which materials remain in use for a long period of time until their value is completely lost [17], [18]. Within a community, water, energy, materials, and nutrients create their own chain of flows. Coordination, timing, and basic infrastructure are required for these flows. This makes them comparable to the small corridors that sustain local resilience [19], [20], [21]. We use the term green corridor to reflect this idea [22]. The term remains general enough to cover water, energy, and material cycles without fixing the concept to a single type of flow. It

[1] al-tarābuṭ (الترابُط) is an Arabic term meaning "interconnection," "interdependence," or "cohesion between elements." It is commonly used in Modern Standard Arabic to describe links that support and stabilize a system. For lexical definition, see: Hans Wehr, A Dictionary of Modern Written Arabic, 4th ed., edited by J. Milton Cowan, Wiesbaden: Harrassowitz, 1994.

also aligns with the aim of the project: to support communities through steady and low-impact resource circulation [23], [24]. In this sense, the ECONEXUS model interprets logistics not only as the movement of goods, but as the coordinated circulation of secondary resources within a controlled corridor.

2. BACKGROUND. CONCEPTUAL FRAMEWORK

Three brief tables will be used to begin the backdrop. A distinct layer of the system we describe is explained by each table. The relationship between water, energy, materials, and fertilisers is described in the first table. Each element's primary roles and how they assist a local circular model are displayed (Table 1). How these components spread throughout the community is described in the second table. The green water corridor's flows and the locations where waste turns into a resource are shown (Table 2). The criteria that let these flows to function are the subject of the third table. It describes straightforward methods of participation, government, and education that support tiny communities in upholding a stable system [25] (Table 3). These tables work together. They connect the structure of the nexus, the logic of the flows, and the social setting in which the system functions. The tables also serve as a basis for defining measurable operational indicators that will be used in subsequent pilot testing. We use this structure to keep the framework clear and accessible. It also helps us show that technical solutions alone are not enough. As shown in Section 3.1, symbiosis depends on the alignment between resources, practices, and local routines.

2.1. Urban & Industrial Symbiosis

Symbiosis comes from biology. Two organisms share space, resources, and metabolic cycles [26]. Each gain something. The idea moved into environmental studies because it helps us describe systems that exchange materials rather than compete for them. Urban and industrial actors do not behave like biological species. It points to flow. It also shifts our attention from waste disposal to resource use. In operational terms of our ECONEXUS project, this shift means that treated water, recovered energy, and secondary materials are reintroduced into nearby processes through short and controlled routes.

In industrial and urban environments, the waste generated becomes a carrier of value and this aspect contributes to strengthening the principles of sustainable development. Industrial symbiosis is important for the economy and sustainability objectives [27], [27], [28]. Industrial symbiosis contributes to collaboration between companies, and waste from one company can become resources for another. This symbiosis contributes to achieving organizational objectives, increasing competitiveness, economic growth, saving resources, stimulating innovation and developing new jobs [25], [29]. The transformation of waste into resources is a flow in the circular economy model that contributes to the concept of symbiosis [3], [30], [31], [32]. That transition supports circularity and gives small communities more control over their own metabolism [26], [28], [33]. Any local system's core is shaped by water, energy, materials, and nutrients. A distinct kind of resource cycle is supported by each component. These roles are clearly mentioned in the tables.

Table 1. Basic element of the nexus (author's own research)

Nexus element	Core function	Waste stream	Resource output	Role in local symbiosis
Water	Supports daily use and small agriculture	Wastewater from households and micro-industries	Treated water for local reuse	Keeps the corridor stable and reduces external demand
Energy	Provides heat and electricity for basic needs	Organic residues, food waste, sludge	Biogas or low-intensity thermal energy	Reduces reliance on external grids and supports closed-loop cycles

Materials	Maintains small production and repair activities	Plastics, glass, metals, construction debris	Recovered materials for reuse or simple processing	Extends product life and lowers waste volumes
Fertilizers	Supports small farming and soil health	Nutrient-rich effluents, composted organic matter	Local fertilizers with predictable quality	Links water and energy systems to agriculture in a steady cycle

Only when these components spread throughout the community do they become relevant. Just as important as the materials themselves are the flows. The circulation of these elements is described in the second table. We present the main entry points, the transformations, and the local outputs. The table shows where waste streams change direction and become resources. It also illustrates the logic behind the green corridor we propose.

Table 2. Flow logic of the green corridor (author's own research)

Flow type	Entry point	Transformation process	Output	Local benefit
Water flow	Household and micro-industry use	Decentralized treatment	Reuse water for services and irrigation	Lower pressure on supply networks
Energy flow	Organic residues	Anaerobic digestion	Biogas and heat	Stable energy for basic needs
Material flow	Plastics, glass, metals, biomass	Simple sorting and recovery	Reusable materials	Less external sourcing
Nutrient flow	Sludge and organic waste	Composting and nutrient extraction	Local fertilizers	Stronger links between water and agriculture
Knowledge flow	Community practices	Learning and adaptation	Operational routines	Better long-term resilience

Flows do not operate on their own. They need routines, people, and simple forms of coordination. The third table focuses on the social and organizational conditions that stabilize the system. We look at governance, engagement, skills, and trust. These conditions allow the flows to remain steady and predictable. The table completes the framework by linking technologies with daily practices.

Table 3. Organizational and social conditions for local symbiosis (author's own research)

Condition type	Core requirement	Practical expression	Effect on the system
Governance	Clear coordination	Local rules, simple agreements, shared tasks	Stable operation of flows
Community engagement	Basic involvement	Routine habits, attention to sorting, small repairs	Higher quality of resource streams
Institutional support	Minimal but steady backing	Municipal services, local monitoring, small budgets	Predictability in daily operations
Knowledge and skills	Practical understanding	Training sessions, peer learning, simple manuals	Fewer disruptions and better adaptation
Economic signals	Incentives that make sense locally	Reduced fees, small savings, shared tools	Stronger motivation to use recovered resources
Social trust	Cooperative mindset	Transparent decisions, visible results, steady communication	Lower resistance to new routines

Together, the three tables form a coherent structure. The first table clarifies the elements of the nexus. The second table shows their movement through the community. The third table explains the conditions that support this movement. We use this framework to understand how a small community can sustain a green corridor through resource circulation and coordinated practices.

2.2. Concept Alignment

We add a conceptual table to clarify the terms we use in the article (Table 4). The concepts come from different fields and describe resources, processes, and forms of cooperation. We extend each meaning with a short note, as the project works with water-based resources, biochar, electrochemical treatment, and digital modules. The table shows how these terms relate to the theme of the conference and why a project built around small resource cycles can be read as a form of green corridor.

Table 4. Terms concept alignment (author's own research)

Concept	Short meaning	How it aligns with
Urban symbiosis	A set of links between community practices and local resource cycles. It includes water reuse, organic residues, and small recovery steps.	Builds internal corridors that stabilise everyday flows in small communities.
Industrial symbiosis	Exchanges between local processes that use each other's outputs. It includes treated water as a resource, recovered materials, and energy from residues.	Functions as a resource logistics chain that mirrors small transport corridors.
Resource-from-water	Wastewater becomes a source of nutrients, clean water, and materials. The focus shifts from disposal to extraction.	Minimises reliance on outside supplies and promotes reliable local infrastructure.
Biochar and pyrolysis	Plant residues become carbon-rich material and low-intensity energy. The process develops new inputs for soil and thermal needs.	Adds energy and material loops with sustainable outputs to extend the corridor.
Electrochemical treatment	Filtration, ozonation, and electro-dosing are ways used to treat water. These procedures develop quality and recover materials.	Develops a dependable and regulated path for the flow of nutrients and water.
Digital and automated modules	The pilot station includes minor operational adjustments, water quality, and energy consumption.	Uses real-time data to support the concept of a smart corridor.
From pollution to circularity	Pollution is reduced by turning residues into usable inputs. Material losses decline.	Fits the broader aim of resilient and low-impact corridors.
Technology transfer	Solutions move from research to industry. Processes become practical and scalable.	Strengthens local capacity to operate green and adaptable infrastructures.
Green corridor	A simple route through which local resources circulate with low losses. The corridor links processes, technologies, and community routines.	Matches focus on corridors that support stable and resilient systems.

The ideas outlined in the table form a clear structure for understanding our project. Each concept describes a part of a larger chain in which resources move through simple and repeatable steps. The chain works as a local logistic route. Water, energy, materials, and nutrients follow paths that resemble small transport flows [1]. These paths can be organized and monitored in the same way as other logistic activities. The structure can be applied even in a seaside port, where resource cycles often run in parallel with standard operations. Ports work with concentrated flows [34], predictable routines, and modular units. The processes we describe can support these settings and offer an additional layer of stability through a green corridor built around resource circulation. This alignment is a conceptual one at this step, but it reflects operational principles that are already applied to port logistics, such as modularity, flow control, and routine-based management.

3. LITERATURE REVIEW

We structure the literature review around four search cues (Table 5). Each cue reflects a part of the project and supports the link between industrial symbiosis, the nexus water–energy–materials–nutrients, and the idea of a green corridor in small communities. We selected recent studies published between 2020 and 2025 and used an analytical search with Consensus. The goal is to outline the main directions in the literature and to identify concepts and findings that guide the project. The review remains short and functional. We focus on themes that connect recovery processes, local resource cycles, and modular systems that can be used in communities and port environments.

Table 5. Recent studies (2020-2025) to outline main project directions (author's own research)

Rank	Search cue	Synthesis	Key sources
A	"industrial symbiosis definition resource recovery"; "urban symbiosis circular economy small communities"; "industrial symbiosis waste-to-resource case studies"	Industrial and urban symbiosis link different actors through shared resource cycles. By turning waste streams into inputs for other processes, local flows are stabilized and external demand is decreased. Research indicates that energy integration, material reuse, and nutrient recovery support tiny loops in both small settlements and industrial settings. The work emphasizes the importance of clear routines, straightforward infrastructures, and teamwork.	[26]; [20]; [4]; [27]; [19]; [13]; [23]; [28]; [17].
B	"water energy materials nutrients nexus small-scale systems"; "nexus modelling rural communities circularity"	Integrated perspectives of resource flows are provided by Nexus models. Trade-offs, synergies, and local optimization choices are highlighted by analytical tools. Circular techniques that assist local energy generation, recover nutrients, and reuse water are advantageous for small and rural systems. Circularity and nexus have a strong but not automatic relationship. Small systems require adaptable techniques, and context is important.	[29]; [30]; [31]; [32]; [22]; [33]; [34]; [35], [36]; [37]; [38].
C	"decentralized wastewater treatment resource recovery community scale"; "biogas small communities anaerobic digestion benefits"; "material recovery low-tech circular economy models"	Decentralized systems minimize operational impacts and are appropriate for small communities. They sustain local water, nutrients, and energy circuits. Anaerobic digestion produces biogas from organic waste and offers long-term advantages at the local level. Recovery potential is increased when flows are separated. The research demonstrates that low-tech methods are still useful and adaptable to various situations.	[7]; [39]; [40]; [9]; [6]; [41]; [42]; [43]; [44]; [5].
D	"industrial symbiosis metabolic analogy environmental systems"; "circular resource flows local metabolism concept"	Metabolic models describe how cities and industrial systems process resources. The aim is to transform linear flows into circular ones by linking the actors that share materials and energy. The approach supports industrial symbiosis and aligns with local planning. Quantitative tools help identify opportunities for circularity. Case studies show how flows can behave like natural cycles when loops are created at local scale.	[45]; [24]; [12]; [46]; [47]; [2]; [18].

4. METHODOLOGY

This research used a simple methodological structure (see Figure 1). The methodology focuses on early-stage system design and pilot validation rather than full-scale performance optimization. The project is in its early stages and therefore we rely on the early system proposed since the conception of the project. Each stage of the system supports the idea of a green corridor built through innovative approaches to water, energy, materials and nutrients.

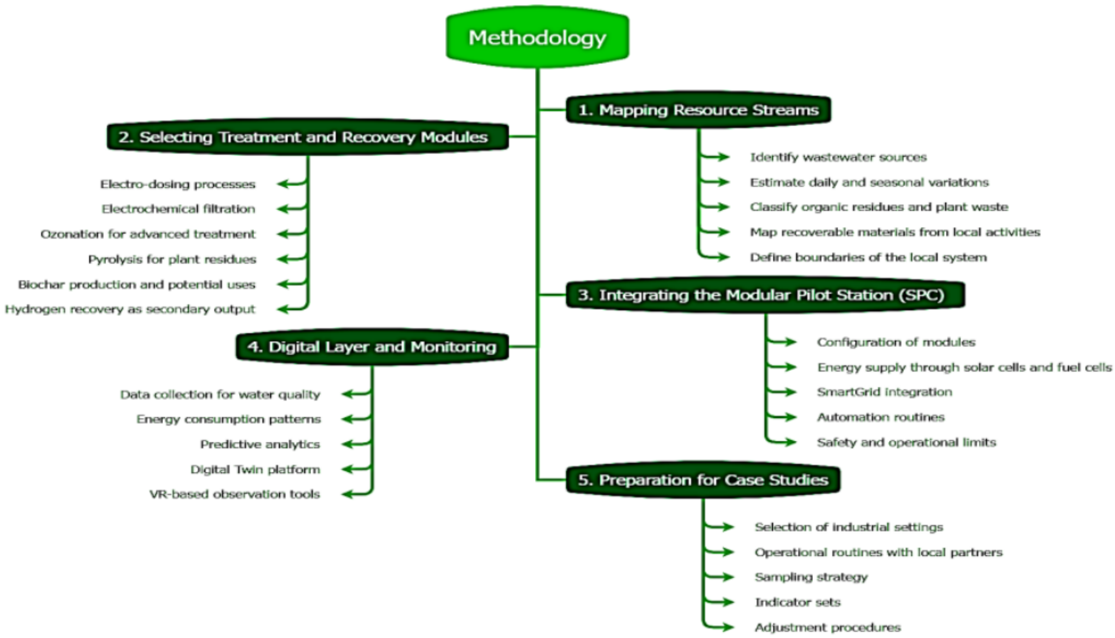

Figure 1: Methodological Structure (author's own contribution)

We start with the identification of local resource streams. We map the sources of wastewater, organic residues, and recoverable materials in standard operating conditions. The mapping offers a basic picture of volumes and fluctuations. We use this picture to define the limits of the modular processes. The next step is the selection of treatment and recovery modules. Although the ECONEXUS project is currently in an early implementation phase, a set of performance indicators was defined to guide pilot testing and to support future empirical validation. These indicators are aligned with established practices in industrial symbiosis, decentralized resource recovery, and nexus-based system assessment. The indicators proposed at this stage aim to ensure the measurability, comparability and operational transparency of the proposed green corridor model. The indicators contribute to the formation of four interconnected dimensions: water recovery, energy performance, material and nutrient circularity and system operability. The four dimensions contribute to developing a basis for assessing how local resource flows are stabilized, reused and reintegrated into nearby processes through short and controlled routes. Table 6 presents the systematization of these selected indicators, their scope and their relevance for assessing industrial symbiosis at a community scale.

Table 6. Performance indicators for the ECONEXUS green corridor (author's own research)

Indicator category	Performance indicator	Description	Relevance for industrial symbiosis
Water recovery	Water recovery rate (%)	Percentage of treated wastewater from the local community	Contributes to increasing the efficiency of local water loops
Energy performance	Energy balance (kWh recovered / kWh consumed)	The ratio of energy generated from waste to energy from treatment modules	Evaluates the energy efficiency of decentralized systems
Nutrient circularity	Nutrient recovery potential (mg/L N, P)	Concentration of nutrients that can be utilized from wastewater and organic residues	Replaces chemical fertilizers and offers a solution for their reuse in agriculture
Material circularity	Material diversion rate (%)	Percentage of materials that were not disposed of and were included in reuse or recovery functions	Measures the effectiveness of waste-to-resource functions
System operability	Operational stability (hours of continuous operation)	The function of the modules to operate without interruption.	Outlines the reliability of the green corridor by providing a complete picture.
System adaptability	Modular adaptability (number of tested configurations)	Ability to adjust, modify or reconfigure the system according to local contexts	Contributes to scalability and replication in small communities

The selection of these indicators is based on the existing literature that focuses on the performance of circular economy models. There are a number of models that contribute to improving the energy balance, the amount of industrial waste or others [12], [26], [31], [38], [41]. Electrochemical processes, ozonation units and low intensity thermal conversion are used. The modules are evaluated in the laboratory for their stability development and energy needs. Their operability is tested to build the digital layer around the pilot station. Then the next steps of the pilot station are built. This approach mentions the realistic and proportional methodology to the current state of ECONEXUS. It also outlines the idea that a green corridor depends on small and repeatable steps, not on a single major intervention. The proposed structure is consolidated in the theoretical framework part.

5. DISCUSSIONS

The case studies are test environments used to examine the feasibility, adaptability and operational logic of the proposed green corridor model. The focus is on the system behavior, the interaction between the modules and the relevance of the performance indicators proposed in the methodological section. The three-case studies outline: (i) a community-scale wastewater and organic waste flow, (ii) a semi- industrial environment with fluctuating material and energy flows and (iii) a mixed-use environment with characteristics comparable to port-related activities. The current work confirms, at a theoretical level, a compatibility of the theoretical model with the industrial-scale model that will be transferred.

The research is at the level of the specialized literature following the following validation and development stages.

The project makes it possible to use small modular systems in broader environments. From an operational viewpoint, the green corridor functions as a decentralized logistics chain for secondary resources. Shipyards and ports deal with concentrated fluxes of materials, energy, and water. Although they follow predictable protocols, these flows vary throughout operations. These conditions can be supported by the structure we suggest. The modules can operate with little assistance if they are positioned near the point of generating. Wastewater produced by daily use, maintenance tasks, and cleaning operations is turned into a resource. Materials are extracted and pollution loads are decreased by electrochemical procedures. The port's non-potable usage can be supported by the recovered water. This stabilises regular activity and lessens the strain on supply networks. Mixed residues are produced at shipyards. Some originate from hull cleaning, cutting, or sanding, while others emerge from surface treatment. These residues can be incorporated into recovery loops and have short routes. Plant waste from packaging streams or green spaces can be processed using pyrolysis modules. When used for filtration or soil enhancement, the charcoal turns into a valuable resource.

Compact and adaptable infrastructure is used in ports. This model is compatible with the pilot station. It is portable, containerised, and modular. Variations in energy use and flow are recorded by the digital layer. Digital tools are already used by ports for monitoring and scheduling. Instead of focussing on ship movements, the station adds an additional layer that deals with resource transfers. The concept of a green corridor inside the port is supported by this alignment. Routines for recovery, monitoring, and therapy are connected via the corridor. These findings demonstrate the project's alignment with the more general concept of resilient and intelligent logistics corridors. Transferring resources replaces the idea of transferring things. The processes create a chain that functions similarly to a tiny logistical route. Communities, industrial sectors, and port environments can all use the route. Simple routines, little losses, and constant flows are advantageous for every situation. Although the project is still in its early stages, the structure indicates that symbiosis can sustain places where resource management is directly related to day-to-day activities and can go beyond tiny communities. We are keeping the following restrictions in mind: i) Scalability: The modules operate with small flows and we need more data to be able to transform them into larger operations; ii) Variability: The operational cycles are not complete at present. Industrial flows are currently changing and current routines support simple variants; iii) Energy integration: To have a mobile solution we need independent energy solutions. Not all the details are settled; iv) Digitalization: The mobile solution requires digitalization, and the modules are not fully defined at this time, and v) Limitation is contextual: there are safety restrictions and comprehensive involvement.

6. CONCLUSIONS. LIMITATIONS. FUTURE DIRECTIONS

The project highlights how local water, energy, and material cycles can be supported by small modular systems. The following conclusions can be drawn:

(1) The project demonstrates that a comprehensive approach to circular economy technologies, energy systems, and resources management technologies can contribute to a complex solution that would benefit local communities.

(2) The system is based on the idea of a green corridor. This corridor includes controlled flows and short routes. This idea of structure is similar to port configurations. Ports operate with concentrated flows and established routines and this idea was followed in this approach. Digitalization and technological advancement contribute to the finalization of the solution.

(3) Industrial symbiosis becomes a sustainable option. Developing solutions for the community through technology transfer from research organizations to industrial partners represents a solid step in the circular economy.

(4) The research is still in its early stages. These results are preliminary and represent results obtained in the design phase of the mobile idea of obtaining resources from waste.

(5) By framing industrial symbiosis as a green corridor, the ECONEXUS model contributes to the development of smart and resilient logistics corridors focused on resource circulation rather than conventional freight flows.

To sum up, we hope that ECONEXUS model contributes also to the MARLOG 15 concept of smart and resilient corridors by reframing logistics as the circulation of resources rather than goods.

7. ACKNOWLEDGMENTS

This research is partially supported by the project "Innovative Technological Solutions to Circularity and Urban-Industrial Symbiosis within the Water-Energy-Materials-Fertilizers Nexus (ECO NEXUS)", Smart Growth, Digitization and Financial Instruments Program, 2021-2027, MySMIS no. 336912.

8. DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

During the preparation of this work, the authors used Consensus and Writefull in order to support literature searching and assist with language accuracy. After using this tool/service, the author(s) reviewed and edited the content as necessary and take full responsibility for the content of the publication.

9. REFERENCES

[1] Rodias, Emmanouil, Eleni Aivazidou, Christos Achillas, Dimitrios Aidonis, and Dimitrios Bochtis. "Water- Energy-Nutrients Synergies in the Agrifood Sector: A Circular Economy Framework." Energies 14 (2021). (1): 159. https://doi:10.3390/en14010159.

[2] Lu, Chuan, Xuhui Pan, Xiaoyu Chen, Jing Mao, Jiawei Pang, and Baoguo Xue. "Modeling of Waste Flow in Industrial Symbiosis System at City-Region Level: A Case Study of Jinchang, China." Sustainability 13 (2021). (2): 466. https://doi:10.3390/su13020466.

[3] Udugama, Isuru A., Leander A.H. Petersen, Francesco C. Falco, Helena Junicke, Alexandar Mitic, Xavier Flores Alsina, Seyed Soheil Mansouri, Krist V. Gernaey. "Resource Recovery from Waste Streams in a Water-Energy-Food Nexus Perspective: Toward More Sustainable Food Processing." Food and Bioproducts Processing 119 (2020): 133–147. https://doi:10.1016/j.fbp.2019.10.014.

[4] Ferreira, Inês A., Ricardo Godina, and Helena Carvalho. "Waste Valorization through Additive Manufacturing in an Industrial Symbiosis Setting." Sustainability 13 (2021) (1): 234. https://doi:10.3390/su13010234.

[5] Zeynali, Rahim, et al. "Smart Municipal Wastewater Treatment Sludge Management: Enhancement of Biogas Production from Anaerobic Digestion Amended by Optimized Sludge-Derived Biochar." Science of the Total Environment 989 (2025): 179860. https://doi:10.1016/j.scitotenv.2025.179860.

[6] Xiao, Jie, Ulrich Alewell, Ingo Bruch, and Harald Steinmetz. "Development of a Self-Sustaining Wastewater Treatment with Phosphorus Recovery for Small Rural Settlements." Sustainability 13 (2021) (3): 1363. https://doi:10.3390/su13031363.

[7] Estévez, Susana, Santiago González-García, Gumersindo Feijoo, and María Teresa Moreira. "How Decentralized Treatment Can Contribute to the Symbiosis between Environmental Protection and Resource Recovery." Science of the Total Environment 812 (2022): 151485. https://doi:10.1016/j.scitotenv.2021.151485.

[8] Khoury, Michel, et al. "Towards the Development of an Online Platform for an Industry Metabolic Pathway." Water Science and Technology 91 (2025) (4): 382–399. https://doi:10.2166/wst.2025.020.

[9] Besson, Marion, S. Berger, L. Tiruta-Barna, Eric Paul, and M. Spérandio. (2021). "Environmental Assessment of Urine, Black and Grey Water Separation for Resource Recovery..." Journal of Cleaner Production 301: 126868. https://doi:10.1016/j.jclepro.2021.126868.

[10] Néméthy, Susanne A., Anna Ternell, Lena Bornmalm, Bengt Lagerqvist, and László Szemethy.

"Environmental Viability Analysis of Connected European Inland–Marine Waterways..." Atmosphere 13 (2022) (6): 951. https://doi:10.3390/atmos13060951.

[11] European Commission. (2019). The European Green Deal. Accessed November 27, 2025.

https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[12] Feiferytė-Skirienė, Agnė, and Žaneta Stasiškienė. "Seeking Circularity: Circular Urban Metabolism in the Context of Industrial Symbiosis." Sustainability 13 (2021) (16): 9094. https://doi:10.3390/su13169094.

[13] Bian, Yu, Liang Dong, Zongguo Liu, and Ling Zhang. "A Sectoral Eco-Efficiency Analysis on Urban-Industrial Symbiosis." Sustainability 12 (2020) (9): 3650. https://doi:10.3390/su12093650.

[14] Agache, Tiberiu, Anca Agache and Larisa Ivascu "Economic Growth and Circular Economy: A Statistical Approach to Resource Management." Proceedings of the International Conference on Business Excellence, vol. 19 (2025) (1). https://doi:10.2478/picbe-2025-0404.

[15] Magliocca, Nicholas R. "Agent-Based Modeling for Integrating Human Behavior into the Food–Energy–Water Nexus." Land 9 (2020) (12): 519. https://doi:10.3390/land9120519.

[16] Jugović, Alen, Marko Sirotić, Tomislav P. Jugović, and Damir Žgaljić. "Green Shipping Corridors: ABibliometric Analysis of Policy, Technology, and Stakeholder Collaboration." Applied Sciences 15 (2025) (6): 3304. https://doi:10.3390/app15063304.

[17] Södergren, Karin, and Jenny Palm. "Governing Industrial and Urban Symbiosis: Internal and External Strategies for Municipal Development." Journal of Environmental Management 384 (2025): 125469. https://doi:10.1016/j.jenvman.2025.125469.

[18] Genc, Omer, Ahmet Kurt, Dervis M. Yazan, and Emin Erdis. "Circular Eco-Industrial Park Design Inspired by Nature..." Journal of Environmental Management 270 (2020): 110866. https://doi:10.1016/j.jenvman.2020.110866.

[19] Momirski, Lijana Ažman, Boštjan Mušič, Borut Cotič, Riccardo Gamberini, and Angela Butturi. "Urban Strategies Enabling Industrial and Urban Symbiosis..." Sustainability 13 (2021) (9): 4616. https://doi:10.3390/su13094616.

[20] Neves, Ana, Ricardo Godina, Sérgio G. Azevedo, and João C. O. Matias. "A Comprehensive Review of Industrial Symbiosis." Journal of Cleaner Production 247 (2020): 119113. https://doi:10.1016/j.jclepro.2019.119113.

[21] Chamas, Zaher, M. Abou Najm, M. Al-Hindi, Ali Yassine, and R. Khattar. "Sustainable Resource Optimization under Water-Energy-Food-Carbon Nexus." Journal of Cleaner Production 278 (2021): 123894. https://doi:10.1016/j.jclepro.2020.123894.

[22] Laspidou, Charalampia S., Nikolaos Mellios, Aikaterini Spyropoulou, Dimitrios Kofinas, and Maria P. Papadopoulou. "Systems Thinking on the Resource Nexus..." Science of the Total Environment 717 (2020): 137264. https://doi:10.1016/j.scitotenv.2020.137264.

[23] Haller, Hans, et al. "Towards a Resilient and Resource-Efficient Local Food System Based on Industrial Symbiosis..." Sustainability 14 (2022) (4): 2197. https://doi:10.3390/su14042197.

[24] Ivanović, Branka. "Multi-Functional Land-Use Planning as a Regulator of Urban Metabolism." Spatium 43 (2020): 52–58. https://doi:10.2298/spat2043052i.

[25] Pierson, Thomas C. "Hyperconcentrated Flow - Transitional Process between Water Flow and Debris Flow." In Debris-Flow Hazards and Related Phenomena, 159–202, 2005. https://doi:10.1007/3-540-27129-5_8.

[26] Yu, Yang, Dervis M. Yazan, S. Bhochhibhoya, and Lysette Volker. "Towards Circular Economy through Industrial Symbiosis in the Dutch Construction Industry." Journal of Cleaner Production 293 (2021): 126083. https://doi:10.1016/j.jclepro.2021.126083.

[27] Haq, Hassan, Petteri Välisuo, and Sami Niemi. "Modelling Sustainable Industrial Symbiosis." Energies 14 (2021) (4): 1172. https://doi:10.3390/en14041172.

[28] Rincón-Moreno, Julio, Marta Ormazabal, María J. Álvarez, and Carlos Jaca. "Shortcomings of Transforming a Local Circular Economy System..." Sustainability 12 (2020) (20): 8423. https://doi:10.3390/su12208423.

[29] Nika, Christina E., V. Vasilaki, D. Renfrew, M. Danishvar, A. Echchelh, and Eleni Katsou. "Assessing Circularity of Multi-Sectoral Systems under the Water-Energy-Food-Ecosystems Nexus." Water Research 221 (2022): 118842. https://doi:10.1016/j.watres.2022.118842.

[30] Vinca, Alessandro, et al. "The NExus Solutions Tool (NEST) v1.0." Geoscientific Model Development 13 (2020) (3): 1095–1121. https://doi:10.5194/gmd-13-1095-2020.

[31] Authier, Romain, et al. "Towards Sustainable Land Management in Small Islands: A Water-Energy-Food Nexus Approach." PLoS One 19 (2024) (11): e0310632. https://doi:10.1371/journal.pone.0310632.

[32] Yu, Lixia, Ying Xiao, Xiao-Ting Zeng, Yi-Ping Li, and Yu-Rong Fan. "Planning Water-Energy-Food Nexus System Management under Multi-Level and Uncertainty." Journal of Cleaner Production 251 (2020): 119658. https://doi:10.1016/j.jclepro.2019.119658.

[33] Liu, Shuang, and Lin Zhao. "Development and Synergetic Evolution of the Water–Energy–Food Nexus System in the Yellow River Basin." Environmental Science and Pollution Research 29 (2022) (43): 65549– 65564. https://doi:10.1007/s11356-022-20405-9.

[34] Naidoo, Dhesigen, et al. "Operationalising the Water-Energy-Food Nexus through the Theory of Change." Renewable and Sustainable Energy Reviews 149 (2021): 111416. https://doi:10.1016/j.rser.2021.111416.

[35] Nhamo, Lazarus, and Beauty Ndlela. "Nexus Planning as a Pathway towards Sustainable Environmental and Human Health Post Covid-19." Environmental Research 192 (2021): 110376. https://doi:10.1016/j.envres.2020.110376.

[36] Nhamo, Lazarus, Beauty Ndlela, Samson Mpandeli, and Tafadzwa Mabhaudhi. "The Water-Energy-Food Nexus as an Adaptation Strategy..." Sustainability 12 (2020) (20): 8582. https://doi:10.3390/su12208582.

[37] Mpandeli, Samson, et al. "Migration under Climate Change in Southern Africa: A Nexus Planning Perspective." Sustainability 12 (2020) (11): 4722. https://doi:10.3390/su12114722.

[38] Parsa, Amir, Mark J. Van de Wiel, and Uwe Schmutz. "Intersection, Interrelation or Interdependence? The Relationship between Circular Economy and Nexus Approach." Journal of Cleaner Production 313 (2021): 127794. https://doi:10.1016/j.jclepro.2021.127794.

[39] Arias, Alba, Margarita Rama, Santiago González-García, Gumersindo Feijoo, and María Teresa Moreira. "Environmental Analysis of Servicing Centralised and Decentralised Wastewater Treatment..." Journal of Water Process Engineering 37 (2020): 101469. https://doi:10.1016/j.jwpe.2020.101469.

[40] Bernal, Diego, Iván Restrepo, and Sonia Grueso-Casquete. "Key Criteria for Considering Decentralization in Municipal Wastewater Management." Heliyon 7 (2021) (3): e06375. https://doi:10.1016/j.heliyon.2021.e06375.

[41] Ngabala, Francois J., and John K. Emmanuel. "Potential Substrates for Biogas Production through Anaerobic Digestion." Heliyon 10 (2024) (23): e40632. https://doi:10.1016/j.heliyon.2024.e40632.

[42] Miller, Kelly E., T. Herman, D. A. Philipinanto, and S. C. Davis. "Anaerobic Digestion of Food Waste, Brewery Waste, and Agricultural Residues..." Sustainability 13 (2021) (12): 6509. https://doi:10.3390/su13126509.

[43] Nindhia, Tjokorda G. T., Mark McDonald, and David Styles. "Greenhouse Gas Mitigation and Rural Electricity Generation by a Novel Two-Stroke Biogas Engine." Journal of Cleaner Production 280 (2021): 124473. https://doi:10.1016/j.jclepro.2020.124473.

[44] Gyadi, Tayo, Ankit Bharti, S. Basack, Praveen Kumar, and Enrico Lucchi. "Influential Factors in Anaerobic Digestion of Rice-Derived Food Waste and Animal Manure." Bioresource Technology 413 (2024): 131398. https://doi:10.1016/j.biortech.2024.131398.

[45] Lucertini, Giulio, and Francesco Musco. "Circular Urban Metabolism Framework." One Earth 2 (2020) (2): 138–142. https://doi:10.1016/j.oneear.2020.02.004.

[46] Fraccascia, Luca, Ivan Giannoccaro, and Vito Albino. "Ecosystem Indicators for Measuring Industrial Symbiosis." Ecological Economics 183 (2021): 106944. https://doi:10.1016/j.ecolecon.2021.106944.

[47] Silva, Ana, et al. "Analysis of Regional Economic Metabolism through Modeling." Energy Reports 6(2020): 102–107. https://doi:10.1016/j.egyr.2019.08.026.