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Industrial Urban symbiosis and its social, economic and environmental impact on different European regions (SYMSITES)

Independent Assessment of the approach and methods developed by Klink Srl

Aim of the report

The aim of this report is to provide Klink Srl with an independent assessment of the approach and method developed within the framework of the project SYMSITES. The assessment focuses on the *k*-Social Decision Support System module designed by Klink to enhance the quality of decision making processes in the context of Industrial Urban Symbiosis. Klink's contribution is analysed through a policy oriented perspective. The report shows that the strengths of the approach in terms of path-breaking practices and tools for policy making largely exceed its shortcomings. The report is structured as it follows. In section 1 a reconstruction of the literature in the field of Industrial Urban Symbiosis is provided; in section 2 I describe different existing models of Industrial Urban Symbiosis; in sections 3 and 4 I summarise, respectively, a policy tool and a governance perspective to Industrial Urban Symbiosis, which allow to set Klink's approach in a wider theoretical framework; section 5 describes Klink's role in SYMSITES, while section 6 is dedicated to highlight the strengths and weakness of Klink's approach.

Keywords

Industrial Urban Symbiosis; user-oriented policy tool; decision making; simulations; FCM; ABM.

1. Industrial Urban Symbiosis: an overview

Industrial Urban Symbiosis (I-US) represents an advanced evolution of Industrial Symbiosis (IS), a core principle of the Circular Economy (CE). Industrial symbiosis is a key concept in industrial ecology, defined as a voluntary cooperation of enterprises. It involves the physical exchange of materials, energy, water, and by-products between traditionally separate industries operating in geographic proximity and urban areas (Chertow 2000; Vitálišová, Borkesova 2016; Domenech et al. 2019). In Europe, I-US is increasingly recognized as a vital strategy to enhance resource efficiency, reduce environmental impact, and foster regional competitiveness, often supported by EU-level strategies like the Circular Economy Action Plan.

Literature on Industrial Urban Symbiosis (I-US) highlights three main domains where I-US is expected to have significant impacts: the environment, the economy and society.

As for the environmental impact, the primary scientific consensus highlights the significant positive benefits of I-US across European regions (Domenech et al. 2019) in terms of Waste Diversion/Resource Efficiency, Reduced Emissions and Water Management. By treating industrial and urban waste streams (e.g., wastewater, municipal solid waste) as secondary raw materials or energy sources for industrial processes, I-US reduces the volume of waste sent to landfills (Cao et al., 2017). This also conserves virgin raw materials, decreasing the environmental pressures associated with their extraction and processing. Moreover, synergies lead to lower overall energy consumption and decreased reliance on fossil fuels. Scientific studies, particularly those using methodologies like Material Flow Analysis (MFA) and Life Cycle Assessment (LCA), quantify the reduction in Greenhouse Gas emissions (e.g., CO₂) and other air pollutants across the networked activities. Examples include using industrial excess heat to provide district heating for nearby urban populations. In the field of Water Management, I-US promotes the efficient use of water resources through cascading systems where wastewater from one process (industrial or urban) is treated and reused in another, mitigating the strain on local water bodies, a crucial benefit in water-stressed Southern European regions.

Concerning its economic impacts, I-US is expected to foster economic advantages by creating new business opportunities, reducing operational costs, and promoting regional resilience (European Commission 2015). Companies engaged in symbiotic exchanges should benefit from lower raw material and disposal costs. Selling by-products and waste streams creates a new revenue source, transforming liabilities into assets. The European Commission has estimated that implementing Industrial Symbiosis could result in significant annual savings and new sales across the EU. Also, the complexity of identifying and implementing symbiotic links drives technological innovation in waste treatment, valorization, and energy recovery. This specialization can enhance the overall competitiveness of the industrial ecosystems within a region, leading to the formation of specialized clusters and new “green’ jobs”. Moreover, in some Southern Regions (e.g. Catalonia, in Spain), I-US initiatives have demonstrated how interlinked, long-term collaborations gradually contribute to the emergence of more resilient and diversified regional industrial ecosystems, making them less vulnerable to external economic shocks (Susur et al. 2019).

Finally, the social benefits of IUS are deemed crucial for local acceptance and sustainable development, yet they are often less quantified than economic or environmental impacts. In this respect, the need for new infrastructure, management systems, and innovative technologies to facilitate I-US is expected to stimulate the creation of high-skilled local jobs. Moreover, since I-US necessitates a strong network of actors – industries, municipalities and local communities – it should help fostering collective engagement and mutual trust (Henriques et al et al 2021). This collaborative culture is an intangible asset that improves governance and the efficiency of public services. By reducing pollution, lowering landfill usage, and improving resource security, I-US contributes also to a greener, healthier local environment for urban populations. This is particularly relevant in densely populated industrial areas where poor air or water quality is a major concern.

2. Models of Industrial Urban Symbiosis

Chertow (2000) maintains that industrial symbiosis typically evolves according to one of two alternative models: a *planned model* or a *self-organizing* (spontaneous) model. Unfortunately, as Vitálišová and Borkesova (2016) argue, the spontaneous development of symbiotic industrial networks is quite rare and usually requires a significant amount of time to emerge. This spontaneous growth is heavily dependent on how the existing social, economic, technical, and political conditions within a given geographic area either support or hinder the exchange of industrial by-products. Essentially, the more proactive and supportive these embedded conditions are, the greater the likelihood that industrial symbiosis will develop successfully.

In this respect, as Eriksen et al (2023) maintain, developing I-US requires changes that can be proactively fostered through intentional efforts by key participants, a concept often referred to as “change agency”. According to Grillitsch and Sotarauta (2020), this change agency can be broken down into three essential types, all of which are crucial for driving both regional development and the transition to industrial symbiosis: Schumpeterian innovative entrepreneurship, which focuses on radical new economic activity; institutional entrepreneurship, which involves reshaping the rules and norms of the system; and place-based leadership, which is rooted in local action and vision. A specific focus on informal institutions – such as values, norms and culture – is needed, as it avoids to place interventions in a *vacuum* of community support.

Another way of classifying different types of I-US consists in considering the scale or level at which the partnerships are formed Buda, Ricz (2022). This scaling approach typically involves three categories (Neves et al 2019):

1. Micro Level, that refers to symbiotic activities implemented within a single company or corporation.
2. Meso Level, describing cooperation among companies that are close to one another geographically, such as those co-located in eco-industrial parks.
3. Macro Level, that encompasses symbiotic initiatives that operate across a wider geographic area, such as a region or an entire nation.

In contrast, other researchers (Henriques et al. 2021) suggest an alternative framework that focuses more on the type of material “exchange” rather than just the physical location. They categorize industrial symbiosis into four specific types:

1. Internal Exchange: the circulation and reuse of materials that happen entirely inside one company.
2. External Exchange: the utilization of a company's waste or by-products by a separate, external company.
3. Eco-Industrial Park: symbiosis that occurs specifically within a dedicated industrial park setting.
4. Urban Industrial Symbiosis: partnerships that connect industrial processes with the wider urban system.

Table 1 – I-US: scaling approach, types of exchange and actors

Level	Form of exchange	Actors
<i>Micro</i>	Internal exchange	One single company
	External exchange	Two or more companies
<i>Meso</i>	(Eco) Industrial Park	Companies in the industrial park and park management authority
	Urban Industrial Symbiosis	Local community (authority) and companies
<i>Macro</i>	Nation-wide Industrial Symbiosis	Economic sectors

Source: author's re-adaptation from Buda, Ricz (2022): 171.

In Table 1 we summarize the forms of exchange and actors associated to each level. Essentially, while one typology is based on geographic and organizational scale, the other is defined by the nature and scope of the material transaction.

As Buda and Ricz (2022) notice, Industrial symbiosis policies can also be categorized using two distinct pairings: top-down vs bottom-up and direct vs indirect (Lybaek et al. 2021). These distinctions highlights, respectively, whether the policy originates from a high or low organizational level and whether its purpose is explicitly about symbiosis or whether it has an unintended but positive influence on it. *Top-down* policies are established by central governments or large international bodies, while *bottom-up* policies are initiated by local stakeholders or come from local governments, often taking the form of local incentives or subsidies that cover municipal and regional levels. As for *direct* policies, they are created by a governmental body (at any level) with the explicit goal of promoting, supporting or legally enforcing industrial symbiosis. Finally, *indirect* policies are those that were not specifically designed for industrial symbiosis but still have a significant impact on its development. These policies cover a broad range of general conditions, such as infrastructure planning, general tax and customs rules (like a landfill tax), waste management policies, and other general regulations that shape the market for resources, products, and services.

3. Industrial Urban Symbiosis: A Policy Tool Perspective

The pursue of Industrial Urban Symbiosis strategies entail complex questions about policy formulation and design. The process of policy formulation involves generating different alternatives for solving a public problem, by identifying the political and technical limitations on government activities. Understanding these constraints reveals what actions are possible and what are not, and thus, what actions are actually

feasible. While this seems straightforward, many policy recommendations ignore the real-world limitations on a proposed policy's effectiveness. On contrary, policy-makers must face both *substantive* and *procedural* constraints when comparing possible alternatives (Howlett et al 2016): while the former concern the very nature of the problem itself, the latter have to do with the institutional limits imposed to government activities. The technical aspects of the problem must be analysed on the basis of its political acceptance and administrative feasibility, that generates conflicting pressures. When developing potential courses of action, policy-makers must determine not only the *substance* of the policy, but also the method of execution, considering different strategies along with the specific tools needed for their implementation. These “policy tools” are the mechanisms governments use to carry out their public policies.

To date, the formulation, implementation and impact of I-US vary significantly across European regions, influenced by policy, industrial structure, and culture (Domenech et al. 2019). While in the Northern European clusters some programs like the British National Industrial Symbiosis Programme (NISP) have provided an organized, facilitated approach, showing data on CO2 emissions reduction and resource savings, in Southern Europe I-US is often championed through national or regional Circular Economy strategies. In these areas, the focus is more pronounced on addressing water scarcity and managing urban-industrial interactions within fragmented or smaller industrial sites. Be that as it may, the effectiveness of I-US is directly tied to a supportive legal and institutional framework (European Circular Economy Stakeholder Platform 2021). EU-funded projects and regional Smart Specialization Strategies are instrumental in turning these concepts into practical implementations, ensuring that the benefits – environmental, economic, and social – tend to be maximized and distributed equitably across the participating regions.

From a *policy tool perspective* (PTP), the varying social, economic, and environmental impacts of I-US across European regions are largely determined by the specific instruments chosen by public authorities to facilitate, regulate and incentivize these strategies. Policy tools are typically categorized as: *organization-based*, *authority-based*, *treasure-based* and *nodality-based* (Hood 1986; Howlett et al 2016) – see Figure 1.

Figure 1 – Policy instruments: a taxonomy

Organization	Authority	Treasure	Nodality
Direct provision of goods/services and public enterprise	Command-and-control regulation	Grant and loans	Information collection and release
Government re-organization	Self-regulation	User charges	Advice and exhortation
Family, community, voluntary organizations	Standard-setting and delegated regulation	Taxes and tax expenditures	Advertising
Market creation	Advisory committees and consultations	Interest group creation and funding	Commissions and inquiries

Source: Howlett et al (2016): 116.

While *organization-based* policy tools – which are those instruments that entail direct public intervention (in terms of direct provision, public enterprises, market creation or government re-organization) and/or the involvement of family, community and

voluntary organizations – are generally less utilized in promoting I-US strategies, the other three types of policy tools have been profitably used.

Authority-based tools set the binding rules and standards that directly force or enable resource exchanges, primarily affecting environmental outcomes. The most significant regulatory tool impacting I-US in Europe is the legal definition of waste, governed by the Waste Framework Directive (WFD). The End-of-Waste (EoW) criteria enable certain waste streams to lose their "waste" status and be treated as valuable "secondary raw materials" for use in other industrial or urban processes. Where national and regional authorities effectively implement clear, harmonized EoW criteria, the environmental impact is immediate: materials (e.g., specific ashes, treated biomass, recovered aggregates) can be readily exchanged, resulting in significant waste diversion from landfills and a measurable reduction in virgin material use (Domenech et al. 2019). Conversely, in regions with complex or differing interpretations, regulatory uncertainty acts as a critical barrier to material exchange, slowing the environmental transition. In this respect, differing national interpretations of EU waste legislation is a key hurdle to scaling up I-US across the continent. Another regulatory tool which may be fruitfully employed to implement I-US strategies consists in Urban Planning and Zoning. Regional spatial planning and local zoning regulations can be used to promote the co-location of industries and urban utilities (e.g., wastewater treatment plants near industrial parks) to facilitate thermal or water synergies. This can lead to environmental gains such as the efficient capture and distribution of waste heat from industrial sites to municipal district heating networks (a common synergy in Scandinavian regions), resulting in lower fossil fuel consumption and reduced CO₂ emissions (Chertow 2000).

Treasure-base tools involve using financial incentives or disincentives to influence actors' costs and revenues, directly shaping the economic viability of IUS projects. In this respect, a major role is played by EU Funds and Financial Incentives, which consist in direct financial mechanisms, such as grants from the European Regional Development Fund (ERDF) or funding from Horizon Europe (e.g., the SYMSITES project), which are used to cover the high initial capital expenditure (CAPEX) required for shared infrastructure (pipelines, treatment facilities). These funds are vital in less-developed regions or in countries where the private sector lacks sufficient risk appetite for novel symbiotic exchanges. They improve the Return on Investment (ROI) for businesses, making symbiotic projects economically attractive and fostering regional competitiveness. The economic impact is seen in reduced operational costs (lower energy/material purchases) and new revenue streams from selling by-products (Chertow, Ehrenfeld 2012; European Commission 2015). Another strategy to implement I-US policies is resorting to taxation and fees, that is introducing differential taxation on waste disposal (landfill taxes) or fees for virgin resource use. High landfill taxes, typical in many Northwestern European regions, serve as a strong economic disincentive for traditional disposal, making the recycling or valorization through I-US economically competitive. This policy tool directly steers industrial behavior towards symbiotic solutions.

Chertow (2000) noticed that proximity and information are key to successful symbiosis; digital tools serve as a policy mechanism to overcome the limitation of pure geographical proximity, expanding the social and economic reach of IUS initiatives. Nodality-based tools involve in fact the use of information resources at governments'

disposal: in the field of I-US are deemed crucial for building the trust, knowledge, and network density necessary for successful symbiosis, heavily influencing the social dimensions. A first type of nodality-based tool consists in Symbiosis Facilitation Programs, that is Government-supported third-party facilitators or platforms that identify and match resource flows between industrial and urban actors. This tool may be fruitfully employed in those regions characterized by a high proportion of Small and Medium-sized Enterprises, which lack the internal capacity for complex industrial ecology analyses (Lombardi, Laybourn 2012). In this respect, facilitation reduces the search costs and lowers the transaction costs associated with setting up exchange agreements. These programs may also foster trust, collaboration and network density, which are necessary prerequisites for sustainable regional I-US ecosystems, leading to the creation of "green jobs" in resource management and processing. Another type of nodality-based tool involves the building of publicly or privately managed data repositories and digital platforms (often supported by national or EU R&D projects) that catalogue available waste streams and resource demands. These repositories address the information asymmetry problem – as industries often are not aware of what resource streams are available nearby. By making data accessible, these tools expand the potential scope of I-US beyond immediate geographical clusters, thus democratizing access to the economic and environmental benefits across broader regions.

4. Industrial Urban Symbiosis in Europe: A Governance Perspective

In addition to being framed from a policy tool perspective, the success of Industrial Urban Symbiosis across different European regions may also be framed as a challenge of governance, requiring cooperation across traditional sectoral and administrative boundaries (industries, municipalities, and utilities). The ultimate social, economic, and environmental impact of I-US is not merely a technical question of finding a resource match or a technical solution which is also politically feasible, but also a governance question of building the stable, flexible, and trust-based relational architecture necessary to sustain symbiotic relationships over time (Susur et al. 2019; Eriksen et al 2023).

Governance theories serve as essential analytical tools for comprehending the contemporary world. These theories are varied in their objectives (Ansell, Torfing 2022): some illuminate how various actors (across different jurisdictions, levels, and institutional settings) interact to share knowledge, coordinate efforts, and make binding decisions that generate collective results. Others help clarify the roles of public, private, and civil society participants in governing processes across the globe. Still others focus on design, organization, evolution, and measurement, studying how governance is built, how it changes over time, and its ultimate impact. Furthermore, some theories investigate governance failures or suggest improvements for achieving more effective, democratic, or innovative ways to solve societal problems, deliver services, or regulate society. Collectively, these theories offer a robust analytical toolkit for understanding and engaging in the complex task of establishing ordered rule in our increasingly fragmented and dynamic society.

Governance mechanisms determine the stability, scale, and longevity of symbiotic exchanges, thereby mediating the distribution of social, economic, and environmental benefits (Chertow 2000; Susur et al. 2019). I-US relies on effective multi-level governance, connecting the macro-level policy framework (EU directives) with the

micro-level implementation (local permits and bilateral agreements). Failures at any level – whether due to conflicting mandates or lack of funding – cripple the overall strategy. Policy studies on IUS often distinguish between three ideal-type governance models, which are variably adopted across Europe and yield distinct outcomes: Hierarchical Governance (HG); Network Governance (NG); Market Governance (MG).

HG generally consists in centralized planning and control, often involving the public sector (national or regional government) and/or a dominant industrial actor mandating symbiotic relationships. This model ensures rapid deployment and high environmental certainty (e.g., mandated pollution reduction targets). Hierarchical structures are best suited for securing complex, high-Capital Expenditure infrastructure projects like large-scale pipelines for waste heat or treated wastewater exchange. This ensures long-term environmental benefits, such as significant CO₂ emissions reductions from district heating systems. Economically, it can secure long-term stability for key energy/material flows (since long-term contracts reduce commercial risk, essential for attracting necessary investment), but may be less flexible, slow to integrate smaller firms or innovative exchanges due to bureaucratic complexity, and costly to manage. Socially, it tends to be less inclusive, with limited initial stakeholder input: decisions are centralized, limiting participation from smaller local communities or SMEs. Social benefits primarily stem from the overall guaranteed improvement in regional environmental quality. The establishment of fully planned Eco-Industrial Parks (EIPs), or specific regulatory zones, spread in some highly structured Northern European contexts and larger industrial clusters, represent practical examples of this top-down approach (Roberts 2004).

NG relies on voluntary cooperation, trust-building, and horizontal coordination among multiple, formally separate organizations. Often mediated by a Symbiosis Facilitator (a third-party organization), this approach aims at maximizing social capital and regional resilience. The facilitator plays a crucial role in overcoming "information asymmetry" and establishing the collective confidence essential for network stability (Lombardi, Laybourn 2012). The relevance of a third party to perform place-based leadership has been confirmed in a comparative study by Eriksen et al (2023): in the five regions covered by their analysis, a third-party position fosters cooperation, acting as a moderating voice among actors and promoting trust and opportunities for common visions. In terms of its environmental impact, the NG favours the network's capacity to engage numerous SMEs and disparate municipal waste streams leads to cumulative, distributed environmental benefits, focusing on resource and waste diversion at a regional scale. Economically, the approach promotes the discovery of diverse and often spontaneous synergies among SMEs and local municipalities, fostering local innovation. NG lowers the barriers to entry for SMEs by reducing search and transaction costs. It fosters regional economic innovation and resilience by creating diverse, mutually beneficial exchanges that do not require massive infrastructure investment. NG also fosters high social capital development. The act of facilitated collaboration builds mutual trust and shared knowledge within the regional economy, a vital intangible asset. It promotes regional cohesion and specialized "green job" creation in resource management and matching services. The primary challenge is maintaining trust and commitment in the absence of a binding hierarchy. The spread of National Industrial Symbiosis Programme (NISP)-like networks across the UK and other European countries constitute an example of such an approach.

MG entails that symbiosis arises opportunistically through bilateral exchanges based purely on commercial contracts and price signals, with minimal public intervention. While highly economically efficient for the participating firms (driven by low cost or high revenue), this model lacks robustness. Its environmental impact is limited and unmanaged. While individual exchanges offer environmental benefits (e.g., reducing waste for the selling firm), the model fails to address complex, systemic issues like utilizing low-grade waste heat or managing mixed urban waste streams. The impact is a by-product of individual cost-saving, not planned ecological design. In economic terms, MG secures high individual efficiency. Exchanges are quick, low-cost, and based on clear profits, but the system is unstable and subject to market volatility (e.g., commodity price fluctuations can immediately halt a symbiotic flow). However, its social impact is Minimal. Relationships are transactional, contributing little to community trust or regional planning efforts. Overall, MG is the least stable form of governance for complex I-US systems (Chertow 2000).

To date, most successful I-US initiatives in European regions, such as the famous case of Kalundborg (often cited as hierarchical), actually rely on a hybrid governance model (Chertow 2000; Susur et al. 2019). They use hierarchical planning (e.g., mandated infrastructure via utilities or public bodies) to secure core exchanges (energy, water) while employing network facilitation to continuously identify new, incremental, and socially inclusive resource matches. The policy challenge for European regions is mastering this multi-level coordination to maximize the combined environmental stability, economic flexibility, and social inclusivity that IUS promises.

While I-US offers clear benefits, its successful implementation is often hampered by systemic governance failures that vary across Europe. These challenges prevent the efficient scaling of symbiotic networks and modulate their social, economic, and environmental impacts.

First, in particular in Southern and Eastern Europe, a fragmentation and lack of coordination emerges. In many regions, particularly in certain areas of Italy and Spain, as well as parts of Eastern Europe, the governance structure is highly fragmented. There is a lack of both vertical and horizontal coordination between crucial public actors. Vertical fragmentation occurs when national legislation conflicts with regional or local implementation (e.g., differing interpretations of waste laws). Horizontal fragmentation involves a failure to coordinate across different local jurisdictions (multiple small municipalities, industrial parks, and utility companies) operating within the same geographical area. This severely limits the scale and scope of I-US. Complex resource flows like wastewater or large-scale residual heat exchange often require investment and permitting across multiple municipal boundaries. Fragmentation increases transaction costs and introduces regulatory uncertainty, hindering the economic viability of projects and limiting the achievement of large-scale environmental impacts.

Second, a certain degree of regulatory rigidity and legal uncertainty (the s.c. End-of-Waste Hurdle) represents the most frequently cited legal governance challenge in academic literature. The strict legal definition differentiating a "waste" (subject to rigorous and costly disposal regulations) from a "by-product" or "End-of-Waste" (EoW) material (which can be traded freely as a raw material) creates significant uncertainty. National authorities often interpret the Waste Framework Directive (WFD) differently, or require lengthy, project-specific permits for EoW status. This regulatory rigidity is a

major barrier to the economic and environmental impact of I-US. Industries are hesitant to invest in symbiotic relationships if the legality and cost of the resource flow could change. The lack of harmonized EoW standards across EU member states means that a successful symbiotic exchange viable in one region might be illegal or impractical in a neighbouring country (Domenech et al. 2019), stifling cross-border and regional scaling.

Third governance failures extend to how financial risk is managed and allocated, particularly for infrastructure. I-US requires blended finance (a mix of public and private funds) for shared infrastructure. Governance is poor when public agencies fail to clearly structure financial instruments (Economic tool) or mitigate the high initial perception of risk from the private sector. Furthermore, the governance structure must fairly allocate the risks of supply/demand changes among different actors (e.g., who pays if the waste-supplying firm shuts down?). This primarily restricts the economic impact to small, spontaneous exchanges. Complex, capital-intensive synergies (like energy grids) remain underdeveloped because neither the private industrial partner nor the public municipality is willing to assume the long-term financial risk, particularly in regions with less mature capital markets or lower institutional capacity.

Fourth, as Eriksen et al (2023) observe, the current legal structure lacks of coherence and alignment between national-level legislation and regional-level policies. Furthermore, there is an ongoing necessity to evaluate and interpret potential industrial symbiosis solutions in light of the EU Taxonomy, particularly the “Do No Significant Harm (DNSH)” principle. This is especially problematic in regions where industry is highly scattered and where establishing industrial symbiosis relies on building new infrastructure immediately near the energy-supplying company. Moreover, the sheer complexity of the policy landscape acts as a significant barrier. This difficulty in navigating and interpreting regulations is particularly burdensome for small and medium-sized firms, which typically lack the necessary time and dedicated resources to manage this intricate task.

Finally, but descending from the very last remark, there is a widespread lack of institutional capacity and knowledge. The ability to implement I-US depends on specialized human resources and institutional memory. Many local and regional authorities lack the specialized expertise to act as symbiosis facilitators or to conduct the necessary Life Cycle Assessments (LCA) to prove the environmental benefit of a proposed exchange. The social aspect of governance – building trust and maintaining long-term commitments – requires dedicated institutional effort. Without dedicated institutional capacity (e.g., regional development agencies that act as “symbiosis brokers”), projects rely solely on spontaneous, often fragile, market dynamics. This limits the social impact (job creation in facilitation and local consensus building) and prevents the development of robust, resilient networks (Lombardi Laybourn 2012). Regions that have successfully implemented I-US (e.g., those using the NISP model) explicitly invested in this human and institutional capacity.

5. The SYMSITES Project: KLINK's role

The SYMSITES project is a major European initiative dedicated to developing and validating new technologies and integrated solutions based on the Industrial and Urban Symbiosis (I-US) concept. The main goal of the SYMSITES project is to implement I-US across four diverse European regions, chosen for their differing socio-economic

and environmental contexts: Denmark, Austria, Spain and Greece. These four locations (the EcoSites) utilize the same core technologies for waste and wastewater treatment, and for energy production and recycling. This approach allows for a reliable comparison of the environmental, economic and social impacts across the regional settings. The project aims at creating virtuous cycles of energy and treated waste/wastewater between urban and industrial entities. To achieve this, a number of enabling technologies and tools have been developed and implemented, including a Social Decision Support System (which represents the main object of this report), and initiatives to spread the I-U Symbiosis concept throughout Europe as well.

The core goal of SYMSITES is to transform linear economic models into circular ones by fostering local and regional collaborations between diverse actors – specifically citizens, municipalities, and enterprises – to improve the sustainable use and management of industrial and societal resources, starting notably from wastewater and waste materials. The project's scope is to address the social, economic, and environmental impact of I-US across different European regions.

KLINK is involved in building the IT Based in Regional Management Platform (ITRMP), through the design and development of the k -SDSS, where k should be framed in terms of both $\kappa\alpha\lambda\acute{o}\varsigma$, to remark the aim to include and make space for the good moral quality in social decision support; and as *knowledge*, to remark the aim to improve knowledge-based decision-making. The module addresses the crucial social dimension of the policy process concerning I-US dynamics. KLINK resorts to either «Social Perspective» or «Social Questions» as proxies for a subset of terms included under the nomenclature fields #28 “Social Questions” and #44 “Employment and Working Conditions” of the EuroVoc Thesaurus, by building on the *acquis communautaire* – thus deriving the Social Perspective from the pool of social policies related to employment promotion, living and working conditions improvements, adequate social protection provision and combat social exclusion.

The ITRMP is a sophisticated tool designed to aid decision-making and management. Its primary purpose is to promote the replication and simplify the implementation of an I-US system throughout every stage of its development. This includes the initial phases (scoping, feasibility study, planning, and development) as well as the subsequent stages of ramp-up management and system upgrades. The ITRMP is built to support all essential actors and stakeholders involved. Specifically, its Social Decision Support System (SDSS) component provides assistance with the assessment, adoption, implementation, and ramp-up processes of I-US systems based on the EcoSites. The SDSS resorts to AI Agent Based Modelling and Social Network Analysis to identify key actors (agents) and potential actions for policy making based on social dimensions; Semantic AI based techniques and recommended algorithms for industry, urban wastewater and waste characterization to be achieved considering industry classification, expert inputs and existing papers; monitoring legislation constrictions and market restrictions to identify potential constraints and facilitate the matchmaking; and GIS to generate calculate and to implement potential maps. The Dynamic SDSS results in a scalable GIS WEB client-server paradigm solution oriented to services, to be tested in each EcoSite

The k -SDSS has been based on a Requirements Analysis and Specification (ReAS), aimed at identifying the user needs and capabilities to be met when using the tool, thus favouring an agreed framing between stakeholders that enables the validation of the

tool against real-world dynamics and the implementability of the emerging solutions. The system is designed to help decision-makers investigate the social dimension of various I-US possibilities, including their potential benefits and drawbacks. The exploration takes into account the perspective of each relevant stakeholder throughout all phases of the I-US system's lifecycle. The act of "helping understanding" involves giving users the ability to search for explanatory insights within the available data, analyses, and models. Furthermore, it offers the capability to discover and/or adopt different frames for interpretation. The system allows users to build scenarios and run simulations, which results in "*what-if*" analyses. These simulations generate virtual narratives of alternative solution pathways, which allow to demonstrate the potential for replicating the I-US model in regions or contexts different from the EcoSites.

The k-SDSS aims to incorporate social factors into the I-US decision-making process, along the whole policy cycle. As for sites where I-US systems are not yet established, to evaluate whether an I-US system could be beneficial, the k-SDSS enables users to analyse and understand the social scenarios that emerge from different underlying assumptions. It also provides the flexibility to alter the established decision patterns of the actors involved to assess the potential outcomes. Likewise, during the stages of feasibility studies and planning, the k-SDSS allows users to map out and interpret the resulting social scenarios tied to specific feasibility options and planning choices. Even for established I-US systems, the k-SDSS helps users explore and interpret probable social scenarios that would result from different ramp-up or upgrade decisions. In general, then, the k-SDSS provides users with a way to observe the evolutionary scenarios of the I-US model from the projected social perspective of the actors. This includes simulating how actors might react to a certain decision.

Since highly technical issues often generates conflicting positions within a community, based on different perceptions of the stakes and on in-depth divides between the "scientific" side and and the socio-political side, the k-SDSS is designed to facilitate the collaborative tasks of sharing and negotiating meaning among stakeholders. It achieves this goal by reducing ambiguity and equivocality, through the definition of a shared conceptual framework; as well as by toning down uncertainty and complexity, even when confronting with incomplete information and highly tangles issues. The developers recognizes that the decision support offered by the k-SDSS cannot guarantee neutrality or freedom from bias. However, making its logical framework explicit is essential for maintaining transparency. The framing approaches for handling decisions can be subdivided as it follows:

- Suggesting optimal solutions: proposing choices that are considered the 'best overall' for all observers, based on a predefined set of criteria;
- Mirroring preferences: applying prioritization criteria in a way that aligns with how observers themselves would naturally choose, based on a theory designed to reflect their preferences;
- Applying a single maxim: Using one overarching "super-criterion" (e.g., maximizing total profits);
- Following organizational priorities: applying the prioritization criteria established by the dominant entity in the I-US chain;

- Granting full control: Allowing observers complete control over all choices and 'meta-choices,' including how the decision-making process itself is configured.

These framing approaches fundamentally fall into two main categories:

1. "Nudge": this leans toward a "paternalistic" choice architecture, where the system subtly guides users toward certain outcomes.
2. "Think": this relies on the confidence that well-informed individuals will make sound judgments through deliberation.

A third option involves a choice architecture that allows observers to actively change their context, for instance, by issuing commands or using incentives. In this model, the k-DSS can be highly beneficial for maximizing efficiency (e.g., determining which actor will best amplify the desired behaviour, or finding the minimum incentive needed to start a "snowball effect"). The k-SDSS is required to specifically consider how variations in social values, interests, and formal mandates among stakeholders impact their behaviour within the context of I-US, thus identifying the most relevant facets of Social Questions as they relate to the I-US systems. To date, in fact, a number of deficiencies regarding the documentation and clarity of the social aspects within I-US emerge: a poorly documented connection between the social perspective and industrial or industrial-urban symbiosis is currently poorly documented; the clusters of concepts related to social questions are loosely connected, and in most cases, they have no defined links to one another; the specific links between the actors (stakeholders) and these social concepts are not clearly defined.

KLINK opted for a I-US stakeholder-centric social taxonomy which splits the κ -SDSS along three dimensions: *employment and working conditions*; *living conditions*; *community*. This particular approach makes it possible to highlight I-US' potential impacts on various social groups, including workers, consumers, and communities. It also addresses possible expected benefits, such as: promoting the interests of consumers; improving access to products and services essential for fundamental human needs; enabling communities that are both inclusive and sustainable. An influence map (which illustrates the connections between these social concepts) was reviewed by experts and further discussed with other stakeholders during the design phases of the project to gather additional, complementary insights.

Consistently with the larger ITRMP framework, the I-US model pushed forward by the κ -SDSS is the SYMSITES "EcoSite" model. The EcoSite model provides a high potential for generalization; furthermore, the EcoSite model accurately mirrors the typical stages of an Industrial Symbiosis system's evolution. The involvement of the Urban participant is simply viewed as adding another industrial node and this integration will not alter the established progression of the symbiosis's establishment and subsequent growth.

6. Strengths and weaknesses of the k-SDSS

The k-SDSS is expected to improve decision quality, to minimize users cognitive efforts, to allow users to maintain control over decision strategy choices as well as to provide content type, presentation formats and delivery mechanisms that allow and promote users ownership of outcomes. The k-SDSS also ensures the qualification of users-uses, a managed user access to functionalities and data, a systematic relationship with real-world data, a secure with external digital systems, a proper

management of users access to resources, data and interfaces. To ensure that the knowledge developed remains open-access, the ABMs are run using NetLogo, an open-source engine that benefits from the support of a large academic community. The model consists of different actors modelled with socio-economic behaviour. In addition, process agents are modelled to represent I-US internal patterns (factors external to the agents that affects agents behaviour) and to reflect the effects of external influence.

Differently from the prevailing literature, KLINK's approach provides a classification of the modes of the establishment of the I-US which relies on three classes: *self-organized*, which reminds of the MG model; *facilitated*; and *ICT supported*. However, I am not fully convinced by such a classification, as *ICT supported* may potentially overlap with the *facilitated* mode. Moreover the HG model is not explicitly included in this taxonomy, even if the input to *strategic/planned* modelling could possibly derive from public authorities.

Overall, the approach put forward by KLINK is mainly based on a NG model; organization and authority-based tools; and it is scaled on a meso level (the EcoSites). As already mentioned, NG relies on voluntary cooperation, trust-building, and horizontal coordination among different stakeholders, which is expected to be mediated by a Symbiosis Facilitator (SF). The SF plays a crucial role in overcoming information asymmetries and establishing a collective trust. In this respect, KLINK's approach is aimed to assist users by enabling them to 1) frame social impacts – becoming aware of how a decision related to any aspect of an I-US model might impact specific social dimensions of interest; 2) identify knowledge needs – defining the knowledge framework required to correctly interpret information, thus allowing them to make informed decisions regarding specific social dimensions of interest; 3) share insights collaboratively, thus contributing to participatory co-design, decision-making, and evaluation processes concerning relevant social dimensions.

Facilitators are supposed to possess the flexibility to set up any realistic or hypothetical context, including defining extreme or stress test conditions (such as setting limit values). Within these contexts, they can insert and test various interventions, generating and storing multiple experimental scenarios for comparison. Furthermore, facilitators are equipped to handle data reporting efficiently. They can utilize pre-configured reports or customize the data retained for subsequent analysis and comparison. Crucially, the k-SDSS system maintains analytical neutrality regarding the definition of quantities. The facilitator is free to specify his/her own quantities, units of measurement, and performance benchmarks, as the system operates consistently in a relative rather than absolute mode.

However, it is not clear to me if the facilitator figure/role, which is currently associated to ITG and KLINK, is explicitly foreseen as a specific actor beyond the project developers. Put it differently, it is not completely clear to me if the overall approach is able to work *without* the direct intervention of its developers, once the system has been launched and is operating smoothly. Policy-makers change, over time: elected officials have a fixed term, top-level bureaucrats may be subjected to spoil system; in the same way, the top management of businesses and third-sector organizations involved may change. The project explicitly maintains that (SYMSITES: 109):

A key objective of the k-SDSS is that each principal module (interaction and influence network analysis with FCM and simulation for ABM agents) should also be capable of being

employed independently (utilizing default configurations or configurations generated by other users where necessary).

In this respect, achieving autonomous user operation of the k-SDSS over time requires the constant provision of a whole-of-process facilitation role. A number of questions then arise: Who will act as facilitator (or “orchestrator”, in KLINK’s words)? What kind of expertise would be requested to act as a facilitator? Who is responsible for training such a figure? For the sake of democratic theory and political legitimacy, the profile of such a figure should be clarified, also considering that «The modelling and simulation process may be public and participatory in some instances, while it may also take place under confidential conditions and subject to secrecy regimes in other cases» (SYMSITES: 111). The k-SDSS could provide some more suggestions concerning the procedures to be set to eventually appoint the SF and to avoid possible contestations, whether internal or external.

To prevent internal contestation, at least from an operational point of view, the k-SDSS already provides that stakeholders’ intentions are converted into Stakeholder Requirements. To ensure these intentions were clearly understood, a Concept of Operations was drafted, to translate these needs into requirements without unduly limiting the possible solutions, while maintaining coherence and feasibility. A Domain Analysis was thus performed concurrently to ground the proposed system within a strong theoretical framework and ensure the use of viable technology solutions. Once the Domain Requirements were established, the System Operational Concept (SysOps) was created. This described the stakeholders’ original intentions from the system’s perspective. Finally, the Concept of Operations and the System Operational Concept were combined to form the complete Stakeholder Requirements. These were then formally transformed into the definitive System Requirements. Moreover, other requirement analysis and specification processes were conducted to gather a complete set of requirement types. This full set includes: Functional requirements (what the system must do); Performance requirements (how well the system must perform); Interface requirements (how the system connects with others); Design requirements (constraints on the system’s architecture); Development standards (rules and protocols for creation). All requirements were then weighted to clearly indicate their priority, implementation timing, or relative importance.

The overall system requirements is based on a Stakeholder Analysis to identify and gather the stakeholders’ intentions (needs, goals, and objectives). Stakeholders have been subdivided into different categories: *public authorities; civil society and citizens; NGOs and CSOs; wastewater industry; other industries and companies; research and academia*. In this respect, I’m not fully convinced of this classification: the differences between *civil society and citizens* and *NGOs and CSOs* are not clear, since their potential affiliates may overlap thus failing to meet the condition of mutual exclusivity.

Coherently with the rationale of the approach, the k-SDSS relies on a user-centric paradigm. Thus a major emphasis is dedicated to stakeholder perceptions and engagement, in terms of their knowledges, responsibilities as well as their biases. In this respect, one added value of the approach rests on the creation of a reasoned glossary and a semantic network of concepts, to favour a harmonisation of the meaning of key concepts across the stakeholders’ diverse backgrounds. Defining an ontology means to create a shared vocabulary for researchers who must exchange information within a specific field or domain. It encompasses machine-interpretable

definitions for the fundamental concepts in that domain, as well as the relationships that exist between these concepts. The ontology serves several critical functions within the project framework, primarily designed to enhance shared knowledge and structural clarity:

1. to facilitate shared understanding, as It allows people (and software agents) to share a common understanding of how information is structured within the domain;
2. to make the domain's assumptions explicit, since concepts at the intersection of social, ecological, and industrial systems are often flexible or open to interpretation;
3. to enable knowledge reuse and analysis, as It permits the reuse and analysis of domain knowledge, specifically the continuously growing knowledge concerning how I-US and social domains interact.

The k-SDSS is expected to enhance decision quality by supplying information that supports two key analytical activities: forecasting future scenarios and determining cause-and-effect relationships. A central goal is to boost the quality of policy choices regarding social issues within the context of I-US – ensuring that social considerations are formally integrated into the key planning and execution decisions: to this aim, the use of modelling and simulation is considered as strategic. The k-SDSS design allows users to define the decision problem and the relevant experiments according to their preferred strategy: decision-makers using the k-SDSS maintain control over selecting their decision strategies to ensure that the chosen strategies align with wider policy goals and the interests of various stakeholders . In this respect, KLINK formulates a linear step-by-step approach to decision-making. Figure 2 shows the ideal-typical flow of the process.

Figure 2 – The decision-making process

Step	Core activities	Rationale
<i>Initial Concern & Issue Identification</i>	The process starts when the PM recognizes a societal problem linked to an I-US scenario. The PM must specifically pinpoint a problem within the I-US framework that necessitates a policy decision.	Focus: Establishes the necessity for intervention and defines the initial scope.
<i>Case & Question Formulation</i>	Following the initial identification, the core decision case and a specific focus question are developed. This is the most crucial step as it formally sets the boundaries and the objective for the entire decision-making exercise, clearly articulating the main challenge and the necessary answer.	Scope Definition: Ensures the subsequent analysis is relevant and targeted.
<i>Current Situation/Baseline Outline</i>	The PM then defines the "do-nothing" baseline scenario – the situation that would exist without any new policy or intervention. This creates a clear, measurable benchmark.	Evaluation Standard: Provides the necessary reference point against which the success of all proposed actions will be judged.
<i>Intervention Options Outlining</i>	The PM generates several potential solutions or actions. These are strategies designed to tackle the identified social concern within the I-US setting, or they may simply be different values or settings that key drivers could take within the current I-US configuration.	Solution Generation: Provides the set of alternatives to be tested and compared.
<i>Simulation and Data Collection</i>	Each potential intervention is then simulated (or modelled) to predict its outcome, and relevant impact data are systematically collected. This is a key analytical stage that produces empirical evidence on the possible effects of each option.	Evidence Generation: Allows for anticipation of real-world effectiveness and impacts before implementation.

Step	Core activities	Rationale
<i>Comparison and Analysis of Outputs</i>	The data from the simulations are rigorously compared and analysed. This analytical review identifies the advantages and disadvantages of each option, creating a semi-quantitative foundation for the subsequent policy choice.	Assessment: Translates raw data into actionable insights for decision-making.
<i>Comprehensive Report Compilation</i>	The simulation results and the subsequent analysis are compiled into a formal, comprehensive report. This document serves as the official record of the process, summarizing all findings and providing evidence-based recommendations.	Documentation & Communication: Formalizes the findings and prepares them for the final decision-making phase.
<i>Resumption of Decision-Making</i>	Equipped with the new evidence and the final report, the PM completes the decision-making loop. The final action is to leverage the report's insights to make an informed decision on the best course of action to resolve the initial social concern.	Informed Action: Ensures the final policy decision is supported by rigorous analysis and empirical evidence.

At a first glance, the decision-making design of the k-SDSS relies on a top-down approach, since its developers not only foreseen the main steps of the process, but also its implications and potential consequences. However, to avoid the limits of a hyper-rationalist and scarcely realistic approach to policy making, the system resorts to an inherently exploratory, bottom-up, and forward-looking approach. This means that back-casting (determining the actions needed to achieve a predefined future outcome) is not automated. Instead, back-casting is performed manually by the users through an iterative process of adjusting intervention parameters and subsequently comparing the simulation results. However, in my opinion, as it stands now the approach poorly develops the role of the SF, which is crucial to avoid potential never-ending bargaining among the users and consequent authoritative decisions by the public bodies involved.

Despite minor weaknesses concerning the loosely specified role of the SF and the classification of the modes of the establishment of the I-US and the stakeholders, KLINK's approach looks very sound, paving the way for innovative practices in decision-making processes.

First, it privileges a users-oriented approach to decision making, by favouring a “*steering bottom-up knowledge circulation*”, based on actors' framing processes within a defined theoretical framework. This is the added value of the approach, as it avoids that the analyst presents “pre-packaged”, top-down solutions to the policy makers that may be inappropriate for the social, cultural, economic, and political context, rendering them impractical or unfeasible to pursue. In this respect, the information baseline has been built along different steps, specifically: a systematic literature review; an interactive survey submitted during a co-design workshop held in Pisa; a survey and consultation with EcoSites' partners; consultations with experts and leaders from the stakeholders' fields. The Domain of decisions has thus been framed from different points of views (promoter of innovation, regulator, planner, permitter, or partner).

Second, the approach allows for experimental practices: users investigate specific instances of I-US (real or fictitious) as defined in one Experiment Configuration. This is another path-breaking aspect of the k-SDSS: built upon a sound and agreed information baseline, users can run reliable simulations of the chain of events and mechanisms that can be activated through specific configurations of variables.

Qualified users can either choose an existing experimental setting or create a new one. By conducting experiments using the k-SDSS, users can investigate how certain variables related to social factors are likely to evolve within a specific influence map and within a particular I-US specimen (whether real or hypothetical). Two distinct types of exploration are concerned:

1. Modelling and Simulation of the Influence Scenario (Abstract): this type of analysis is abstract and focuses on determining how policy-making and decision-making processes might impact the various social dimensions;
2. Modelling and Simulation of a Specific I-US Specimen: this focuses on a concrete instance of an I-US, examining how that specific project, operating under a defined influence scenario and set of experimental conditions, might affect the relevant social dimensions.

The k-SDSS platform provides the user access to two distinct simulation types:

1. Fuzzy Cognitive Map (FCM) Simulation: used to investigate the causal influences connecting specific patterns within the experimental unit to the resultant social outcomes. The k-SDSS platform integrates social factors directly into the decision-making framework for I-US. This integration allows the system to analyse and understand the various social outcomes that might result from different strategic decisions, such as scaling up or implementing upgrades. By doing this, users can track how a specific I-US model would develop over time, specifically from the viewpoint of different involved parties or stakeholders. The system is pre-loaded with a fuzzy map that outlines the connections between the key components that define the social dynamics within an I-US setting, focusing on three core guiding dimensions. By "calibrating" this map to suit various real-world situations, simulations can be run effectively. Ultimately, the simulation suggests that several potential strategies exist for tackling the identified challenges. These strategies are all connected to a larger operational environment and have the potential to boost the overall development of the EcoSite initiative.
2. Agent-Based Model (ABM) Simulation: designed to explore how the social impacts of an intervention affect the interactions among defined social agents and how these interactions ultimately shape the social outcomes. Agent-based modelling is a type of computational simulation where agent-based models function as a micro-scale approach. These models simulate the concurrent actions and interactions of numerous agents to reproduce the characteristics of complex real-world phenomena. The primary objective of this technique is to gain explanatory insight into the collective behaviour that emerges when individual agents follow relatively simple rules. An example of this is studying employment trends over time as they relate to the flow of materials and exchange patterns. In the specific context of the EcoSite, this means observing how the involved town and companies behave under different organizational structures and determining the resulting socio-economic outcomes of their symbiotic relationship. The I-USymb model is specifically built to reflect the topology, entities, relationships, and rules that define the simulated environment, or "agent playfield." It also dictates how these elements behave

within an I-US setup, integrating the structural and supporting characteristics of an Ecosite as conceptualized by the SYMSITES project.

Policy makers are empowered to monitor and track all experimental stages and their respective outcomes, enabling the comparison of the impact resulting from each tested intervention. Once the simulation experiments are complete, users have the capability to perform two main analytical tasks:

1. Compare key social variables, assessing the value a single social variable takes in different scenarios resulting from various experiments. This comparison applies both to the I-US social scenarios (outputs from ABM, simulations) and the social influence scenarios (outputs from FCM simulations).
2. Trace key variables: users are able to track and follow the progression of key variables throughout the generated I-US scenarios.

The design of k-SDSS FCM simulation tool, the design of Agent Based Modelling and simulation, as well as the reporting functions of the k-SDSS and the session management are described in-depth, with practical guidelines and orientations for users. Moreover policy-makers retain ownership and accountability for the results produced by simulations: this should ensure that policy-makers are accountable for the choices derived from that data, thus favouring their subsequent commitment in the planning and implementation phases, which should strengthen the integrity and effectiveness of the resulting policy actions.

The social dimension of the k-SDSS is structured around three core guiding sub-dimensions, already mentioned above:

- Employment and Working Conditions;
- Living Conditions;
- Community Development.

In this respect, KLINK provides both ABM and FCM modelling simulations for each Ecosite included in SYMSITES. Despite being calibrated to specific cases, the reports follow the same rationale and analytical structure – a standardization which is helpful for potential users to approach the simulation. More specifically, in the k-SDSS-ABM applied to the EcoSite model, the urban environment is primarily treated as a source of waste for the EcoSite. The urban area is not modelled as an active agent participating directly in the transformative processes, technologies, or flows. The user (whether a policy maker or an analyst: still, the role of the Symbiosis Facilitator should be mentioned here) utilizes the information generated by the system to inform their decisions regarding:

- The socio-economic consequences that might arise from a particular I-US configuration;
- The modelled configuration that could potentially yield the desired or hypothesized outcomes;
- A comparison of the scenarios resulting from various I-US configurations.

In Figure 3 a synthesis of the process is provided

Figure 3 – The *k*-SDSS – ABM: rationale

Entity	Role/Focus	Output/Decision
<i>Urban Environment</i>	Waste Source (Passive)	Not an active agent in transformation
<i>k</i> -SDSS User	Policy Maker/Analyst/Symbiosis Facilitator	Informed decisions on I-US
<i>Model Output</i>	Information provided	Embedded Work and Added Value Created
<i>Decision Maker</i>	Experimenting Policy Actor	Determines labour policy

KLINK draws inspiration from the Environmental Impact Momentum indicators (EIMi and EIMo) as proposed by Felicio et al. (2016) – who measures the environmental burden associated with the material/energy flows entering (inbound) or leaving (outbound) a firm within an industrial symbiosis network – by resorting instead to the concepts of “embedded work” and “added value”. The decision maker then can opt for different labour policies, thus simulating how to influence or manage the social allocation of the value added by the I-US.

As for the Embedded Work, the concept of Labour Momentum Inbound (SIMi) quantifies the “social cost” in terms of labour time embedded in a firm's received symbiotic exchanges. It stands for the total quantity of human labour (person-hours) embodied in the materials, by-products or recovered end-of-waste materials that a firm receives from other actors within the I-US network. To higher values of SIMi correspond significant amount of collective work from the firm's providers in the network. The concept of Labour Momentum Outbound (SIMo), instead, stands for the total quantity of human labour embodied in the materials, by-products or recovered end-of-waste materials that a specific firm provides to other firms within the I-US network. It quantifies the “social contribution” of a firm in terms of labour time embedded in its provided symbiotic exchanges. In this respect, to higher SIMo correspond significant amounts of a firm's labour to provide the outputs utilized by others in the network. The overall Work-Symbiosis Indicator (WSI) – but probably it would be more correct to speak of an index – increases when more labour value is brought in, while decreases as more labour is sent out.

As for the Added Value – which is usually computed as the difference between a firm's total sales revenue and the cost of all purchased inputs, such as materials, energy, and external services – in the context of a IUS system it represents the total economic wealth generated through the combined and interacting activities of all member firms within the system. Depending on policy makers' orientations, an increased added value possibly translates into the availability of greater resources for public intervention on social issues, such as enhancing living conditions and promoting community development. The Value-Symbiosis (or Value-Momentum) indicator is designed to quantify the net value-added that the I-US is effectively gaining (tapping into) compared to the value it is losing (leaking out). Similarly to the WSI, a Value-Impact Momentum Inbound as well as a Value-Impact Momentum Outbound are calculated to get a Value

Symbiosis Indicator (still, "index" would appear more correct) that indicates the economic benefit derived from the symbiosis activities within the I-US

Conclusive remarks

The aim of this report was to provide an assessment of the approach and methodology developed by Klink within the framework of the SYMSITES project. The focus of the analysis was the k-DSS module, which Klink designed with the aim of enhancing the decision-making processes underpinning public choices regarding urban-industrial symbiosis.

The analysis revealed that the approach and methodology developed by Klink represent a brilliant example of innovation in the field of policy instruments, enabling the formulation of "informed" intervention strategies that are tailored to the specificities of the contexts and based on the knowledge gained through *ex-ante* consultation with stakeholders.

The user-oriented and bottom-up approach is integrated with a sophisticated modelling system, relying on Agent-Based Modelling (ABM) and Fuzzy Cognitive Map (FCM) approaches.

While the guidelines formulated by Klink for the use of the k-DSS are detailed and accessible, the question of "Who" should operate the system remains open. Currently, specific references to the role of the I-US Facilitator only appear in the ABM simulations conducted on the four EcoSites.

It would be advisable, in the future, to develop a more complete reflection on the Facilitator of Industrial-Urban Symbiosis processes: Who should assume this role? The political decision-maker? The involved public service official? An *ad hoc* expert?

The systematic deployment of the k-DSS appears rather improbable, particularly in the case of political decision-makers. Conversely, public officials would require specific training. Even if the Facilitator role is to be undertaken by an expert external to the political-administrative sphere, it will be necessary to anticipate the development and delivery of dedicated training courses, which could become an integral part of the "package" offered by the k-DSS developers.

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