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The industrial region as a promising unit for eco-industrial development—reflections, practical experience and establishment of innovative instruments to support industrial ecology

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Abstract

Eco-industrial developments with a special focus o n material cycles are usually concentrated on the level of the industrial estate/industrial park. However, the results of completed and ongoing research projects in Germany's Rhine–Neckar region indicate that larger regional areas may be more suitable for closing material loops and creating sustainable industrial ecosystems. Nonetheless, this larger size also presents new challenges for industrial ecosystem development, such as establishing the necessary trust and coordination among actors, homogenizing and collecting data to enable comparisons within and between firms, and minimizing the transaction costs involved in searching for appropriate partners. Practical solutions and IT-tools suggested as a means of supporting eco-industrial development that emphasizes positive synergy effects for industrial actors.

Keywords: Regional industrial ecosystems; Material flow management; Waste management software; Eco-industrial networking; SMEs

1. Introduction

The number of recycling oriented networks that have been identified rose sharply in the last decade in various locations all over the world [1–9]. However, these developments were, and still are, highly concentrated on the spatial/organizational level of the industrial estate/industrial park, while approaches and applications to larger areas remain the exception.

In examining the reasons for this trend, our findings correspond with those of Gibbs [1: p. 5], in that "the development of eco-industrial parks is overwhelmingly a public sector led phenomenon". In fact, urban planners and planning agencies tend to pursue one of two primary objectives: either they engage in the restructuring process of an industrial brownfield in order to attract new, promising investors, or they opt for designing a new industrial ecosystem[1] in order to create a greenfield development. The latter generally involves the utilization of an ecology oriented profile of prerequisites and demands with which an investor must comply in order to establish a production plant within this specific greenfield development. In both cases, public subsidies and planning concepts play a key role. Although this may be the only viable method to materialize such development within a relatively short period of time, it is not the manner in which the

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[1] According to Ehrenfeld and Gertler [10: p. 68], an industrial ecosystem is to be understood as a complex of interrelated symbiotic links among groups of firms within a given area.

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famous Kalundborg symbiosis or similar output–input systems[2] developed. Kalundborg developed gradually over the last 30 years, and it evolved without a grand design [10: p. 69]. This industrial symbiosis never received public subsidies[3] and each linkage between firms was negotiated as an independent business deal [10: p. 73]. In other words, the Kalundborg symbiosis has always been driven by market forces, and the actual physical linkages and their economic viability were the subject of bilateral talks between industrial actors without external prompting. These factors must be explicitly stated when using Kalundborg as a standard model for the establishment of eco-industrial developments.

Together with the seminal publications of Frosch and Gallopoulos [14], Allenby [15], Tibbs [16], Schwarz [17], Ehrenfeld and Gertler [10], and others, the empirical results of the Kalundborg symbiosis have had a powerful effect on the development of eco-industrial parks (EIPs) in the US as well as in Europe. Without the knowledge gained from the Kalundborg case, it is doubtful that the recycling network of Upper Styria (Austria) would have been identified or developed [9,17–20]. The same is true for the currently evolving network in the industrial region of Rhine–Neckar [21–23], in which both the knowledge of Kalundborg and Upper Styria were important. In fact, it is hardly imaginable that eco-industrial development would have flourished so strongly in the last 10 years without the identification, intensive study, and well-documented material and monetary savings surrounding the spontaneous innovation in Kalundborg. Even in the US or in Canada, few publications can be found on eco-industrial development which do not mention this success story.

The last decade has produced a plethora of literature and case studies regarding eco-industrial development and its contribution to sustainability [2,4,24–28]. This has not only provided an insight into the development process in various circumstances, but has also given rise to a new skepticism of eco-industrial development which is "centered on the technical and engineering difficulties, coordinating supply and demand needs of participating firms, and regulatory inhibitions" [4: p. 7].

2. The eco-industrial estate approach and its limits

2.1. Learning from that which already exists

Over the years, the results of the Kalundborg case have become common knowledge within the international eco-development community.[4] However, since Kalundborg was "discovered" in 1989, a comparable intensity of output–input connections between companies of different industrial sectors within a given industrial park has not been documented. That being said, we must acknowledge the work of Desrochers [29,30], who was able to identify, through a large variety of articles and books from the 19th and the beginning of the 20th century, that "inter-industry waste recycling linkages are not a contemporary phenomenon, but rather a widespread practice that was well documented in the past" [29: pp. 49–50]. Especially in the chemical industry, outputs that were previously unmarketable and therefore had been completely wasted have attracted the attention of R&D groups who have discovered and implemented various technical innovations.[5]

If we take a look at the contemporary "production verbund[6]" [32] of the BASF in Ludwigshafen, we observe a highly interconnected system of 2000 km (about 1250 miles)[7] of pipes that connect different production units [32][8] in a territorial area of 7 km^2 (i.e. about 3 square miles). If we accept the calculation of

[2] Input–output systems describe the typical structure of an enterprise, in which inputs enter the system, are transformed during the production process (throughput sphere), and leave the system as outputs. In a closed-loop economy, these input–output systems are complemented and followed by output–input connections, which describe the transfer of an undesired output (by-product) to a reducer, who is the industrial producer's complementary actor [11,12]. In an industrial ecosystem, this reducer reduces the by-product as far as necessary until he gains modules or raw materials that he can again offer to a producer. Or, as expressed by Ehrenfeld and Gertler: until "one facility's waste becomes another facility's lifestock" [10: p. 73]. As we wish to place special emphasis on the bridge between the industrial producer and the industrial reducer, we call this interaction between producer and reducer an output–input system. Connections of this kind are essential in closing material loops and thereby reducing the resource intensive extraction of inputs from nature. Recycling oriented bilateral connections or networks, which are characterized by such relations between producers and reducers, could therefore be called output–input systems.

[3] Jørgen Christensen calls this a "non-project" [13].

[4] Well documented, for example, in Schwarz [16], Ehrenfeld and Gertler [10], and Christensen [34]; see also EIDP updates of the Cornell Center for the Environment [26] and the New York State School of Industrial and Labor Relations as well as in the Smart Growth Library of the Smart Growth Network (SGN) [2] in partnership with the Sustainable Communities Network (SCN).

[5] According to Faber et al. [31], the usability of alternative by-products has been an important trigger for radical technological changes during the history of the German chlorine–alkali industry.

[6] The term "verbund" has been left untranslated on the English homepage of the BASF [32]. "Production verbund" translates more or less as a heavily interlinked and complex production system.

[7] The figure of 1200 miles documented on the same homepage only represents those pipes that connect different production units, i.e. pipes within the different production units are not counted here.

[8] The internet homepage of BASF in Ludwigshafen reads: "We use raw materials, energy and intermediates efficiently, re-use by-products and residual materials, and keep the distances that substances need to be transported to a minimum. This reduces the impact on the environment and saves money" [32].

the “verbund effects” [33], the company saves about €500 million per year in comparison with a hypothetical scenario in which 70 comparable production units belong to a network of mid-sized chemical companies located 100 km from each other. So even today there is no question that interlinkages and interconnections of production units are of fundamental importance.

Nevertheless, what happens at the “verbund park” of BASF in Ludwigshafen, happens within the systemic borders of the industrial company itself, in which the transparency of information is high, legal restrictions are comparatively low (e.g. lower level of restrictions for company internal traffic), and where the different elements of the “verbund system” are coordinated and synchronized. BASF can therefore be an example for modern joint production, but not for an eco-industrial development in an existing industrial park with diverse and independent companies. Fortunately, the industrial symbiosis of Kalundborg demonstrates that such a company internal “verbund” with its long-term systemic history is not necessary to establish recycling oriented connections between industrial plants. It further demonstrates that these processes can be economically viable despite the full impact of strict environmental laws, i.e. without enjoying the benefits of more relaxed and well-adjusted company internal regulatory requirements. This also holds for diverse interconnected production plants, even in the absence of public subsidies. Despite this enormous potential and even with the aid of public money, a second Kalundborg has yet to emerge or to be discovered in modern industrial economies. Is the innovation of the Kalundborg symbiosis thus a one-time occurrence with non-transferable results? Yes and no. In order to make valid comparisons, we must consider some fundamental characteristics and drivers which led to the Kalundborg results (see Table 1).

Factors affecting the development of EIPs have been accumulating for years now and various conclusions have been drawn on the basis of the Kalundborg case. Nevertheless, neither brownfield redevelopments, which have to make the best of a given set of actors, nor greenfield EIPs, in which planners are less restricted, have been able to develop a symbiosis similar to Kalundborg. On the contrary, in examining Kalundborg’s fascinating empirical proof that an eco-industrial symbiosis is able to develop and persist by virtue of its own intrinsic forces (see Table 1), politicians’ and planners’ expectations of EIPs rose sharply, especially when one considers the unique degree of freedom involved in planning the use of virgin areas.

As necessary and important as it is to use present time windows to sow the seeds for eco-industrial development, one should bear the following points in mind:

(1) Recycling companies as drivers?

Recycling companies have sometimes been mistakenly regarded as drivers of EIPs. In reality, however, it is the producers who decide where to establish a new production plant and the recyclers who follow, not vice versa. Furthermore, the procurement of secondary materials plays, at best, a secondary role in the producers’ decision of where to locate. The fact that even low cost waste may be transported thousands of kilometers clearly demonstrates the decreasing relevance of transportation costs.

(2) Colocation or complementary establishment of industrial actors as a pathway for loop-closing?

The colocation of industrial plants that fit together is a relatively rare phenomenon, and the probability that an actor needed to close the material cycle actually settles within that site is rather low. First of all, relocations of companies are singularities, and actors do not like to give up their well-known environment. However, if they do move, the expected loss has to be overcompensated by considerable advantages, which have to outweigh the costs and risks involved in such a move. Due to the minor importance of waste costs and relatively low costs of attaining secondary raw materials, it can hardly be expected that special roundput[9] opportunities are primary localization criteria. Much more important considerations include the desired output, its marketing, public subsidies, and even emotional motives. The chance of success for the planned creation and wide dissemination of zero emissions parks [36], in which any waste equals food is therefore rather slim.

(3) Zero emissions design as a key?

Greenfield development, which has been the basis of several EIP concepts, is similar to a drawing-board development during the initial implementation stage of an industrial site. Although such a “big bang” may occur, it is certainly non-recurring if the site is shared by different enterprises. As a matter of fact, the initial constellation of these enterprises cannot last forever, and even the production technologies within production plants are not very stable over time. Even if we idealistically assume that a zero emissions situation could have been realized at an early stage of the industrial zoning process, it could, ceteris paribus, only persist as long as there are no changes in the production processes that affect the kind and quality of undesired outputs, or as long as any actor leaving the site is replaced by another one who also fits

[9] Here we adopt a term used by Korhonen [35 :p. 254], who introduced the term “roundput” to illustrate cooperative material cycles and energy cascades between the actors in industrial ecosystems.

Table 1
Fundamental facts and lessons of the Kalundborg symbiosis

Historical and systemic considerations	*Facts*: • Kalundborg is a small town of about 20,000 inhabitants living together within well-demarcated boundaries. • A small number of relevant industrial decision makers had already cultivated personal contacts with one another, long before the idea of the first waste-based material transfer was discussed. • The symbiosis existed long before its identification as such (in 1989). • An institutionalized platform (Center for Industrial Symbiosis) was developed later on. • All actors and materials remained unchanged since the start of the relevant interaction. *Lessons*: The industrial symbiosis of Kalundborg signifies: → Face-to-face contacts and a short mental distance between key actors of different systems, providing openness, mutual understanding, and collaboration for a common interest, → Intercompany connections on the basis of mutual trust, which seems to be a vital prerequisite for the exchange of information and materials, especially when details regarding the transferred subject are only partly known, → Long-term oriented output–input relations, → Decision makers, who not only work but also live within and around Kalundborg, → A not-too-fast institutionalization of an accompanying network organization, which can, therefore, be well adapted to fulfill well-known needs.
Economic, technical, and political considerations	*Facts*: • The industrial symbiosis of Kalundborg has never been driven by ecological motives, but rather by the firms' intention "to run the companies economically" ([34: p. 109]) under the circumstances of a changing environment. • Nonetheless, ecological aspects were increasingly regarded as a welcomed side effect, and have consequently been systematically explored and exploited. • Pollution control measures of the Danish government changed the price system and thereby changed the attractiveness of technological solutions. • Since the Kalundborg symbiosis was never financially subsidized, no output–input-combination was implemented that was not economically sound. *Lessons*: The industrial symbiosis of Kalundborg signifies: → Proactive answers, instead of defensive reactions, on the part of industrial decisionmakers in order to diminish or compensate cost effects resulting from new or stricter environmental regulations, → An empirical proof that, within such a framework, economy and ecology need not be contradictory; on the contrary, they may well fit together, even in the absence of ecological motives, → A systematic search for similar potential win–win situations and its success in opening new possibilities for further connections, → Innovative spirit and openness of the key actors as an impetus for intercompany cooperation, → Technical innovations as one of the key pillars for high quality cycles, → Further sustainable combinations, which are stabilized and advanced by intrinsic forces. Consequently, even ecology oriented planners or researchers can base their considerations on economic calculations and priorities, and should do so.
Spatial considerations	*Facts*: • The industrial symbiosis started on the basis of bilateral contracts within the industrial area of Kalundborg. • Meanwhile the "inner symbiosis" of Kalundborg has been supplemented by an outer one which involves waste oriented connections between companies from Kalundborg with others from the surrounding region. The industrial symbiosis of Kalundborg signifies: → A nucleus approach which began with a waste oriented connection between not more than two neighboring production plants, → A gradual intensification of recycling and cascading systems within Kalundborg, → A full degree of transparency of material flows on the level of the industrial site, → A selective expansion of industrial recycling and cascading solutions by incorporating attractive actors from the surrounding region, → A rising degree of regional transparency of undesired outputs and desired secondary materials.

Source: Tibbs [16], Schwarz [17], Ehrenfeld and Gertler [10], Christensen [34], personal notes from a visit (Sterr) of the Kalundborg Symbiosis during the Cleaner Production Conference in 1996.

perfectly into a pre-existing closed-loop situation. Most of these scenarios are far from realistic, given that the integration of industrial processes in a closed-loop economy is not a key factor in a prospective investor's decision on where to locate (see point 2).

(4) Eco-industrial development as a future standard?

If the EIP idea is to spread, it must take a more modest and realistic course. This involves focusing more on exploring and exploiting the already existing potential instead of attempting to realize idealistic and unrealistic visions. Beyond that, brownfield redevelopment can often contribute significantly more to overall sustainability than greenfield development. Energy and resources should therefore concentrate much more on how to combine motley actors than on how to find the ideal partners for the establishment of more sophisticated eco-industrial developments. A systematic search for such output–input combinations can be supported by the use or development of adequate instruments (see Section 6).

(5) Tighter connections for higher system stability?

In Kalundborg, there are various kinds of actors and they complement each other well. They developed tight output–input connections up to the level of intercompany pipes that give each of them a specific role in the system but limit the flexibility of the partners. Almost all input or output functions in the industrial symbiosis of Kalundborg are carried out by only one nearly irreplaceable actor (e.g. the producer of gypsum). This lack of redundancy contrasts sharply with natural ecosystems, in which the number of organisms of each species is plentiful, even in relatively small subsystems [37]. Indeed, such a lack of redundancy is rather common within sophisticated EIP approaches and this makes these industrial systems extremely vulnerable towards internal disruptions and external effects. For this reason, there is a danger that an existing closed-loop system will collapse if only one of these unique participants leaves the system or even if one actor merely changes his process technology. The continuous formation of specific by-products, which was and is of central importance to the industrial symbiosis of Kalundborg, cannot be considered a given elsewhere.

(6) The industrial estate as an industrial ecosystem?

As documented by the empirical results from Heidelberg-Pfaffengrund (Section 2.2), the territorial limits are usually too narrow and the market size of a specific industrial estate is usually too small to economically guarantee a recycling company's continued existence. Therefore, the decisions of those companies on where to locate cannot be made entirely on the basis of the potential within the industrial site, but has to depend to a large extent on the situation that is found in the spatial surroundings of the site. Consequently, great emphasis has to be placed on the situation beyond the borders of the industrial site. EIPs are a promising approach for a sustainability oriented change of our material-based economy, but their translation into practice ought to be rethought and discussed to include considerations regarding their potential embeddedness within a regional context milieu.

2.2. The implementation of an eco-industrial approach in Heidelberg's industrial estate of Pfaffengrund

As previously mentioned, the waste-based inter-company connections of Kalundborg developed step-by-step without being identified as a new kind of system. Kalundborg was identified as an industrial symbiosis in 1989[10], and following the Rio Conference of 1992, researchers began studying the Kalundborg case even more intensively [16,17]. Based on these findings, researchers from IUWA (Institute of Eco-Industrial Analyses) began to explore whether this knowledge could serve as a stimulus for the exploration and exploitation of comparable opportunities elsewhere. Since we wanted to make the results of these studies as applicable to as many sites as possible, we decided to examine an industrial site with the most common, and not the most ideal, characteristics. As a result, we searched for a site which had developed over decades and had a high level of middle-sized companies representing a wide variety of industrial branches. Additionally, since networks among different actors of an industrial estate were and continue to be the exception, we looked for one whose industrial actors did not know their neighbors unless they were members of the same branch or supply chain.

Through discussions with the city of Heidelberg, we discovered that such a "classical" industrial site already existed within the boundaries of the city. As this industrial site of "Heidelberg-Pfaffengrund" had suffered from a series of production plant closures, downsizing, and the resulting substantial loss of jobs in the producing sector [38] throughout the first half of the 1990s, the city was very interested in increasing the attractiveness of this location. Although the research project was not politically driven or influenced, it was a great advantage that the researchers from IUWA were

[10] Schwarz [17: p. 98] referring to a Danish publication of Kragh (1990) on the history of the Kalundborg symbiosis. In this publication, Kragh mentioned that it was identified by a group of high school students during a school's project in 1989.

always able to count on the non-monetary support from the community when needed.

The industrial site of Heidelberg-Pfaffengrund is as a territory of about 93 ha (about 230 acres), housing SMEs representing metal, chemical, electronic as well as paper industries. Only one of the enterprises had slightly more than 1000 employees, while 10 of them employed 100–1000 individuals [21]. All of these industrial producers were examined during the study that began in August of 1996 and officially ended in January of 1998. Together with four smaller ones (out of a total of 30 smaller industrial enterprises), 14 enterprises participated in the project, despite having to pay for it. In determining the degree of personal communication between companies, we discovered only two cases of occasional bilateral communication, and these only existed because in each case the companies shared a common history. Neither had an informal network evolved over the 50 years of Heidelberg-Pfaffengrund's industrial existence, nor had the production processes of these enterprises ever been interlinked [21].

How is one to assess this initial framework? On the one hand, this situation leads to the assumption that mutual trust, a prerequisite for the exchange of information or materials might still be absent, but from a scientific point of view, the "Pfaffengrund" had the added benefit of being much more representative of "ordinary industrial sites" than Kalundborg. Consequently, the Pfaffengrund results may be viewed as a minimum of what can realistically be expected of a typical industrial site in the field of eco-industrial development, especially when one considers that the impulse for change comes from external forces and not from the affected industry itself. As the different and diverse waste data of the 10 largest industrial enterprises (representing a total of about 16,000 tons of waste per year) were available for collection and comparison, the level of transparency of waste within the industrial site was high [19,39]. As a consequence, it is highly probable, that all kinds of opportunities for waste-related intercompany coordination were identified within the project. The analyses and recommendations were presented and discussed with the responsible persons of each company within the informational network, which had been created and moderated by one of the authors.

At the end of the Pfaffengrund project in 1998, four kinds of intercompany relations had been implemented, or at least tested. From the most to the less sophisticated these were [21,22]:

- *Direct output–input relations* in the case of polyethylene waste and untreated wood. The polyethylene derived from film roll cases was regranulated to serve as an input for a producer of plastics.
- *Tender solutions* in the case of paper and fluorescent tubes. This kind of an output–input combination could be implemented due to the fact that a producer of corrugated boards and one of fluorescent tubes were present on the site and were ready to open their special disposal paths for trusted neighbors.
- *Joint transportation* of used pallets. Since nearly every enterprise/production plant has to dispose of used pallets, this is an ideal and widely applicable opportunity to share, and thereby reduce, transportation costs.
- *Informational coordination* and comparison among SMEs for a large variety of wastes. A great percentage of SMEs does not have the personnel to keep track of changing disposal opportunities and fluctuating prices on the waste market. As a result, they are rather eager to reduce their individual informational costs by participating in an exchange platform that collects, systematizes, and analyzes waste disposal information from their own and neighboring companies.

Due to a variety of reasons, not all of these combinations, which were initiated through an external impulse, proved to be stable over time.

- The regranulated polyethylene was an ideal input for the producer of plastic products. Nevertheless, it did not reach the stage of normal production since the DSD (Dual System of Germany) guarantees a free of charge disposal of packaging materials. As a consequence, the film developing company refused to set up and maintain two different dustbins for polyethylene film roll cases and for polystyrene-based packaging. As a result of the price structures caused by the DSD system, the material loop could thus not be closed [11: p. 403].
- Two years ago the tender solution with the fluorescent tubes also had to be stopped, because the tube producer had almost ceased production in Heidelberg-Pfaffengrund.

Other linkages that were implemented within the context of the Pfaffengrund project (1996–1998) are still stable or are even in a state of expansion:

- Six years after its introduction, the tender solution with used paper continues to flourish and has even been extended to other companies. A substantial reason for this is that the producer of corrugated boards is still a prosperous enterprise and has had good experiences with its neighboring suppliers of used paper.
- Untreated wood, whose quantities were presented in a local conference at the end of the Pfaffengrund project, proved to be attractive for an industrial

company located in a neighboring town, only 2 km away from the Pfaffengrund site. This was the first time that the new purchaser accepted untreated wood from other personally known industrial companies, who had to pay for transportation costs themselves. The wood is shredded, stored in a silo, and then gradually fed into a combustor that heats the shop floor. This disposal pathway is less expensive for the company supplying the wood, and the purchaser reduces not only the amount of required natural gas, but also substitutes the use of fossil energy for regenerative resources. The linkages have remained stable and meanwhile include additional partners from the surrounding Rhine–Neckar region (see Section 3).

Although it is true that these examples are not more than ex post observations of industrial roundput systems 5 years after their implementation during a 19 month project, they nevertheless provide interesting information on what might influence the stability of material cycles. In the first example, neither the new face-to-face contact nor the close proximity of the two companies could convince the waste producer to accept minimal additional costs in order to realize an ecologically advantageous material cycle. The second case demonstrates that the lack of redundancy on the demand side can lead to the collapse of the recycling path. In the third and fourth examples, the stability on the demand side (actors and technological processes) combined with mutual trust among neighbors, proved to be a guarantor for a continuing output–input combination.

In contrast to the admittedly limited and extremely coincidental possibilities of output–input combinations in the industrial site of Heidelberg-Pfaffengrund, informational coordination proved to be attractive and promising. This proved to be true of almost every actor, independent of individual prospects and opportunities for closing material cycles. Indeed, the informational exchange within the Pfaffengrund network, which was established through the project, was able to improve the economic situation of each of the participants significantly. For about 70% of the project members, who had to pay 10,000 DM (i.e. about € 5000) for their project participation, the ROI was less than 1 year [40: p. 55]. This success led to increased interest in further intercompany communication and a greater willingness to participate in mutual endeavors. Consequently, a central goal of a follow-up project was the development of informational structures that would promote an intercompany exchange of waste information.

3. From a local to a regional eco-industrial approach

The size of the industrial site of Pfaffengrund proved to be much too small for almost every kind of material cycle, and due to a lack of redundancy, the stability of output–input connections was potentially endangered by even the smallest fluctuations. Fortunately, the Pfaffengrund site is deeply embedded in an industrial region with a much larger quantity and variety of actors. This leads to a relatively high probability of finding fitting partners for output–input relations, not only between producers and waste disposers, but even among the industrial producers. The industrial region of Rhine–Neckar, in which the industrial site of Heidelberg-Pfaffengrund is located, had about 2.3 million inhabitants in 2001 and a gross product of € 51.5 billion, of which 40% was earned in the secondary sector [41]. The territorial and systemic dimensions of this region are shown in Fig. 1.

The Rhine–Neckar region is home to several multinational enterprises, such as BASF (in Ludwigshafen), DaimlerChrysler, Roche, and John Deere (in Mannheim), and is highly integrated in the world market. The industrial region of Rhine–Neckar is a very open system that acts as a "node in a global network" [44], which is not only true of the "big players", but also of many of the medium-sized enterprises. As is shown in Fig. 1, the Rhine–Neckar region is a polycentric cluster that is held together by a relatively high intensity of ties. Due to the fact that the Rhine–Neckar region is located on the border of three different federal states of Germany, it is also called the "Rhine–Neckar Triangle".

Focusing on our special subject of interest, i.e. material flows, we regard the Rhine–Neckar region as a set of nodes and interrelations. We thus view it less as an administrative unit but more as a systemic context milieu that is characterized by an agglomeration of industrial actors (nodes) and their mutual linkages (interrelations). Although the possibilities for intercompany relations are abundant within such a regional framework, only a small percentage of them are actually established or even realized. This is at least true of waste-related connections, as industrial waste is usually regarded as an undesired output of which the producers simply want to rid themselves. The regional potential to close material cycles is rather high (Fig. 2) and could provide many more waste disposal alternatives as well as greater stability for industrial ecosystems or "roundput systems". "roundput system" is to be understood in Korhonen's [35] sense, in that cooperative material cycles and energy cascades between the actors are involved. When roundput in the definition of Korhonen [35] means cooperative material cycles and energy cascades between the actors involved. But we also learned that intercompany communication and waste transparency was rather low on the regional level.

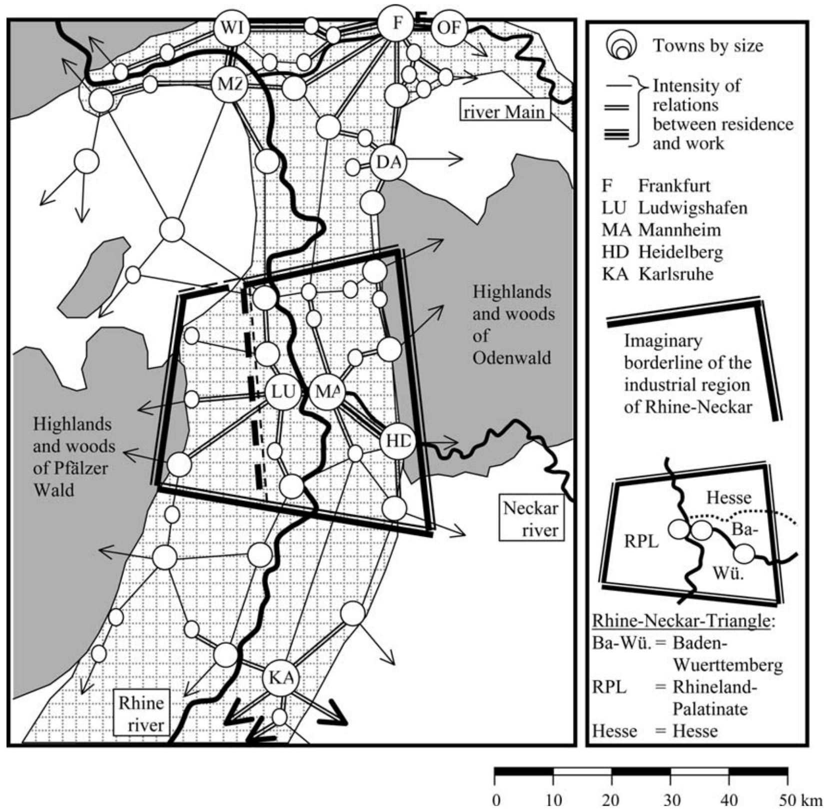

Fig. 1. Rhine–Neckar region. *Source*: Sterr [42: p. 22], based on a study of Fischer [43].

4. Some reflections regarding the "right size"

As mentioned in Table 2, the industrial region is characterized by a much greater number and variety of actors than the industrial estate. This increases the probability of finding an appropriate partner and may consequently lead to a decrease in the production of materials entropy [45]. The rise in the number of

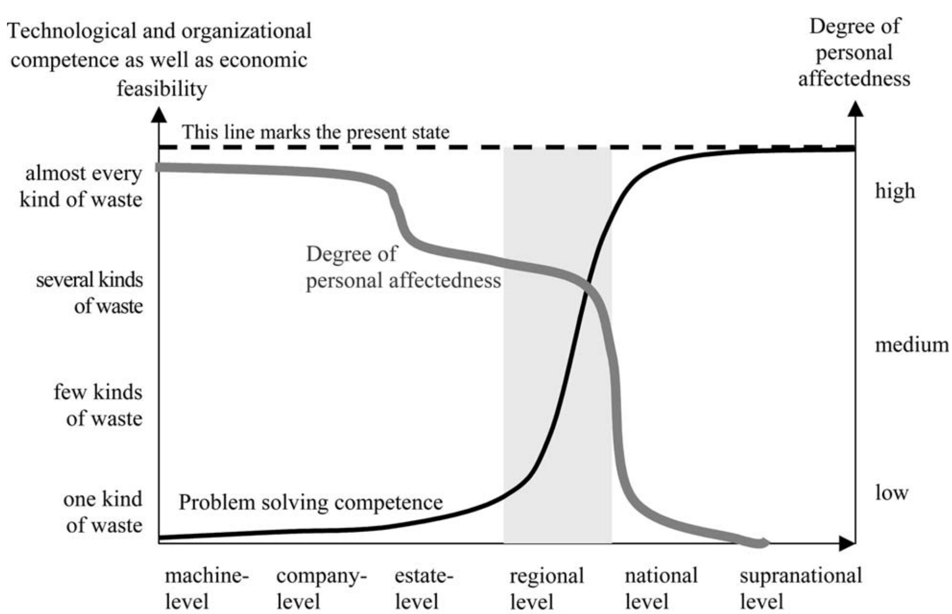

Fig. 2. The particular applicability of the regional dimension for sustainable development. *Source*: Sterr [50, 11: p. 356].

Table 2
From the industrial estate of Pfaffengrund to the industrial agglomeration of the Rhine–Neckar region—towards regional transparency of waste related opportunities

Industrial estate of Heidelberg-Pfaffengrund	Industrial region of Rhine–Neckar	
	Additional advantages of the regional scale	Disadvantages of the regional scale
• Ease of face-to-face contacts • Common territorial unit • Small spatial distances between potential partners • Small to medium-sized enterprises • Full transparency of all kinds of wastes	• Greater number and variety of actors → Increase in supply and demand → Increase in potential partners for direct output–input relations between producers → Increase in redundancy	• Greater distance between actors → Rise in the costs of overcoming spatial and mental distances → Rise in the variety of interests → Increase in the complexity of logistic questions and concepts
	• Greater economies of scale → Greater price effects → Rise in economic viability of recycling processes → Creation of new recycling pathways	• Greater significance of indirect communication → Rise in the complexity of communication → Rise in the costs of communication → Necessity of a central and institutionalized structure for the coordination of information
	• Comprehensive transparency of material flows → Greater utilization of existing recycling capacities → Increase in knowledge concerning a possible creation or extension of recycling capacities → Easier and greater supply of secondary raw materials → Rise in disposal security → Visualization and calculation of niches for new recycling specialists → Establishment of additional possibilities which can contribute to a rise in regional sustainability	• Greater demand for sophisticated electronic database instruments → Rise in the costs of system maintenance → Rise in the required know-how

Source: Sterr [21: p. 77, 22: p. 290].

actors is accompanied by a rise in the redundancy of companies carrying out a specific roundput function, which can contribute considerably to system stabilization (see Section 2.1). The much larger quantities of any kind of waste that can be collected in such a regional frame increase the attractiveness of the cluster for both recyclers and producers that demand for secondary materials[11]. Therefore, it is quite likely that there is already a high probability that the size of the market is already sufficiently large to sustain those specialized industries.

Nonetheless, such favorable correlations raise a couple of new questions: why should these considerations converge on this medium-sized territorial dimension? Why not proceed to include the national, or even the global, dimension? Is the regional size the right size?

[11] As Desrochers [29: p. 57] mentions, when he quotes several publications from the end of the 19th and the beginning of the 20th century (Simmonds 1876, Ross 1896, Devas 1901 Talbot 1920,...), such advantages of industrial clusters had already been realized during the first decades of industrial development.

Eco-industrial development is a management approach with the goal of minimizing the ecological impact of human action. When the input of materials cannot be avoided, the resources should be re-used, remanufactured and recycled in a way that minimizes the distances between the inputs and the outputs of reduction[12] processes. This implies [49]:

- minimal distance on the material level
  → minimal down-cycling
- minimal distance on the territorial level
  → minimal kilometers per ton

[12] We use the term "reduction" in order to describe a process that is mirror-inverted to the term of production. Production binds resources while reduction sets them free. Reduction is not equal to recycling as recycling ends with a resource binding phase (→product), whereas reduction ends with the module or the secondary raw material that can be transderred to a next production process. The term was first introduced in the German scientific literature on production theory by Liesegang in 1992 [12] as well as Dyckhoff [46]. Scholars such as Sterr [11,48] and Souren [47] and others have further elaborated on the idea of production–reduction systems.

Table 3
Spatial-systemic dimensions of connections between industrial production and reduction processes from selected SMEs in the industrial region of Rhine–Neckar

Closed-loop oriented process	Spatial dimension of recycling processes					
	Within company	Within the industrial estate	Within the municipal area	Within the industrial region	Between adjacent regions	Between more distant regions
Composting		Random	Typical	In quite a few cases		
Recycling of building waste		Random	Typical	In quite a few cases		
Repairing of used pallets		Random	Typical	Typical		
Regranulation/ remelting of plastics	Among plastic processors occasionally within plants or companies	Random	Frequent	Typical (especially poly-ethylene)	In quite a few cases (e.g. poly-propylene)	
Oil recycling	In quite a few large companies (emulsion-splitting plants)	Random	In quite a few cases	Typical	In quite a few cases	
Electronic waste recycling		Random	In quite a few cases	Typical	In quite a few cases	
Paper recycling			Random	Typical	Typical	In quite a few cases
Metal slurry processing				Depends on sector	Depends on sector	In quite a few cases
Metal recycling			Typical (shredding)	Frequent (shredding)		Typical (blast furnaces of Rhine–Ruhr)

Source: Sterr [50: p. 9, 51: p. 60].

- minimal distance on the systemic level
  → minimal transaction costs
- minimal distance on the temporal level
  → minimal time for the development of waste-related secondary effects and uncertainties

and leads to a minimization of entropy production as a whole. This multifaceted minimization principle yields the following answer to the above questions: the "right size" is the minimal size in which outputs can be retransformed into desired inputs, thereby adequately closing material loops. Does an industrial region like the Rhine–Neckar area already incorporate this "right size", and if yes, to what extent? The waste data that was collected in 14 enterprises of Heidelberg-Pfaffengrund and in six additional enterprises of the Rhine–Neckar region should give a first insight into answering this central question. Although these indications may not be representative, they are an empirical document of what size may be required for specific "roundput" industrial ecosystems.

Table 3 sketches the frequency of various recycling patterns resulting from the empirical data of those companies investigated within the framework of two research projects in the Rhine–Neckar region. It clearly shows that the level of an industrial region already has an enormous potential to recycle materials internally. The special case of the Rhine–Neckar region reveals only one process (metal recycling) for which intra-regional roundput systems do not currently exist, and most likely will not be possible in the future either[13]. Apart from metal recycling, any kind of material that can be recycled in Germany can also be recycled within the regional boundaries. This means that at least this region possesses the critical mass and the necessary infrastructure, in terms of technical installations, to provide corresponding recycling solutions in an economically viable manner. Despite the fact that there is obviously no need for long-distance loops, only some of the producers realize and take advantage of local recycling solutions. In bilateral discussions with our industrial partners aimed at discovering the individual reasons for this gap, two of them mentioned that the corresponding decisions are made within the corporation, while the small to medium scale manufacturers generally answered that a lack of clarity and knowledge, especially of high quality local recycling options, was the cause. In fact, actors that provide quality recycling options are often small entrepreneurs. In other cases, industrial producers run a special recycling process for their own waste, but these "roundput" or

[13] Since Baden-Wuerttemberg and its surrounding areas possess almost no metal-producing industry, the metal cycle is generally completed using smelting plants in North Rhine–Westphalia (especially for iron and steel); however, in the case of non-ferrous metals, such as copper or aluminum, the cycle is also completed via Hamburg or other federal states.

recycling and cascading options are practically unknown, especially across different business sectors. However, one should not overlook that there is also a lack of inter-company trust, particularly when dealing with waste.

5. The regional dimension and its unique potential

The empirical results in Table 3 clearly show that a regional framework already has the potential to solve a large variety of recycling problems. This is not only true for the technical side, but also for the economic side. Since the recycling channels in Germany are privatized to a rather large extent, the results of Table 3 are a reflection of market forces and not of governmental restrictions or guidance. As a result, it is evident that the market size of an industrial region is sufficiently large for the economically viable establishment and continued existence of roundput systems for a large variety of industrial waste materials. Although it is generally the case that suppliers prefer short-distance solutions to long-distance ones, this is especially true for the disposal of waste. In fact, this sensitive sector has been plagued with scandals throughout the recent past, in which some of the producers saw on the television, that their waste was illegally stored, dumped or even appeared in Indonesia instead of being disposed of as agreed upon in contracts. Industrial producers thus prefer recycling partners in their neighborhood, since they feel that they can verify the recycling company's reliability through spontaneous site visits, since scandals and other problems involving these disposal or recycling companies may be documented in local newspapers, and since the behavior and reputation of nearby recyclers may also be known on a social level. Given the ensuing sense of security and transparency within a regional context, even those decision makers who deny any ecological orientation, prefer to engage in short-distance trade in the case of waste disposal.

In addition, the spatial dimension of a regional context does not only host a dense aggregation of industrial enterprises, but also represents the personal living space of most of the corresponding industrial decision makers. These individuals may personally identify with this area, may place great value on their living environment and that of their family, and may also feel that they have the capability and power to substantially contribute to the protection, or even improvement, of the ecological situation in their vicinity. These all are helpful factors that can contribute to an environmentally sound and socio-culturally balanced "regional milieu"[14] and that make the region a favorable site for sustainable development.

[14] For regional, innovative or creative milieus and identification see, for example [52].

Table 3 already gave an insight into applicability of the industrial region as a spatial dimension with a large problem-solving competence in regards to the establishment of a closed-loop oriented economy. If we try to express these findings with a diagram, in which the x-axis represents incrementally increasing size in a territorial-systemic sense and the y-axis shows increasing number of types of waste, we can draw a line (black line of Fig. 2) with a positive slope that will probably be s-shaped. Furthermore, and contrary to the national and supranational level, the regional scale allows for a high degree of societal control over as well as personal affectedness of ecologically unfavorable behavior. A line that stretches the degree of personal affectedness in such a spatial-systemic context might have the form and negative slope of the thick grey line. It is quite likely that the intersection of these two lines will be within the regional level and will allow for the closing of material loops for many kinds of waste. Admittedly, the lines drawn in Fig. 2 are not yet more than a sketch of plausibilities and are not the result of sophisticated statistical analyses. Nevertheless, the basic form of these curves has been explained in depth in the above argumentation. In plotting the above mentioned curves in a single diagram, as has been done in Fig. 3, it is evident that this combination of structural and emotional considerations in an industrial region makes this medium scale unit a promising host for eco-industrial developments.

Despite this potential, suitable instruments enabling the continuous discussion and exchange of data related to waste and secondary materials have not yet significantly developed. This is partly due to the traditional low-level of organization and diverse interests on the regional scale, but also to the fact that the number, the complexity, and the variety of actors rise sharply from the industrial site to the regional milieu. In addition, face-to-face contacts—which are unproblematic within a small industrial space—have to be (partially) replaced by indirect communication (see Table 2), which reduces the quality of information while at the same time increases the costs of coordination.

In order to minimize the losses ensuing from increasing coordination costs, overcome the obstacles created by indirect communication, and raise the probability of finding and implementing new roundput systems for industrial wastes, it was discovered that at least two kinds of instruments are necessary:

- A platform for intercompany communication for the experts and decision-makers.
- A regular provision of high quality data for the enterprises at a low cost, in order to enable and promote coordinated action.

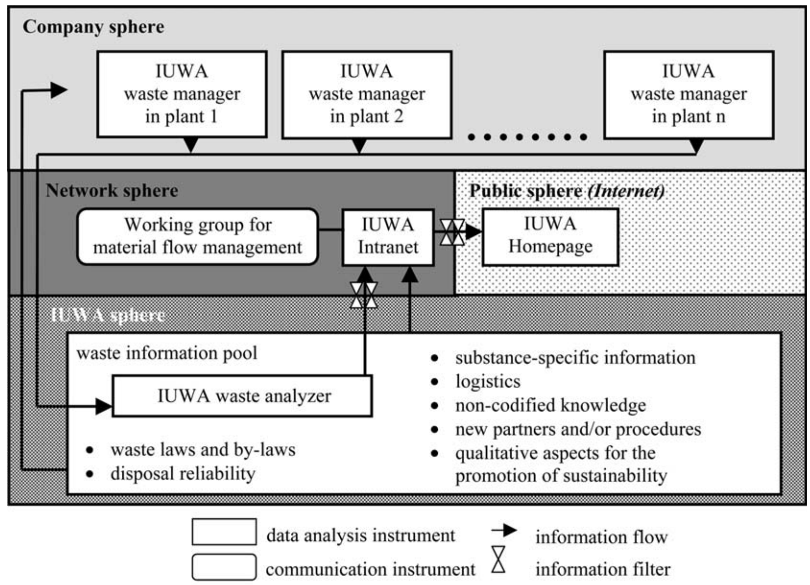

Fig. 3. Instruments for communication and data transfer in a regional environment—the case of the Rhine–Neckar region. *Source*: Sterr [11: p. 442].

6. Innovation processes for the promotion of intra-regional roundput systems

In the Rhine–Neckar industrial region neither of these two kinds of instruments existed prior to the start of the model project. However, it soon became obvious to the project managers that without these instruments, it would be rather difficult to systematically identify the potential of waste-based intercompany coordination, while at the same time keeping the information up to date at a reasonable cost. Therefore, the research team from the IUWA and from the Department of Geography of the University of Mannheim decided to develop the following instruments in a step-by-step process [40]:

- An adequate network structure for the creation and promotion of mutual trust between relevant actors and for the discussion and preparation of coordinated action.
- A waste management software for the standardization, automation, and facilitation of data exchange within and between firms.

Taken together, these two instruments currently form a system of connected tools for information and communication which can be visualized in Fig. 3.

6.1. Adequate network development—a systems approach

Within the boundaries of a company, information systems are well developed and opportunities for the establishment of personal trust are abundant. Formal platforms for discussions among experts are institutionalized and even informal networks between actors of different parts of the enterprise may exist, often without being explicitly regarded or identified as such. Within this spatial unit, the chances of discovering and exploiting new opportunities, including the intended or unintended closing of material loops, remain quite high.

Unfortunately, once the outer boundary of the enterprise is crossed, there is a sharp decrease in the number and intensity of contacts, as well as in the quality of information transferred. Even within the same industrial site the intensity of contacts between neighboring enterprises is rather low, unless they share the same history[15], or belong to the same input–output system (vertical connection along the production chain), both of which remain the exception. The most typical composition of an industrial site is a patchwork of barely interlinked enterprises which do not have much more in common than the same location. As industrial producers tend to fully concentrate on their desired outcome, which is generally different from that of their neighbors, they often do not recognize that their wastes may be rather similar and that they share nearly identical waste management problems and responsibilities. This was true for Heidelberg-Pfaffengrund and therefore, this discovery was one of the first pleasant

[15] In Heidelberg-Pfaffengrund new investors only bought specific subunits of existing enterprises, with the consequence, that former colleagues became members of different companies without having experienced any change in their work.

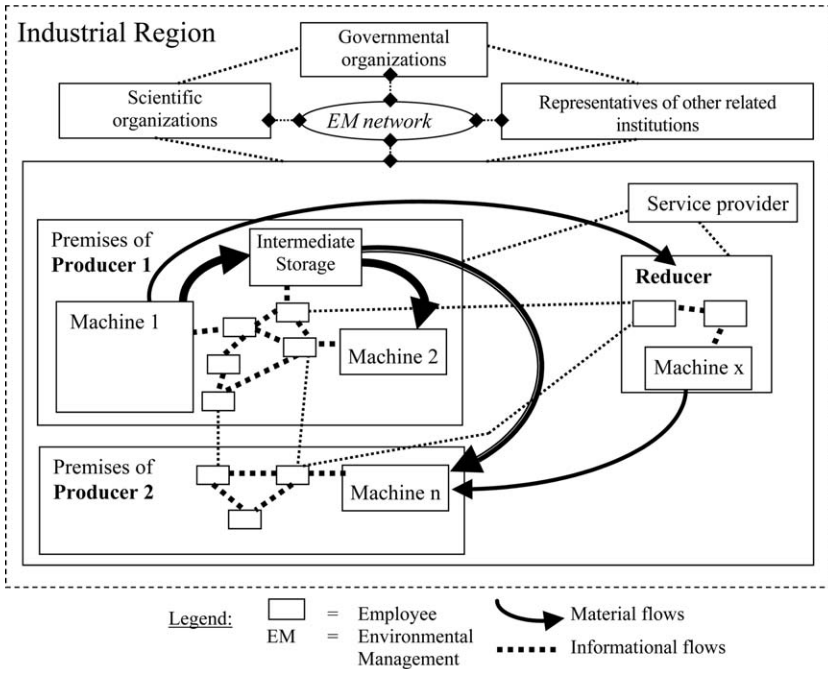

Fig. 4. Potential network partners for the development of "roundput" industrial ecosystems that are likely to be found on the scale of an industrial region. *Source*: Sterr [11: p. 372].

surprises that the different waste managers had when they began meeting each other within the framework of the project [21]. As the moderated exchange of information soon led to substantial economic advantages, the project-based informal waste management network of Pfaffengrund (1996–1998) was not only sustained and expanded, but was transformed in 1999 into an institutionalized roundtable, called Arbeitsgemeinschaft Umweltmanagement e.V. (AGUM)[16]. AGUM adopted the subject of material flow management from the Pfaffengrund network and integrated it within a wider range of tasks in the field of environmental management. Within the 3 years of public funding of AGUM, the network expanded not only beyond the level of the industrial site, but also in its member composition, so that in addition to industrial producers, service providers and a highly specialized recycler were also represented [11].

The informal producers' network of Pfaffengrund, called the "Pfaffengrund-Arbeitskreis", had thus changed into a formal and interorganizational one (AGUM e.V.) [11,53]. To ensure that the industrial actors remained the key actors of the new network as well, the two presidents of AGUM were required to come from industry [53]. Additionally, a four person advisory council was implemented, consisting of a political representative (Beate Weber, the mayor of Heidelberg), a professor from the University of Heidelberg (Prof. Dr. Dietfried G. Liesegang, the chair of the Department of Business Administration), a retired industrial leader, and a legal representative from the Rhine–Neckar Chamber of Commerce. The manager of AGUM was one of the two heads of IUWA [11,54,55].

Fig. 4 shows a functional sketch of such an interorganizational environmental management (EM) network as a tool for promoting the implementation of roundput systems.

Within the systemic borders of an industrial company, there is a rather dense flow of materials (thick solid line connecting physical infrastructure) and information (dotted line connecting employees). Nevertheless, most of the undesired outputs have to leave that system in order to serve as a desired input for another producer or reducer. A service provider may add additional information that is relevant for the material flow, but he himself does not change the physical material flow. Further actors from politics, science, and other groups that are present in the regional context, can also contribute much to the development of environmentally friendly roundput systems, but only by providing information on material flows. On the one hand, the problem-solving competence of such a regional system rises significantly, as does the probability of finding more sustainable solutions, but on the other hand, each new and new kind of actor raises the

[16] AGUM's name translates as "working group for environmentally oriented management". Its legal status is that of a registered non-profit organization.

Table 4
Summary of eco-industrial networks in the Rhine–Neckar region

Recent past		Present	
Industrial site of Pfaffengrund		*Subregional scale of the "IHK region"[a] Rhine–Neckar*	
Network	Producers' network of Pfaffengrund	Network	Environmental working group of the Chamber of Commerce of Rhine–Neckar
Character	Informal	Character	Informal
Subject	Environmentally oriented waste management	Subject	Current tasks in the field of environmental management
Existence	1996–1998	Existence	1995–
Industrial region of Rhine–Neckar		*Regional scale of the Rhine–Neckar Triangle*	
Network	AGUM—working group for environmentally oriented management	Network	UKOM—center for environmental competence in the Rhine–Neckar region
Character	Formal	Character	Formal
Subject	Environmentally oriented management	Subject	Environmentally oriented engineering, management, research and innovation
Existence	1999–2004	Existence	2003–
		Interregional setting (Rhine–Neckar/Ulm)[b]	
		Network	IUWA workgroup on material flow management
		Character	Internal network of IUWA e.V. and its industrial members
		Subject	Environmentally oriented materials flow management and the promotion of industrial roundput systems
		Existence	2002–

[a] The Chamber of Commerce (IHK) Rhine–Neckar is only responsible for that part of the Rhine–Neckar region that lies within Baden-Wuerttemberg.
[b] See Section 8.

complexity of the system enormously (see Section 3). As a consequence, the need for an interorganizational EM network able to coordinate all these forces and interests rises as well. This coordination function was carried out by AGUM.

After some restructuring processes, AGUM is presently being incorporated in an even more ambitious network, called UKOM, which translates as the "Center for Environmental Competence in the Rhine–Neckar region". The legal status of UKOM is also that of a registered non-profit organization, but in contrast to AGUM, it is located in the municipality of Heidelberg. The network was officially founded in April of 2003 and will not only focus on the means and methods of closing material loops, but also intends to promote the development and implementation of environment-friendly solutions as a whole by providing a fertile ground for the creation of environmentally superior technical and organizational innovations [56]. It will reflect the Rhine–Neckar industrial region's status as a "node in the global network" in accordance with Amin/Thrift [44] and it aims to promote and advance the region's position as a highly competitive player in this promising economic field.

The history of network development in the Rhine–Neckar region that fulfilled or continues to fulfill specific tasks in the field of sustainability oriented material flow management is summarized below.

The interregional network in the lower right corner of Table 4 has been implemented within an interregional project that is headed by the authors of this article[17].

6.2. Adequate software development—mastering increasing data and data exchange

With increasing size, an informational network must face the challenges involved with increasing indirect communication. In response to these changing needs, the project partners of IUWA and the University of Mannheim decided to develop a waste management software ("IUWA waste manager") that was able to meet both the individual company's internal needs regarding waste related information and analysis as well as the requirements for intercompany exchange and coordination [40,57]. In accordance with the design of Fig. 3, the data of the company based waste managers are collected into the waste analyzer. The data from the analyzer can be fed into a materials (and energy) flow management software, called Umberto [58], which shall be combined with a geographic

[17] The English title of that project would be: "Systems for the sustainability oriented management of material flows: approaches for the design of cyclic flows from the intracompany to the supraregional level."

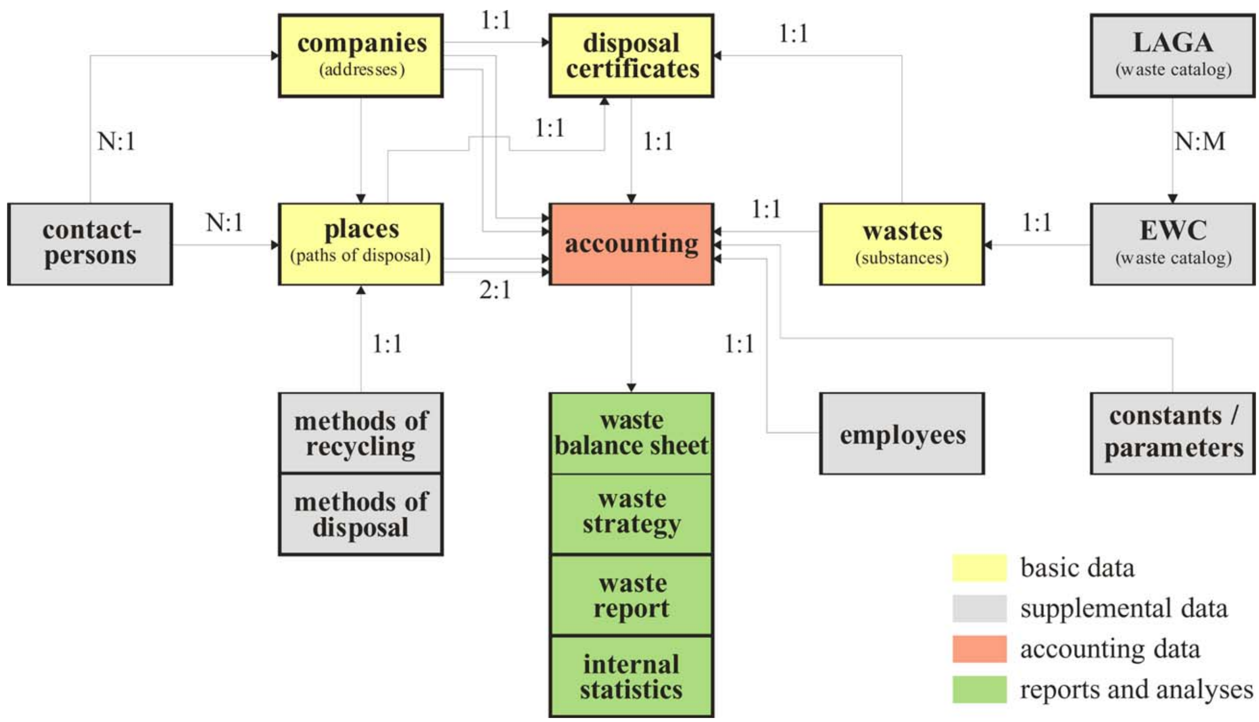

Fig. 5. Entity relationship model of the IUWA waste manager. *Source*: Ott and Sterr [60], Sterr and Ott [58].

information system (GIS). Both instruments provide sophisticated tools that can optimize material flows in terms of costs, quantities, and transport distances.

In technical terms, the IUWA waste manager is a database application based on Microsoft Access, a major component of the widespread Microsoft Office Package. It is thus very easily integrated into the existing IT-environment of the participating companies. As is shown in the entity relationship model (see Fig. 5), the software is composed of a set of connected tables, which in turn are comprised of basic data entries (e.g. information on substances/wastes, companies and places involved in the disposal process as well as accounting data). Based on this data, the waste manager offers a wide variety of reports and data analysis functions [59,60]. In order to increase its applicability as an instrument for the support of the sustainability oriented management of wastes, we equipped the software with a detailed table of indicators, which are calculated automatically [11: p. 440]. Several other features also provide important information regarding differences in current figures (e.g. changing waste amounts or the market price for a ton of waste *x*), and they can be used as control instruments for evaluating recyclers, renegotiating existing contracts, and identifying trends over time.

The software is based on a client–server structure, in which the data is stored on a central server and client access and the range of applications can be installed on any PC within the company. A convenient user and access rights management system provides tools to ensure data integrity and reliability as well as a maximum of informational transparency throughout the company. As some project partners rely on the software in all their branches and sites around the globe, the user interface is multilingual. German, English, Spanish, and French versions already exist, and versions in other European languages are in the development process.

In order to maximize the probability and practicability of implementation of this new instrument for each of the industrial project participants, the waste management software was designed to meet the following requirements [59]:

- Fulfill all the desires that the company could previously fulfill with their formerly used software tool;
- Provide waste disposal security by meeting legal requirements and providing internal documentation;
- Offer insight into internal weaknesses and potential for improvement in regards to economic and ecological efficiency;
- Minimize the time required for becoming familiar with this new software;
- Stick to essential functions without unnecessary paraphernalia;
- Provide a simple, user-friendly, and flexible user interface;
- Minimize the time and complexity for ordinary data entry by concentrating all information from waste invoices on a single data entry form;

- Provide easily accessible data reports with variable structures by selecting from sophisticated data analysis functions;
- Display and summarize relevant waste data and waste indicators for ISO 14001 or EMAS certifications as well as for environmental reports;
- Create an additional benefit for the company as a whole in terms of transparency, organization, and synergy effects.

The first version of the waste manager was implemented in a company for the first time in the spring of 2000. At present, the third major version of the IUWA waste manager is the standard waste software for 10 different industrial project members, representing 18 different locations. Since the completion of a website and the new manual [60], the software package has also been sold to external companies.

7. Current and future developments

As previously mentioned, the development of further software tools continues and will soon be enriched by a IUWA waste analyzer. While the waste manager is company based, the waste analyzer is designed as an intercompany tool operated at the project management level (Fig. 3). Its structural design is fully compatible with the architecture of the waste manager software. It will offer the participating companies comprehensive analyses and benchmarking, both of which will be communicated regularly through a IUWA Intranet surface. The benchmarking and indices calculated from the data pool may either be used for improvement projects within a company by virtue of providing best-practice information and price comparisons, or they can serve as a basis for revealing potential fields of cooperation and collaboration among different project members.

The quantity and quality of data generated by the IUWA waste analyzer greatly depends on the willingness of the companies to share their waste data. This is essentially a question of mutual trust based on the established network structures that have been developed since 1996 (see Section 6.1 and Fig. 3, respectively)[18].

The results calculated by the waste analyzer software will be gradually enhanced by additional information on substances (e.g. hazards, transport requirements, etc.), legal documents and procedures, as well as a detailed list of disposal companies within the region. The final outcome will be a comprehensive waste information database (see Fig. 3), accessible through the already existing IUWA intranet. This database will combine basic information regarding material flows in the new IUWA network with current prices and qualitative information.

8. Conclusion: regional development in an open system

As elaborated upon in the previous sections, the industrial region of the Rhine–Neckar has a substantial problem-solving capacity. Such industrial agglomerations are large enough to provide loop-closing processes for many of the industrial wastes and substances that are currently recyclable in Germany under the present economic and legal conditions. In contrast to closed-loop EIP concepts that tend to be limited to the visualization and elaboration of local potentials, the industrial region seems to be a much more promising frame for the creation and maintenance of a sustainability oriented industrial closed-loop economy.

However, the development of suitable instruments for the optimal exploitation of the already existing potential has only just begun. There are a multitude of reasons for this shortcoming. One main factor is the absence of suitable regional bodies and fora (either on an administrative or intercompany level). Another reason is that, unlike in the local community, finding suitable partners among industrial producers or disposal companies in a regional context involves much higher transaction costs. On the one hand, privately organized waste disposal companies in the industrial region are well acquainted with the regional waste market, but on the other hand, we must note that most of them are subsidiaries of nationwide actors or even multinationals. As such, they want to incorporate the waste into their company network in order to treat it anywhere. Sometimes, they only act as intermediates but do not recycle themselves. They just put the waste into an intermediate store or even transfer it directly to an interested producer.

In general, the knowledge of both the supply and the demand side of the regional and supraregional waste market is a key factor for the economic success of disposal companies and especially for those who only act as middlemen and consequently depend on this informational gap to a considerable extent. These middlemen risk elimination if the producer of waste already knows of the prospective buyer, i.e. a producer who is interested in secondary materials and marks the beginning of a second material cycle. Thus, waste disposal companies are rarely interested in contributing to any kind of transparency that may create more favorable alternatives for the producers of waste or the waste accepting producer. As a consequence, vast quantities of industrial wastes move in unnecessarily wide circles

[18] Producer's network ofHeidelberg-Pfaffengrund on ecology oriented waste management (1996–1998)→AGUM (workgroup for environmentally oriented management) (1999–2004)→IUWA workgroup on material flow management (2002–)

and it is difficult to direct these to the input locations that would be the most favorable in ecological terms.

With the establishment and further development of this network approach, we aim to identify economically and ecologically superior pathways and solutions. However, in order to fully exploit the benefits available in the industrial region, well-adapted software tools are needed. One such instrument is a waste management software that permits the homogenization, pooling, and combined analysis of each individual company's data, thereby enabling intercompany comparisons. This transparency of quantitative data must be accompanied by both an intranet platform with qualitative information on individual waste and substances, as well as a forum for the discussion and exchange of practical experience, legal advice, and business guidance.

As the waste manager software follows a client–server architecture with full network support, the users are not necessarily dependent upon a regional pooling agency (presently operated by IUWA). Due to the network capabilities and the multilingual user interface, they will be able to use it worldwide. Additionally, they will be able to benchmark their waste data by using the above-mentioned waste analyzer, which will also be applicable as a company-internal data pooling instrument. The combined use of these two instruments is likely to have a positive influence on material flows, both in terms of expenditures and environmental compatibility.

With the ongoing support of the companies in our project, we will continue developing further innovative instruments in order to maximize informational transparency within the industrial region of Rhine–Neckar and to stimulate further developments towards ecologically advantageous management of material flows. As representatives from private industry are the key actors, they must be treated as such. Together with our research partners in the industrial region of Ulm/Neu-Ulm[19], with whom we share and transfer knowledge and experience, we hope to be able to demonstrate that the applicability of the instruments mentioned in this paper is not restricted to specific conditions found in the Rhine–Neckar region, but may fit into the context milieu of other industrial regions as well. Combining various findings from scientific literature with our 5 years of practical experience on the regional scale, we believe that stable eco-industrial regions rarely emerge as the result of ambitious planning efforts by regional authorities, but rather develop through a solid foundation of comprehensive information transparency. In order to realize suitable output–input connections, mutual trust among the industrial actors and the willingness to cooperate are essential. Nonetheless, political interests, the legal framework, and planning efforts can help to set the things in motion. In addition, academic research, consultants, or reputable intermediates can contribute substantially to discovering and exploiting new possibilities and in connecting fitting partners. With this in mind, eco-industrial regions may be understood as environmentally sensitive open systems that accumulate enough materials and intrinsic problem-solving competence to host a large variety of roundput systems. Evolutionary processes towards such an industrial ecosystem are more likely to happen if adequate instruments for the exchange of data and experiences among industrial actors are provided in combination with interorganizational communication on the regional scale. Due to a variety of factors addressed in this article, success stories, practical examples, and solutions are still scarce or difficult to find and extensive research is still missing.

[19] Ulm/Neu-Ulm is located about 200 km SE on the border between the federal states of Baden-Wuerttemberg and Bavaria.

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