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Enabling the Identification of Industrial Symbiosis (IS) through Information Communication Technology (ICT)

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Abstract

Industrial Symbiosis (IS) is an emerging business tool with a systemic and collaborative approach to optimize and close cycles of materials and energy by identifying synergies and fostering cross-sectoral cooperation among economic actors. The major facilitator of revealing IS opportunities for organizations is both analyzing the status quo with quantitative methods and connecting the supply and demand of the entities involved through an adequate Information Communication Technology (ICT) solution. This study analyzed the extant body of literature and the corresponding ICT tools of IS in order to design a preliminary concept of an Information Technology (IT) supported IS tool that supports the identification and assessment of IS potentials, providing more transparency among market players and proposing potential cooperation partners according to selectable criteria (e.g. geographical radius, material properties, material quality, purchase quantity, delivery period), bringing synergy partners together.

1. Introduction

Today´s era is called “the Anthropocene”, human activities have become the main driver of global change such as climate change, environmental pollution and increasing scarcity of resources [1]. Especially a resource efficient circular economy contributes to a trajectory of sustainable development [2]. Industrial Symbiosis (IS) is considered to be a key enabling factor for resource efficiency, which takes an emerging priority on the European Union (EU) policy agenda [2].

Industrial Symbiosis (IS) falls under the umbrella of Industrial Ecology (IE) [3]. It is a systemic and collaborative business approach to optimize and close cycles of materials and energy while generating ecological, technical, social and economic benefits [3,4,5]. The most cited definition is from [3], “IS engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and byproducts.” According to [6], “IS engages diverse organizations in a network to foster eco innovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes.”

Many IS networks exist across the globe, there are round about 121 case studies in Europe [7]. The most well known and analyzed IS network is located in Kalundborg (Denmark), where an Eco-Industrial Park (EIP) has emerged spontaneously [8]. EIPs have been investigated in various comparative studies, but mostly in developed countries, so there is a research gap concerning developing countries [61], although there is a modest number of published studies [50,51,60,61,65], while the tendency is increasing.

Industrial Parks (IPs) can contribute to regional and economic growth, but without considering environmental issues in a sophisticated and holistic manner into the planning and construction of IPs, economic gains can be generated in the short term,

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but come at a loss of disturbed ecosystem services and quality within and around the location of the IPs, which even can pose economic threats to the development of IPs in the long term due to possible water shortages, amongst others [61,62]. So potential negative feedback-loops need to be avoided in advance or at least slowed down or reduced, especially in emerging and developing countries where the growth of IPs is rapidly rising, as for example in China [62].

Each entity involved in the (Eco-)Industrial Park (EIP) can be considered as a node in a widely ramified network, so IPs could or should be seen as entire eco(sub-)systems [58], which are embedded in the overarching natural ecosystem [62]. Usually IS connections are built between organizations of different industrial sectors which have not entered into a customer-supplier business relation [5], therefore IS synergies between companies only can be identified when an inter-organizational cooperation and communication is supported [42]. So an information system can serve as a facilitator of communication and distributor of knowledge, while providing cross-organizational access and information exchange [9]. Many ICT tools have been developed to support the identification and expansion of IS, but most of them are no longer in use [15,43].

2. Literature Review

This study investigates retrospectively the extant body of literature of Industrial Symbiosis (IS) and the current state of IS tools in order to derive various implications for the advancement of ICT solutions in the context of IS and emerging and developing countries, proposing a preliminary concept for an IT-supported IS tool for the identification and assessment of IS opportunities based on a conducted systematic literature review. So this study was conducted to converge to possible answers to a certain extent of the following research questions: *How can industrial symbioses (IS) be identified and enhanced? (RQ1) How can an appropriate IT tool be designed? (RQ2)*

As there are several concepts of IS such as synergies among firms (e.g. along supply chains) that are not co-located or within one specific industrial branch (homogeneous setting), this study focuses on IS network expansion within existing industrial parks, so co-located firms across various industrial sectors (heterogeneous setting). The focal point is especially on the identification of synergies between factories with geographical proximity. In the literature, a clear distinction between designing a new industrial park and converting an existing industrial park into an Eco-Industrial Park (EIP) is rare [11]. This study concentrates on the scenario of retrofitting an existing industrial park to an EIP.

Publications were sourced from the following databases such as ResearchGate, google scholar, Thomson Reuters Web of Knowledge and the conference website of EnviroInfo. The queries search the following terms “industrial symbiosis“, “industrial symbiosis in developing countries”, “eco-industrial park“, “information systems”, “ICT tool” and its various combinations.

Based on the already collected scientific references, the snowballing technique, a backward and forward analysis based on the citations of the relevant publications was applied to identify further relevant literature. Only publications in English and German were included in the study.

3. Facilitating Industrial Symbiosis

3.1. Quantitative Methods & Case Studies

Industrial Symbiosis (IS) reveals opportunities for organizations to improve their economic, technical and ecological performance by connecting the supply and demand of various industries [9]. Cross-industry and cross-sectoral collaboration within a community is required in order to exchange materials, energy, water and human resources [10], so the given heterogeneous capabilities and resources in the business environment must be taken into account [5].

Fig. 1 shows one possible approach for an Eco-Industrial Park (EIP) evolution following a continuous improvement process, the principle of PDCA (Plan-Do-Check-Act), whereat this study focuses on the first two steps: system analysis and the identification of IS opportunities. Noteworthy, the process borders of the five illustrated steps are not sharp, but partly overlapping and intertwining, especially step 2 and 3.

The process of retrofitting an existing Industrial Park (IP) and thus identifying potential industrial symbioses (IS) can be conducted by various quantitative methods. First of all, the actual state of the system of the IP and its economic actors needs to be analyzed. As a first starting point, a list of the companies involved can be assembled, in order to identify further (potential) linkages between the occupants such as same supplier and waste disposal companies. Then appropriate methods of constructing such connections can be defined and/or new elements that can be established into the park such as additional block heat and power stations, renewable energy sources and wastewater treatment plants can be detected [11]. For example, [10] firstly determined an initial synergy network of the participating companies in an IP, in order to identify common suppliers. They modelled an IS network where the entities involved as suppliers, receivers and processes were conceived in analogy as a supply chain. Therefore, they developed an industrial symbiosis supply chain model (ISSC), in order to point out IS opportunities that the companies may have in comparison to a traditional supply chain [10].

relationships in production or business networks. [52] analyzed the Kalundborg Industrial Symbiosis in Denmark using SNA to gain insights of the resilience of an IS network, suggesting design strategies for resilient and sustainable industrial symbiotic networks such as increased diversity, redundancy, and multi-functionality to ensure flexibility and plasticity.

The following three methods are mainly based on the principles of Output-Input and Supply-Demand

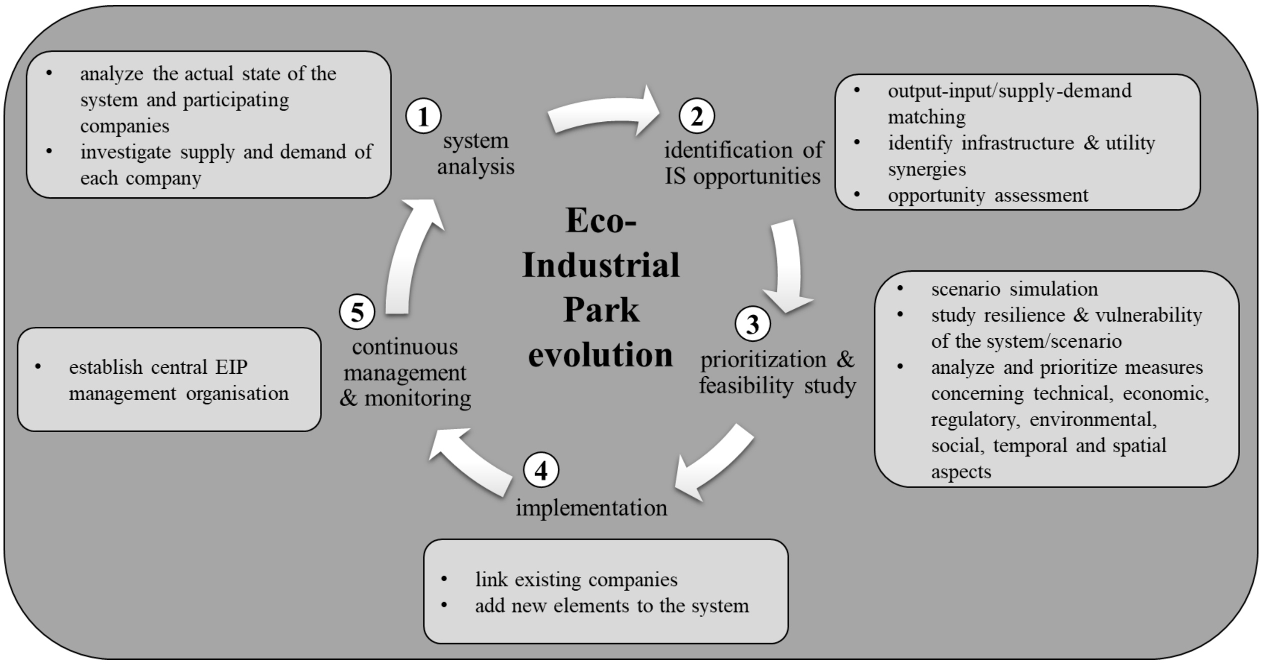

Fig. 1: One possible approach for an Eco-Industrial Park (EIP) evolution.

In this study, four basic methods were identified that have been used in case studies to reveal IS opportunities and network expansion: Social Network Analysis (SNA), Material Flow Analysis (MFA), Material Flow Cost Accounting (MFCA) and Life Cycle Assessment (LCA).

SNA investigates social structures of networks and characterizes elements within the network in terms of nodes (e.g. individual actors, companies, people) and the connecting ties or links (relationships or interactions) [11,24,44,45]. SNA can provide insights for understanding the social aspects of such a network system and how (social) business relationships drive the exchanges of materials, energy and information [45]. For instance, [44] investigated the relationships among industrial organizations in an IP in Puerto Rico, including interpersonal and organizational relationships, trust and the associated relationships within the IS network. [45] used SNA in an empirical study of IS that addressed trust

Matchings of the entities involved. So by analyzing each supply-demand and output-input (e.g. human and material resources, utilities and (infra-)structure) of each company, possible IS potentials can be identified.

MFA quantifies the flows and stocks of materials and energy of the system under consideration in physical units [11,24]. For instance, [51] conducted a multiyear investigation of industrial sites in Puerto Rico between 2001 and 2007. They used MFA to develop IS scenarios focused on utility sharing, joint service provision and by-product exchanges, which were evaluated by technical, economic and environmental criteria afterwards. [50] applied MFA to an industrial area in South India to analyze the recovery, reuse and recycling of industrial residuals and to identify existing symbiotic connections within this area. [12] conceptualized a web-based ICT solution that enables cross-organizational access and information exchange in order to reveal IS opportunities. It supports the planning, development and management of an IP from an environmental and sustainability perspective with the method of MFA.

LCA quantifies the flows and stocks of materials and energy of the system under consideration and assesses the associated environmental impacts [11,24]. [13] analyzed a Finnish Forest Industry Complex around a pulp and paper mill using LCA, in order to identify inter alia potential additional connections of the occupants. While [53] investigated IS in the biofuel industry in Sweden using LCA to identify synergies and quantify the environmental performance of the firms in the IS network. This method also offered an approach to distribute impacts and credits for the IS exchanges among the entities involved and to assess the benefits of the IS network [53]. It was proposed that this may also have implications for future development of taxes, incentives and subsidies [53].

MFCA traces and quantifies the flows and stocks of materials and energy of the system under consideration in physical and monetary units. Especially the material losses, non-product and waste flows are evaluated. Consequently, waste flows are attributed an economic value which incentivizes the optimization the company´s processes as well as the use of resources [32]. Previous research has shown that remarkable environmental and economic benefits have been achieved by implementing and applying MFCA on the level of an individual company [46,47]. The costs associated with wasted materials can accumulate to 40-70% for individual companies [48,49]. [14] conducted a case study in Indonesia by using a complementary approach of MFA, LCA and MFCA, proposing a preliminary new system design of cement production.

3.2. IT-supported Industrial Symbiosis Tools, learnings and implications

17 ICT applications for Industrial Symbiosis (IS) were investigated by [15], whereat most of them are either inoperative or not publicly available. Three of them specifically addressed the geographical scale of an industrial park (IP): *Knowledge-Based Decision Support System* (KBDSS), which is not available, *Designing Industrial Ecosystems Toolkit (DIET)*, which is reportedly unusable and *Industrial Ecology Planning Tool (IEPT)*, which requires ArcView GIS and its source code is available [15]. The geographical scope of the other tools considered the city/state, region and nation [15].

Nevertheless, based on the conducted literature analysis, there were three publicly available ICT solutions found which explicitly facilitates IS identification. [9] found several more IT tools, but note that they included various concepts such as social network platforms and IS knowledge repositories and region identification systems for IS. This study focuses on the actual IS identification among economic actors.

The Italian agency for new technologies, energy and sustainable economic development (ENEA) developed a *GIS-based web platform* to identify IS opportunities on a regional scale by Input-Output Matching [16]. The most significant non-technical barriers for IS implementation were the regulatory and control systems, including environmental regulation, lack of cooperation and trust between industries, economic barriers, as well as lack of information sharing [16].

The Resource eXchange Platform (TRXP) is a resource exchange web-platform that facilitates Industrial Symbiosis (IS) by building a network of organizations in Europe to enable the reuse of industrial streams of ICT equipment [17]. [17] showed that the tool was technically feasible, but nevertheless economic validity and regulatory constraints were considered to be challenging.

eSymbiosis is a web-based platform, providing knowledge-based services that reveal IS opportunities by matching supply and demand of resources in Europe [18]. It is built as an e-marketplace to trade the residual and by-product flows in a business-to-business (B2B) domain [18].

The studies of [9,15] conclude that most of the systems have not been designed for commercial purposes but predominantly concentrated more on the functionality and technical opportunities rather than connecting economic actors by building human and business relationships which is considered to be one of the main reasons for their failure. So they pointed out general strengths such as the identification of possible physical exchange processes in the sense of closing material flows, but they identified a lack of sociability, for example the inputs and outputs were connected well but the responsible people have been neglected [9,15].

Potentials for improvement for developing ICT tools for IS should address the social aspects such as better relationship management, initiation processes, the formation of trustworthy relationships between the economic actors participating in an IS and the facilitation of cooperation [9,15]. Additionally, many of the investigated tools presuppose advanced computer and programming skills and a comprehensive knowledge of the industrial organizations, so advancements of ICT tools for IS should address a better usability and sociability to shorten the duration of training and generate higher motivation for new users [15]. Further success criteria are the industry adoption of standardized (waste) taxonomy and the presence of a key number of organizations [9]. For example, the web-based waste exchange platform *WasteX* was developed for developing economies, but the system was cancelled due to a lack of industrial adoption [9,19].

Most of the investigated ICT tools for IS apply the method of output-input matching of various resource flows among industrial organizations, but do not provide decision support such as advanced analysis regarding economic viability of different IS opportunities, which is an essential challenge in enabling and facilitating IS [20,21].

[20] developed a system architecture of an IS collaboration platform by using the by-product exchange network (BEN) model. The BEN model is based on an agent-based modelling approach (ABM) [20]. ABM is a class of computational models for simulating various scenarios of the outcome of the actions and interactions of autonomous agents within a system (both individual or collective entities such as organizations or groups) [11,23]. They used a case study of food waste in Singapore, they applied the model as a decision support tool for companies to evaluate the economic viability of IS [20]. So in the model, entities such as plants or facilities in the IS network are represented by agents that are programmed based on rules to actively consume and/or produce resources, while resources are represented by agents that passively change their states such as quantities and locations [20].

As there are first starting points and approaches to solve these issues gradually, the lessons learned and corresponding implications have been incorporated into a preliminary concept for an IT-supported IS tool, whereat the ABM approach was not included because the focal point of this study was on the system analysis and IS identification (see Fig. 1, step 1 & 2).

4. A preliminary concept for an IT-supported Industrial Symbiosis tool

Usually an Industrial Park (IP) is mainly characterized by small and medium-sized companies, hence it is considered that an overarching coordinating body or organizational unit plays an essential role to support various Industrial Symbiosis (IS) activities such as the implementation of supply-demand/output-input matches, logistics, capacity management [5,9,25].

Based on the conducted literature analysis, a preliminary concept for an IT-supported IS tool is presented in this study, which is currently in the phase of prototyping. The elements of IS identification and assessment are combined into an overall web-based platform (this can be extended to a mobile application with responsive design as well) in order to provide integrated extensive toolboxes. Additionally, it shall support the coordination and management, specifically to facilitate the retrofitting of an industrial park into an EIP by identifying IS potentials and initiate implementation processes.

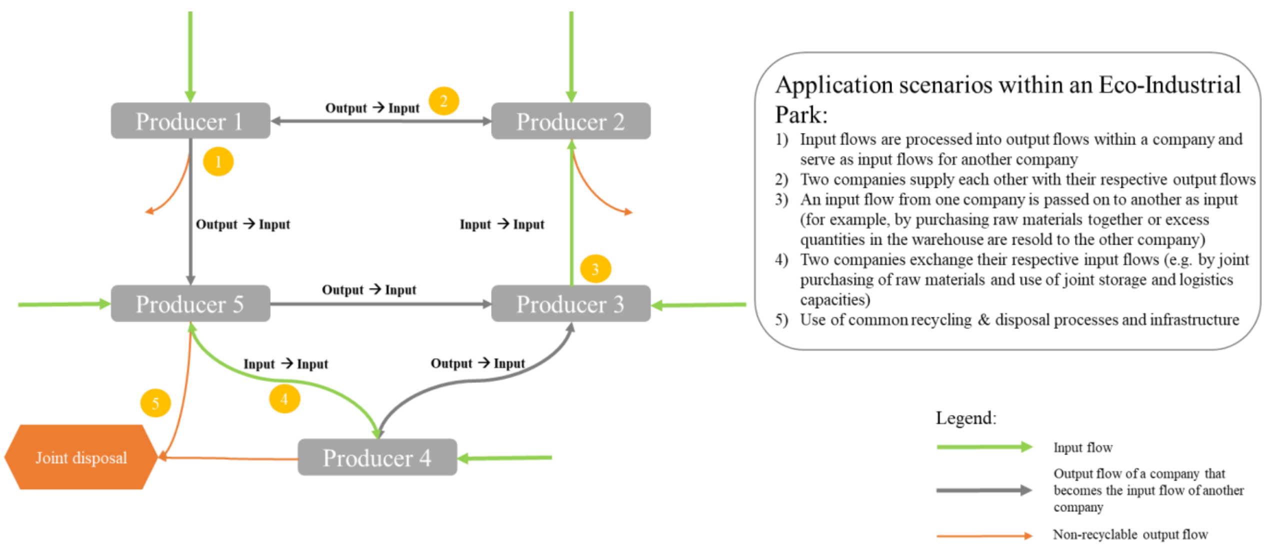

Fig. 2. Application scenarios within an Eco-Industrial Park for the concept of the web-based Industrial Symbiosis tool.

Fig. 2 shows several application scenarios included in the concept for the web-based IS tool. It goes beyond a simple output-input matching of the involved entities, it also considers the development of joint procurement, recycling and disposal processes and (infra-)structures.

The preliminary concept for an IT-supported IS tool comprises five modular functionalities: 1) analysis toolbox, 2) facilitated synergy identification (IS), 3) interactive marketplace, 4) communication and collaboration platform, 5) cross-company management (see Fig. 3).

which only shows the relevant input and output material and energy flows that lead into and leave the plant, whereby a deeper detailed level of process mapping does not take place [22]. However, this basic model is too abstract to identify weak points and optimization potentials, so that the operational processes have to be presented in more detail [22]. In addition to depth

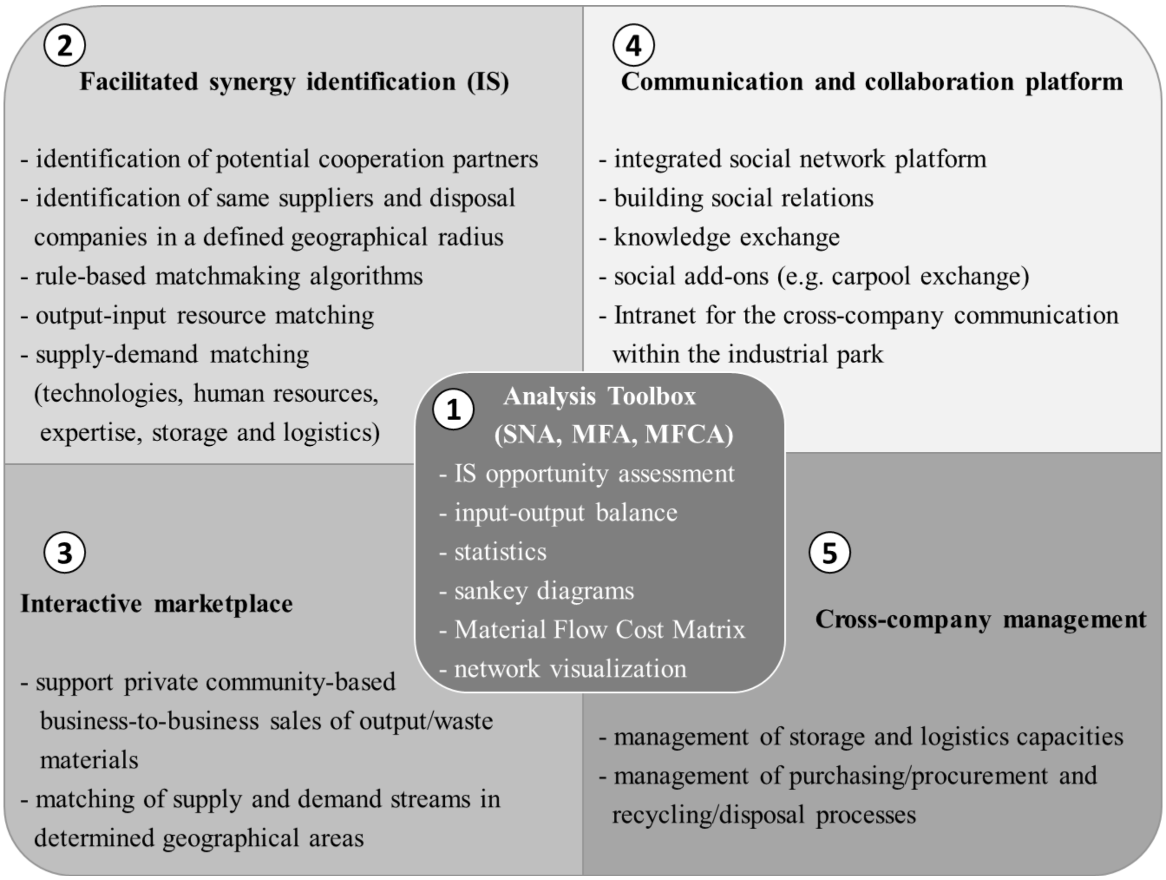

Fig. 3. Preliminary concept for a web-based Industrial Symbiosis application.

1) As an integrated component-based module, the flexible modelling of operational processes at the level of material and energy flows is to be analyzed and presented. Therefore, an *integrated analysis toolbox* with various evaluation methods (SNA, MFA, MFCA) is provided in the central core of the web application. In this case, the method of LCA can be optionally integrated, but requires a connection to a database such as GaBi or ecoinvent. For cost reasons, therefore, the LCA method is not included in the concept for the basic package. The simplest case of an energy and material flow model is the black box model of the plant,

resolution, the modeling system also has to allow flexible resolution in width, so that the scope of the energy and material balance can also be flexibly expanded, for example, upstream (suppliers) [22] or downstream. As a basis for a simulation of planned measures, the material and energy flow model also enables the estimation and evaluation of alternative actions [22]. A flexible modeling system with the evaluation options mentioned (SNA, MFA, MFCA) thus serves as an instrument for decision support. A comprehensive dashboard with visualized results in form of inter alia sankey diagrams, statistics and input-output balances shall be provided.

2) The *facilitated synergy identification* of IS opportunities is based on underlying rule-based match-making algorithms including output-input as well as supply-demand resources such as technologies, human resources, expertise, storage and logistics in order to enable the identification of potential cooperation partners in a defined geographical radius, for example to identify same suppliers and disposal companies or to match input-output tables, for example the reutilization of industrial organic waste to bioenergy [59].
3) The *interactive marketplace* shall support private community-based business-to-business sales of residual output, waste materials by matching the supply and demand streams in determined geographical areas, in which material and waste taxonomy will be one of the greatest challenges, especially the specification of material and waste properties, including material quality.
4) As [26] pointed out “coordination does not automatically mean cooperation”, one component of the IS tool shall address social aspects in order to promote good personal relationships and the cultivation of cooperation [11,60].

   The *communication and collaboration platform* includes an integrated social network platform, enabling social relations, intensifying networking and trust building among the economic actors. Participating companies shall be able to exchange knowledge and experiences concerning the identification and implementation of IS opportunities.

   Social add-ons shall be incorporated as well, e.g. a carpool exchange for the industrial area. Furthermore, inter-company communication and coordination is supported, for example by organizing cross-company sports, benefit and other cultural events via an integrated "Social Media" area or by creating other interest groups.
5) In the module of *cross-company management*, potential capacities of storage and logistics shall be identified in order to utilize free capacities optimally. The procurement, recycling and disposal processes shall be managed efficiently by merging external services and (infra-) structure for joint usage and better purchasing and payment conditions, resulting in mutual cost reduction and higher revenues due to increased capacity utilization.

The usability and sociability shall be increased by providing customized data input masks, clear and easy-to-understand visualization of results and interactive communication possibilities via an integrated social media platform. Data confidentiality shall be tackled inter alia by a login system with specified access and permission rules.

Furthermore, an internal evaluation for the entire industrial site is possible for the monitoring and control of regional energy and material flow management and hence the expansion of synergetic cascade use, provided that a higher-level organizational unit has been established for the industrial park. The individual companies would have the choice of which data and information they would release to/share with the overarching organization unit of the industrial park and can nevertheless make full use of the evaluation options for their internal purposes. The IT-supported tool to be developed is intended to provide concrete recommendations for action and starting points to companies and thus offers valuable information for decision making to improve their economic, ecological and technical performances. Furthermore, it can improve cross-company and employee communication and the expansion of social networking, as well as increase employee awareness for sustainability issues, leading to a reduction of the ecological footprint through increased resource efficiency.

5. Discussion and concluding remarks

In emerging and developing economies, industrial parks can be transformed towards Eco-Industrial Parks (EIPs), generating significant benefits for the environment, economy and society, as [61] found out by investigating 33 examples of EIPs in 12 developing and emerging economies, including their policy context. The progressive field of Industrial Ecology (IE), providing various approaches, perspectives and methods such as Industrial Symbiosis (IS) to tackle (at least partly) the nowadays challenges, raises enormous opportunities to improve resource productivity and efficiency while reducing the environmental burden [62]. Emerging and developing countries can exploit the concepts and tools of IE to generate and detect chances to capture new opportunities for a sustainable industrialization and development, enabling a resilient economy [63].

Such an IT-supported IS tool could be considered as a small cogwheel in a complex large system, a point of contact and leverage point to contribute to the trajectory of sustainable development, facilitating the expansion and intensification of interconnectedness and intra- and inter-organizational collaboration. The focus of such IS tools should be the identification of potential cooperation partners. This can be done via initial output-input matchmakings, but manual data entry of individual residual material flows is too cost-intensive from an economic point of view. So this can be partly tackled by (semi-) automated data gathering via specific sensors during the production processes [54]. Furthermore, many researchers argue that incorporating environmental data sets can benefit the IS identification tool regarding the exploration and assessment of IS opportunities [9,16,35,36,37].

IS tools for industrial companies should be designed for a commercial market, where the initial identification of cooperation partners should be the main focus in order to enable long-term business relationships. The IS tool should therefore provide more transparency among market players and propose potential cooperation partners according to selectable criteria (e.g. geographical radius, material properties, material quality, purchase quantity, delivery period), bringing synergy partners together. This tool can serve for initiation and provide decision support, but the complex business-driven negotiations and agreements for a long-term business relationship can only be supported to a certain limit. This is accompanied by confidence building and enables the economic evaluation of a company with regard to possible opportunities and risks such as security of supply of resources, including possible (seasonal, temporal and qualitative) variability and fluctuations, medium to long-term agreements on price and quality.

This is the reason why an industrial park is a good and feasible starting point with promising long lasting impacts and business relationships due to the "community effect" of an industrial park. So the expansion of an IS network is predominantly based on the collaboration and synergistic opportunities revealed by geographical proximity of the involved entities [4]. Thus, the resilience and sustainability of industrial symbioses are supported by geographical proximity and the long-term cooperation of the economic actors. The long-term exchange of resources such as excess waste heat flows can only be achieved by establishing a common infrastructure (common heat pipes) or other types of synergies such as joint procurement and disposal, as well as utility sharing requires geographical proximity. Building exchange networks of resources may create vulnerabilities by a higher degree of interdependencies among the entities and their performances, which requires an increased level of trust [9,39]. Utility sharing can be a tempting starting point to enhance IS, but several case studies suggest that material (by-product) exchanges may be a better first starting point for existing industrial parks [9,39,40,41]. It is argued that material exchanges have less potential of adverse effects [9,40,41]. Additionally, having backup systems can increase the resilience of an IS network by introducing redundant or similar entities [9].

This kind of ICT solution can be promising, especially from the perspective of small and medium sized enterprises (SMEs), concerning cost-benefit relationship and a continuous improvement of their economic, environmental and technical performance. Especially SMEs can benefit from such an IS approach, by identifying common suppliers and waste-disposal and recycling companies via the method of SNA in order to establish joint processes of procurement of materials as well as waste management and reduce costs.

Another challenge to be met adequately and in a sophisticated manner is the economic factor, which is considered to be the primary motivation and main driving factors to change existing systems [27,28,29,30,60]. Investments are to be made to implement IS opportunities, hence costs will occur [11,60]. Therefore, the question of the distribution of costs and potential future savings among the economic actors will arise [11]. If this is not considered fairly distributed, they may not adopt the proposed IS opportunity [11]. So one major facilitator for the expansion of IS networks is a component of an IS tool that shows the economic viability to the participating organizations [20]. A data oriented approach would be advantageous for revealing new IS opportunities as well as for assessing the economic benefits, substantiating the IS viability [31]. Such approaches can be inter alia applied by the method of MFCA. From a business perspective, placing MFA and MFCA at the starting point with a boundary of a production system and then exploring potential IS connections among the entities, a useful "road map" can be pursued to assess and prioritize IS opportunities from an economic perspective. Additionally, the basis of analysis can be expanded inter alia with the method of LCA to value chains and finally all life cycle stages of a product or service as it reduces the starting barrier and increases the complexity and scope gradually [33]. So in fact, MFCA shares a similar information and data base with various methods such as MFA, LCA and Carbon Footprinting [34].

Further research should address the combination of IS identification and assessment with the method of MFCA, as previous research has been scarce on that special topic. Additionally, the environmental and economic performance of an entire industrial park could be assessed and controlled. This could be investigated more in detail by conducting several case studies, in which especially knowledge and insights of barriers, enablers, benefits, risks and challenges of IS identification and implementation is gathered. The following questions are an excerpt of a possible questionnaire for future research:

- What is the current state of knowledge of the economic actors in an industrial park concerning IS and its applied methods to reveal IS opportunities?
- What are the key factors and drivers associated with IS implementation and the expansion of IS networks?
- What are the barriers, vulnerabilities and challenges of IS adoption? And how to tackle them?
- What are the success criteria for retrofitting an EIP?
- What can an optimally utilized industrial symbiosis of a given area look like?
- What is the current status of the area under consideration?
- How to achieve the desired future EIP scenario from the present status?
- Where are first simple starting points and leverage points for an expansion of an IS network?
- How might stakeholders become meaningfully engaged in systems co-design, so as to shape the emergent technology-enabled ecosystem?

For inter-organizational collaboration teams virtual work environments are becoming more relevant, therefore approaches such as Collaboration Engineering (CE) can be effective for creating design patterns and deriving design guidelines for virtual collaboration processes [56]. To design such collaboration systems many interrelated issues of higher complexity and volume in a social-technical context have to be addressed adequately. Referring to [55,64], a Seven-Layers Model of Collaboration (SLMC) was developed for designers of collaboration support systems in the context of CE, which considers differing levels of abstraction and addressing different concepts, techniques and tools in each layer. According to [57], “the power of facilitated collaboration is also validated as helpful for trust development.” They made several implications, such as proposing a series of trust antecedents, a treatment design of a CE approach for trust improvement, and a new context application of CE [57].

With regard to enabling Industrial Symbiosis (IS), the great challenges lie in building trust and intensifying cooperation among economic actors [15], developing a healthy balance among all stakeholders´ interests [60], while maintaining data confidentiality, regulatory compliance and reducing potential organizational risks such as misuse of provided information [9]. More research is necessary to address such topics adequately, in order to remove or at least lower technical, economic, organizational and social barriers [38], increase the resilience of an emerging EIP and foster long lasting business relationships in the context of IS, enabling safe operating cooperation environments.

10. References

[1] P. J. Crutzen, “Geology of mankind”, Nature, Macmillan Magazines Ltd., Vol. 415, 2002, p. 23.
[2] EEA, European Environment Agency, “More from less – material resource efficiency in Europe”, EEA report No 10/2016 Technical report European Environment Agency, 2016.
[3] M. R. Chertow, “Industrial symbiosis: literature and taxonomy”, Annual Reviews Energy Environment, Vol. 25, No. 1, 2000, pp. 313-337.
[4] M. R. Chertow, “Industrial Symbiosis”, Encyclopedia of Energy, Vol. 3, 2004, pp. 407-415.
[5] G. Herczeg, R. Akkerman, M. Z. Hauschild, “Supply Chain Management in Industrial Symbiosis Networks”, PhD thesis, 2016, Technical University of Denmark, pp. 7-45.
[6] D. R. Lombardi, P. Laybourn, “Redefining industrial symbiosis”, Jounral of Industrial Ecology, Vol. 16, No. 1, 2012, pp. 28-37.
[7] G. Massard, O. Jacquat, L. Wagner, D. Zürcher, “International survey on eco-innovation parks. Learnings from experiences on the spatial dimension of eco-innovation”, Bundesamt für Umwelt BAFU, 2012, Swiss conferation.
[8] J. Ehrenfeld, N. Gertler, “Industrial ecology in practice: The evolution of interdependence at Kalundborg”, Journal of Industrial Ecology, Vol. 1, No. 1, 1997, pp. 67-80.
[9] G. van Capelleveen, C. Amrit, D. M. Yazan, “A Literature Survey of Information Systems Facilitating the Identification of Industrial Symbiosis”, by B. Otjacques et al. (eds.). From Science to Society, Progress in IS. In Springer International Publishing AG, 2018, pp. 155-169.
[10] C. Ruiz-Puente, E. Bayona, “Modelling of an industrial symbiosis network as a supply chain”, Conference Paper, 2017.
[11] C. A. Kastner, R. Lau, M. Kraft, “Quantitative tools for cultivating symbiosis in industrial parks; a literature review“, Cambridge Centre for Computational Chemical

Engineering, University of Cambridge, ISSN 1473-4273, 2015.
[12] A. Matusevicus, V. Wohlgemuth, “Konzeptionierung einer Webanwendung zur Beurteilung von Stoff- und Energieströmen am Beispiel des Industrie- und Gewerbestandortes Berlin-Schöneweide“, In H. C. Mayr, M. Pinzger (eds.): INFORMATIK 2016, Lecture Notes in Informatics (LNI), Gesellschaft für Informatik, 2016, Bonn, pp. 1251-1262.
[13] L. Sokka, S. Lehtoranta, A. Nissinen, M. Melanen, “Analyzing the Environmental Benefits of Industrial Symbiosis”, Journal of Industrial Ecology, Vol. 15, No. 1, 2010, pp. 137-155.
[14] N. Ulhasanah, N. Goto, “Preliminary Design of Eco-City by Using Industrial Symbiosis and Waste Co-Processing Based on MFA, LCA, and MFCA of Cement Industry in Indonesia”, International Journal of Environmental Science and Development, Vol. 3, No. 6, 2012, pp. 553-561.
[15] G. B. Grant, T. P. Saeger, G. Massard, L. Nies, “Information and communication technology for industrial symbiosis”, Journal of Industrial Ecology, Vol. 14, No. 5, 2010, pp. 740-753.
[16] L. Cutaia et al., “The experience of the first industrial symbiosis platform in Italy”, Environmental Engineering and Management Journal, Vol. 14, No. 7, 2015, pp. 1521-1533.
[17] J. Dietrich et al., “Extending product lifetimes: a reuse network for ICT hardware”, Proceedings of the Institution of Civil Engineers - Waste and Resource Management, Vol 167, Issue 3, 2014, ISSN 1747-6526, pp. 123-135.
[18] F. Cecelja et al., “e-Symbiosis: technology-enabled support for industrial symbiosis targeting small and medium enterprises and innovation”, Journal of Cleaner Production, Vol. 98, 2015, pp. 336-352.
[19] A. Clayton, J. Muirhead, H. Reichgelt, “Enabling industrial symbiosis through a web-based waste exchange”, Journal of Greener Management International, Vol. 40, 2002, pp. 93-107.
[20] B. Raabe et al., “Collaboration platform for enabling industrial symbiosis: Application of the by-product exchange network model”, Procedia CIRP, Vol. 61, 2017, pp. 263-268.
[21] J.O. Levänen, J.I. Hukkinen, “A methodology for facilitating the feedback between mental models and institutional change in industrial ecosystem governance: A waste management case-study from northern Finland”, Journal of Ecological Economics, Vol. 87, 2013, pp. 15-23.
[22] V. Wohlgemuth, “Komponentenbasierte Unterstützung von Methoden der Modellbildung und Simulation im Einsatzkontext des betrieblichen Umweltschutzes“, Umweltinformatik, Shaker Verlag, 2005, ISBN 3-8322-4383-6, p. 148.
[23] R. L. Axtell, C. J. Andrews, and M. J. Small, “Agent-based modeling and industrial ecology”, Journal of Industrial Ecology, Vol. 5, No. 4, 2001, pp. 10-13.
[24] Y. Zhang, H. Zheng, B. Chen, M. Su, G. Liu, “A review of industrial symbiosis research: theory and methodology“, Frontiers of Earth Sciences, Vol. 9, No. 1, 2015, pp. 91-104.
[25] M. Mirata, “Experiences from early stages of a national industrial symbiosis programme in the uk: determinants and coordination challenges”, Journal of Cleaner Production, Vol. 12, No. 810, 2004, pp. 967-983.
[26] F. A. A. Boons, L. W. Baas, “Types of industrial ecology: The problem of coordination”, Journal of Cleaner Production, Vol. 5, No. 1-2, 1997, pp. 79-86.
[27] R. Heeres, W. Vermeulen, F. de Walle, “Eco-industrial park initiatives in the USA and the Netherlands: first lessons”, Journal of Cleaner Production, Vol. 12, No. 8-10, 2004, pp. 985-995.
[28] T. Jackson, R. Clift, “Where’s the profit in industrial ecology?”, Journal of Industrial Ecology, Vol. 2, No. 1, 1998, pp. 3-5.
[29] S. Pakarinen, T. Mattila, M. Melanen, A. Nissinen, L. Sokka, “Sustainability and industrial symbiosis - The evolution of a Finnish forest industry complex”, Resources, Conservation and Recycling, Vol. 54, No. 12, 2010, pp. 1393-1404.
[30] N. Senlier, A. N. Albayrak, “Opportunities for sustainable industrial development in turkey: Eco-industrial parks”, Gazi University Journal of Science, Vol. 24, No. 3, 2011, pp. 637-646.
[31] B. Song, Z. Yeo, P. Kohls, C. Herrmann, “Industrial symbiosis: Exploring big-data approach for waste stream discovery”, Procedia CIRP 61, 2017, pp. 353-358.
[32] T. Viere, M. Prox, A. Möller, M. Schmidt, “Implications of Material Flow Cost Accounting for Life Cycle Engineering”, Conference Paper, 18th CIRP International Conference on Life Cycle Engineering, 2011, Braunschweig.
[33] A. Möller, M. Prox, “From Material Flow Cost Accounting to MFA and LCA”, Proceedings of the 8th International Conference on EcoBalance, Dec. 10-12, 2008, Tokyo.
[34] M. Prox, “Material Flow Cost Accounting extended to the Supply Chain – Challenges, Benefits and Links to Life Cycle Engineering”, The 22nd CIRP conference on Life Cycle Engineering, Procedia CIRP 29, 2015, pp. 486-491.
[35] T. Sterr, T. Ott, “The industrial region as a promising unit for eco-industrial development reflections, practical experience and establishment of innovative instruments to support industrial ecology”, Journal of Cleaner Production, Vol. 12, No. 810, 2004, pp. 947-965.
[36] C. Davis, I. Nikoli, G. P. J. Dijkema, “Integration of life cycle assessment into agent-based modeling”, Journal of Industrial Ecology, Vol. 13, No. 2, 2009, pp. 306-325.
[37] T. Mattila, S. Lehtoranta, L. Sokka, M. Melanen, A. Nissinen, “Methodological aspects of applying life cycle assessment to industrial symbioses”, Journal of Industrial Ecology, Vol. 16, No. 1, 2012, pp. 51-60.
[38] E. Perl-Vorbach, S. Vorbach, “Ökoinformationssystem Mödling: Analyse einer industriellen Symbiose“, Von Hauff, M., Isenmann, R., Müller-Christ, G. (eds.). In Industrial Ecology Management – Nachhaltige Entwicklung durch Unternehmensverbünde. Springer Gabler, 2012, pp. 315-335.
[39] D. Gibbs, “Trust and networking in inter-firm relations: The case of eco-industrial development”, Local Economy, Vol. 18, No. 3, 2003, pp. 222-236.

[40] M. R. Chertow, “Uncovering industrial symbiosis”, Journal of Industrial Ecology, Vol. 11, No. 1, 2008, pp. 11-30.
[41] R. A. Frosch, N. E. Gallopoulos, “Strategies for manufacturing”, Scientific American, Vol. 189, No. 3, 1989, pp. 1-7.
[42] Y. Ismail, “Industrial Symbiosis at Supply Chain”, International Journal of Business, Economics and Law, Vol. 4, Issue 1, 2014, ISSN 2289-1552.
[43] R. Isenmann, “Beitrag betrieblicher Umweltinformatik für die Industrial Ecology – Analyse von BUIS-Software-Werkzeugen zur Unterstützung von Industriesymbiosen“, In J. M. Gómez, C. Lang, V. Wohlgemuth, (eds.), IT-gestütztes Ressourcen- und Energiemanagement, 2014, Springer-Verlag Berlin Heidelberg, pp. 397-407.
[44] W. S. Ashton, “Understanding the organization of industrial ecosystems: a social network approach”, Journal of Industrial Ecology, Vol. 12, No. 1, 2008, pp. 34-51.
[45] T. Doménech, M. Davies, “The social aspects of industrial symbiosis: the application of social network analysis to industrial symbiosis networks”, Progress in Industrial Ecology, Vol. 6, No. 1, 2009, pp. 68-99.
[46] S. Schaltegger, D. Zvezdov, “Expanding material flow cost accounting. Framework, review and potentials”, Journal of Cleaner Production, Vol. 108, 2015, pp. 1333-1341.
[47] M. Schmidt, M. Nakajima, “Material Flow Cost Accounting as an Approach to Improve Resource Efficiency in Manufacturing Companies” Resources, Vol. 2, 2013, pp. 358-369.
[48] S. Bautista-Lazo, T. Short, “Introducing the all seeing eye of business: a model for understanding the nature, impact and potential uses of waste”, Journal of Cleaner Production, Vol. 40, 2013, pp. 141-150.
[49] C. Jasch, “Environmental and Material Flow Cost Accounting”, Springer, 2009, Netherlands, Dordrecht.
[50] A. Bain, M. Shenoy, W. Ashton, M. Chertow, “Industrial symbiosis and waste recovery in an Indian industrial area”, Resources, Conservation and Recycling, Vol. 54, 2010, pp. 1278-1287.
[51] M. R. Chertow, W. S. Ashton, J. C. Espinosa, “Industrial Symbiosis in Puerto Rico: Environmentally Related Agglomeration Economies”, Regional Studies, Vol. 42, No. 10, 2008, pp. 1299-1312.
[52] S. S. Chopra, V. Khanna, “Understanding resilience in industrial symbiosis networks: Insights from network analysis”, Journal of Environmental Management, Vol. 141, 2014, pp. 86-94.
[53] M. Martin, “Industrial Symbiosis in the Biofuel Industry: Quantification of the Environmental Performance and Identification of Synergies”, Dissertation No. 1507, Linköping Studies in Science and Technology, 2013, ISSN: 0345-7524.
[54] A. Lütje, A. Möller, V. Wohlgemuth, “A Preliminary Concept for an IT-Supported Industrial Symbiosis (IS) Tool Using Extended Material Flow Cost Accounting (MFCA) - Impulses for Environmental Management Information Systems (EMIS)”, 2018, Springer Nature Switzerland AG (Accepted for publication in H.-J. Bungartz, D. Kranzlmüller, V. Wohlgemuth (eds.) “Advances and New Trends in Environmental Informatics”).
[55] R.O. Briggs, G.L. Kolfschoten, G.J. De Vreede, D.L. Dean, “Defining Key Concepts for Collaboration Engineering”, Proceedings of the Twelfth Americas Conference on Information Systems, Acapulco, Mexico, 2006, pp. 121-128.
[56] G.J. De Vreede, R.O. Briggs, A.P. Massey, “Collaboration engineering: Foundations and opportunities”, Editorial to the special issue of the Journal of the Association for Information Systems, Vol. 10, No. 3, 2009, pp. 121-137.
[57] X. Cheng, S. Fu, D. Druckenmiller, “Trust Development in Globally Distributed Collaboration: A Case of US and Chinese Mixed Teams”, Journal of Management Information Systems, Vol. 33, No. 4, 2017, pp. 978-1007.
[58] R. Côté, J. Hall, “Industrial parks as ecosystems”, Journal of Cleaner Production, Vol. 3, No. 1-2, 1995, pp. 41-46.
[59] V. Wohlgemuth, A. Lütje, “Using the Method of Material Flow Cost Accounting (MFCA) to quantify Industrial Organic Waste Streams for Energetic Utilization”, International Workshop “Ecological sustainable waste management – energetic utilization of organic waste (Biowaste4E)”, 2018 (Accepted for publication in Workshop Proceedings).
[60] D. Sakr, L. Baas, S. El-Haggar, D. Huisingh, “Critical success and limiting factors for eco-industrial parks: global trends and Egyptian context”, Journal of Cleaner Production, Vol. 19, 2011, pp. 1158-1169.
[61] United Nations Industrial Development Organization, UNIDO, “Global Assessment of Eco-Industrial Parks in Developing and Emerging Countries”, UNIDO Report, 2016, pp. 3-36.
[62] M.R. Chertow, “Industrial Ecology in a Developing Context”, chapter from C. Clini, I. Musu, M. Gullino, eds., “Sustainable Development and Environmental Management”, Springer, 2008, pp. 1-19.
[63] M. Shenoy, “Industrial Ecology in Developing Countries”, in R. Clift, A. Druckmann (eds.) “Taking Stock of Industrial Ecology”, Springer, Chapter 11, 2016, pp. 229-245.
[64] R.O. Briggs, G.L. Kolfschoten, G.J. De Vreede, C. Albrecht, D.R. Dean, S. Lukosch, “A Seven-Layer Model of Collaboration: Separation of Concerns for Designers of Collaboration Systems”, Proceedings of the Twelfth Americas Conference on Information Systems, Acapulco, Mexico, 2006, pp. 121-128.
[65] B. Li, P. Xiang, M. Hu, C. Zhang, L. Dong, “The vulnerability of industrial symbiosis: a case study of Qijiang Industrial Park, China”, Journal of Cleaner Production, 2017, doi: 10.1016/j.jclepro.2017.04.087.