Industrial symbiosis marketplace concept for waste valorization pathways

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Abstract. Acceleration of raw materials' depletion and waste accumulation create a need for stakeholders to shift from linear to circular business models by adopting novel strategies. Circular economy (CE) and industrial symbiosis (IS) offer a direction towards sustainable, resource efficient systems and eco-friendly waste management approaches. IS encompasses all types of interfirm cooperation in order to achieve a green, waste-free supply chain and at the same time to attain profits. However, among other barriers hampering widespread adoption of IS is lack of information exchange. Digital tools have emerged as facilitators of IS, since they enable real-time data sharing, identification and evaluation of symbiotic opportunities, while continuous progress of those tools is necessary for the digital transformation of IS. Important elements for the functionality and success of such tools are the criteria determining the matching of potential stakeholders and the support of the decision-making process. In the ongoing research that is presented, these matching criteria and benchmarks for waste valorization pathways are investigated and a matchmaking framework is proposed. The objective of the framework is to identify the most suitable collaborators to be deployed later to an automated matchmaking process, revealing latent possibilities (e.g. by suggesting indirect matches) and advantages of symbiotic actions from a holistic perspective. This tailor-made assessment is aspired to evaluate stakeholders' compatibility based on more than a mere waste streams' valorization match. Stakeholders' specific requirements and motivations are incorporated in the potential partnership evaluation, thereby a multicriterion approach is proposed considering the potential cooperators' relevance in terms of aspects like strategic goals, the level of IS embracement or synergy's environmental impact.

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1 Introduction

Industrial Symbiosis (IS) promotes a circular industrial waste management strategy with a long-term perspective to achieve economic and environmental benefits, by applying interfirm physical exchange of residual streams (materials, energy, water), as well as exchange or sharing of utilities, infrastructure, services and knowledge. Among the barriers preventing the widespread adoption of IS, lack of trust and data exchange between stakeholders is important, often addressed by usage of ICT tools, which act as facilitators and support information sharing, identification of symbiotic opportunities and assessment of potential synergies [1]–[4]. E-marketplaces are facilitating IS by enabling transactions of industrial wastes/by-products, by identifying and matching compatible businesses' supply and demand streams. Advancement of those tools is attempted, by providing effective recommendations according to the economic and environmental impact of the proposed symbiotic partnerships [1], [3], [5]. Moreover, tools have been identified that envisage to estimate the compatibility of potential partners from a holistic point of view, by embedding qualitative information such as companies' interests, incentives and long-term managerial orientation [6], [7], [8]. One research work that incorporates companies' strategy in the matchmaking procedure is introduced by Łękawska-Andrinopoulou, 2021, proposing the Circular Economy (CE) matchmaking framework. A comprehensive concept for matching compatible partners is presented, which integrates the similarity of two users in terms of CE principles' embracement within the algorithm [7]. Based on this work and considering that no digital tool incorporating the extent of adoption of IS practices in the matchmaking process was identified, this study aimed to address this research gap. The goal was to introduce a novel IS matchmaking conceptual framework, envisaged to be deployed in a marketplace for waste valorization pathways, providing the users with a comprehensive evaluation, which includes both quantitative and qualitative information and contributes to the decision-making process.

2 Methodology

In this section, the methodology that led to the design of the conceptual framework, applied in this study is presented briefly. This research work is an expansion of the CE matchmaking framework proposed by [7] to IS. A non-systematic, targeted literature search was performed to appropriately address the topic of IS, utilizing among others, papers and knowledge gained during preparation of a previously performed by our team systematic literature review [8], for the adjustment of the CE matchmaking framework for IS. For the design of level A of the framework, a set of questions targeting the stakeholders' adoption level of IS practices was developed according to identified studies employing questionnaires related to IS [2], [7], [9]–[11]. For the selection of the benchmarks used within the proposed framework, studies deliberating on matchmaking criteria were identified and further utilized in the design of levels B and C [2], [5], [6], [10], [12]–[14].

3 Design

In this section, the description of the design of each level of the IS matchmaking framework is presented. The objective was to assess the possible matches using a multi-level approach. The outcome is a total relevance score between users being cross-sectorial companies in a given geographical area, with pre-identified technically feasible synergies, according to information stakeholders shared against a relevant database. The methodology of synergies' identification and database development are beyond the scope of this paper. The main factors that might affect the decision making of users are assessed and a relevance subscore is

calculated for each level using this approach. The three levels that are regarded are: (i) level A: stakeholders' compatibility regarding IS compliance level assessed via a questionnaire, expressed as subscore A, (ii) level B: flow analysis expressed as subscore B, and (iii) level C: environmental impact of a potential synergy by utilizing the Life Cycle Assessment (LCA), expressed as subscore C. Each subscore A, B or C has a value in the range 0-1 and they are combined into a Total Relevance Score (TRS), calculated based on the Equation 1. The weighting agents α, β and γ of Equation 1 are discussed in section 3.4. Potential synergies are ranked based on the TRS %. The partnership with the greater TRS% is suggested by the marketplace as the optimal in the given network. The IS matchmaking framework and TRS calculation is presented in Figure 1.

$$TRS\ (\%)=(a*A+\beta*B+\gamma*C)*100\% \qquad (1)$$

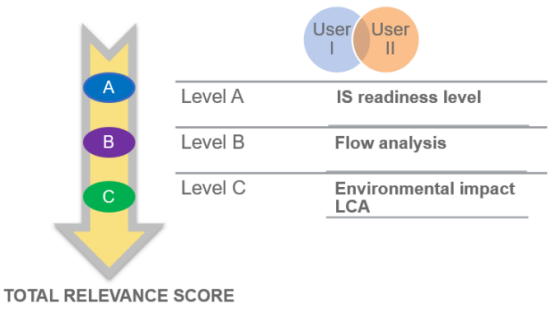

Figure 1: Proposed IS matchmaking framework and Total Relevance Score (TRS%).

3.1 Level A: IS readiness level

Level A is designed to assess the embracement level of each stakeholder regarding IS practices and evaluate the maturity similarity of two actors. Users with greater cognitive proximity regarding adoption of symbiotic endeavours are more likely to successfully implement and sustain the relationship [8], [15]. The concept of Symbiosis Readiness Level (SRL) introduced by Sommer, 2020 [10] aims to identify and assess the status and progress of a symbiotic project or initiative comprehensively. Consequently, the term IS readiness level in this paper is inspired by SRL, since this study attempts to evaluate the stakeholders' existing level of involvement in IS practices and matchmake them according to that. A questionnaire, to be answered by each platform user, is created to assist the collection of qualitative data, to address the existing level of IS implementation. The structure of the questionnaire and the questions' context are based on the four different dimensions proposed by [10], namely business, managerial, technology and ecological. Each dimension is divided into more detailed readiness areas, resulting in a questionnaire that consists of a set of nine questions, as presented in Table 1. The marketplace users are asked to self-assess their company using responses reflecting the spectrum of maturity levels, choosing one out of the four qualitative answers: (1) Not involved, (2) Engaged at ad-hoc levels, (3) Beginning to engage in a more systematic way, (4) Well embedded. These answers are introduced by [16], with one additional response option, as presented in [7]. Subscore A is an indicator of the similarity of two potential partners in terms of their readiness to adopt IS and is calculated by comparing responses to the answers provided by potential pairs of users. Similarly, the scoring scheme of Subscore A is used as in [7]; identical answers are rated 1, one level apart answers are rated 0.75, two levels apart are rated 0.5 and three levels apart (two extreme answers) are rated 0.25, finally resulting to Subscore A, an average value of ratings, in the range between 0.25 and 1.

Table 1: IS readiness questionnaire.

Symbiosis Readiness Dimensions	**Readiness area**	**Question: To what extent…**
Business	Strategy	are IS practices incorporated in your company's strategy?
	Investment	does your company invest in time, capital and personnel to practice IS, create new value chains, overcome regulatory barriers etc.?
Managerial	Sharing practices	does your company engage in sharing practices: utilities, infrastructure, facilities and/or logistic services?
	Cooperation-Private sector	does your company cooperate and communicate with other companies, by sharing knowledge and exchanging information, to implement IS practices?
	Cooperation-Public sector	does your company cooperate with local community or public entities to implement IS practices at regional scale?
Technology	Input streams	are the input raw materials, used within your company, obtained from secondary materials (e.g. waste or by-products of other processes, materials that were recycled, elements that are reused)?
	Output streams	does your company provide the produced output streams (wastes, by-products) to other stakeholders as raw materials?
	Waste treatment	does your company perform internal waste treatment of the output streams before disposal or provision to other companies/facilities as input streams (e.g. recycling, composting, energy recovery etc.)?
Ecological	Sustainability	does your company monitor and evaluate the environmental benefits achieved by IS practices?

3.2 Level B: Flow Analysis

Level B of matching is designed to quantify the potential between two stakeholders regarding matching of flows, based on the total number of direct and indirect matches and the possible opportunities for cooperation in a regional symbiotic network. The notion for this level of relevance assessment, is to assist the users to evaluate the collaboration opportunity and select the partner with the greater potential to cooperate, in terms of flow matching. Ideally, the outflow from one user, matches the needs of another stakeholder and can be directly used as secondary raw material input without the need for waste treatment (direct match). In case of indirect matches, an intermediate stakeholder is required to provide the technology for waste processing, which is considered more complex as it entails a greater number of processes and stakeholders. Therefore, subscore B is calculated based on the number and the directness of flow matches between two users; the higher the number of flow matches and the majority of those being direct, lead to a greater value of subscore B. Normalization of subscore B is performed comparatively to the other possible opportunities in the regional network.

3.3 Level C: Environmental impact LCA

Level C of matching is designed to quantify the environmental footprint between two stakeholders with matched flows, based on the total number of direct and indirect potential matches. The notion for this level of relevance assessment, is to assist the users to select the partnership, leading to the lowest environmental impact possible and the most sustainable products or processes' development. The design of this level allows for the selection of the most sustainable valorization routes between stakeholders. The product system is defined as the matching between two stakeholders and the system boundaries include all relevant life cycle stages and processes involved in matching. The functional unit is defined as 1 tn of valorized waste and all input and output flows are collected by the relevant stakeholders in the inventory analysis phase. Subscore C of two users is determined by the type and quantity

of various flows, the integration processes of various flows, the energy and water consumption of integration processes and the number of flow matches. Subscore C is greater when the environmental impact is lower and as an indicator, will depict the environmental impact category "global warming", evaluated using LCA tools. Normalization of the indicator will be performed by comparing baseline scenario (current valorization routes without any symbiotic connections) to the marketplace using scenario, namely for the various possible partners and the corresponding waste valorization routes.

3.4 Application of IS matchmaking framework

To illustrate the application of IS matchmaking framework, a hypothetical case of a network of three potential users (I, II and III) is presumed and presented in Figure 2.

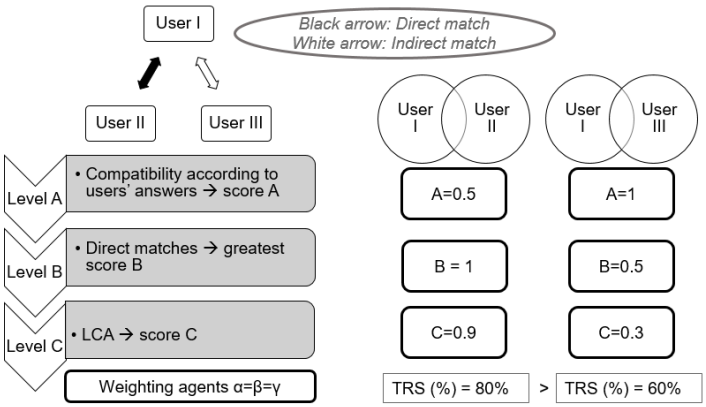

Figure 2: Hypothetical case of an IS network with assumed values for Subscores A, B and C.

The weighting agents α, β and γ of Equation 1, which are assumed equal for the presented case, influence the TRS%, as they determine its final value. The sum of weighting agents α, β and γ is equal to 1. The proposed method for weighting agents' determination, currently under development, involves fixed sets of values according to different scenarios, which stem from the corresponding answers to the Level A questionnaire. Compatibility between two users will be directing to established scenarios focusing on the four different dimensions of the collaboration: managerial, business, technological or environmental.

4 Discussion – Conclusions

An innovative IS matchmaking framework for the comprehensive compatibility assessment of two symbiotic partners to be deployed in a marketplace is presented. Particularly, the IS readiness level similarity assessment constitutes the novelty of this framework, which also includes the quantification of potential of flow matching and environmental impact between two stakeholders. Validation of the proposed framework is ongoing, with companies contributing with real data by answering a survey related to all three levels. Some areas for future research involve the specification of different scenarios according to users' compatibility on different readiness dimensions, integration of cost analysis and expansion of the framework to Industrial-Urban Symbiosis.

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