URBAN SYMBIOSIS – A CONCEPT TO SUPPORT RESOURCE-EFFICIENT SETTLEMENT DEVELOPMENT?

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Abstract

Provision and use of the built environment result in the consumption of huge amounts of natural resources. Due to this, there are many projects and initiatives to improve resource efficiency in the built environment; a task which can definitely be called ambitious. The built environment is made up of very different components, such as buildings, transport systems and infrastructures. In practice, the planning authorities have been organizing these tasks sectorally and scarcely interconnected with each other. Nevertheless, there are numerous potential (physical) interactions between these components. For example, organic waste can be used for energy production as well as sewage sludge or heat from waste water. Moreover, wastewater systems can be designed to combine wastewater treatment with the irrigation of energy crops, etc. The concept of "Industrial Symbiosis" delivers a possible methodological approach to link these different areas of the built environment. Industrial symbiosis, as a concept predominantly discussed in industrial ecology, addresses similar phenomena among industries. Through a collective approach combining input and output flows in industrial (eco) parks, the industrial system as a whole as well as the individual companies gain a competitive advantage. The application of this approach to urban development is not trivial. The settlement system is complex, the range of tasks is broad, and buildings and infrastructures are characterized by long lifespans and huge investment costs. As a result, they are subject to strong path dependencies while the number of actors involved in decision-making processes is large.
The project EUDYSÉ funded by the German Ministry of Education and Research tries to address the challenges arising from these characteristics by looking for adaptation paths in different thematic areas of settlement and land use development (energy supply, agriculture of energy crops, water, wastewater, waste management, traffic, urban development) towards an overall normative goal of resource efficiency. Starting points are current challenges and constraints within the mentioned thematic areas in two case study areas: two regions in Germany which have been affected by demographic change and will undergo a dramatic process of restructuring in the coming decades.

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Within a scenario process, adaptation strategies that consider inter-sectoral cross-references, are being developed for the thematic areas. This paper presents the methodology used and tries to elaborate possible contributions, opportunities and difficulties of the concept of industrial symbiosis (or rather urban symbiosis) to support the process of resource-efficient urban and land use development.

1. Introduction

Industrial symbiosis was introduced to the scientific debate end of the 1980ies, as a concept to combine input and output streams of at least two different companies or industries. The industrial park of Kalundborg in Denmark served as the first case study where "high level of resource cycling among separate firms" (Ashton, 2008, p. 35) was discovered. The term industrial symbiosis is defined by Chertow as "engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products" (Chertow, 2007, p. 12).
Research in this field can be divided into case studies, literature review, identification of the ecosystems analogy, methodological work as well as measurement and quantification of the effect of industrial symbiosis. While the first pieces of work focussed on descriptive considerations of case studies and the ecosystems analogy, current research rather deals with methodological aspects and the modelling of industrial symbiosis (cf. for example: Chertow, 2007; Chertow & Ehrenfeld, 2012; Cimren et al. 2011; etc.). Desrochers (2002) discusses the relationship of industrial symbiosis and cities, but rather identifies cities as the place where industries are located.

The built environment requires huge amounts of natural resources for its establishment and maintenance, and the theme of resource efficiency is of growing importance due to environmental, social and economic concerns. Natural resources are scarce and an efficient use is going to be of eminent importance in the future. Additionally, settlements and the built environment are complex systems, and are made up of very different components and elements: buildings, transport systems and other parts of infrastructure, for example. Such infrastructural services, e.g. waste management, water supply, sewage disposal, energy supply, waste disposal etc. are currently scarcely interlinked, but rather managed separately. Nevertheless, an integrated thinking and interlinked approach like *industrial symbiosis* could provide benefits for the settlement as a whole. The various components of the built environment could be better connected in order to benefit from each other through such an *urban symbiosis*.

The term *urban symbiosis* was used in a slightly different context before. E.g. Herberg (1973) discussed the symbiotic relationship between city centres and the suburbs, while Victor and Hope (2011) focus on the nexuses between rural areas and urban areas without targeting infrastructures. Urban metabolism introduced in the 1960ies by Wolman (1965) addresses similar problems, but does not exactly mean the same as it rather refers to the flows of material and energy only, and

neglects the opportunities of an integrative management and control of the flows. However, within this paper urban metabolism is discussed in its relationship to urban symbiosis where necessary.

In this paper the approach of *industrial symbiosis* is transferred to an urban context, developing the concept of *urban symbiosis*. The concept is exemplary applied to a project addressing resource efficiency in settlement and land use development. Additionally, the opportunities of the approach in fostering settlements towards a more resource-efficient development are explored as well as possible shortcomings of the concept are discussed.

The next paragraph deals with the characteristics of industrial symbiosis and urban symbiosis. Additionally, the similarities are discussed.

2. From Industrial Symbiosis to Urban Symbiosis – State of knowledge

As explained in the introduction, *industrial symbiosis* is derived from industrial ecologists as an analogy to ecosystems. It can be understood as the application of a biological symbiosis to the level of industrial parks, where different companies benefit from each other through the exchange of by-products.

Kanduri (2007) introduces phenomena of industrial ecology to settlements in his doctoral thesis comparing ecosystems with human settlements. Urban metabolism as a similar concept was introduced in the 1960ies by Wolman (1965) and refers to the material flows in settlements. It is, therefore, closely connected to urban symbiosis, but still different, as urban symbiosis not only refers to material flows. Urban symbiosis also includes the steering and management of these flows through an integrative planning involving all relevant entities of sectoral planning.

Lambooy (1973) deals with urban core symbiosis and defined it as the positive effect of shops and other necessities of everyday in urban core areas, and identified an analogy to biotic ecosystems in this aspect as well.

Van Berkel et al. (2009, p. 1545) already introduce the notion *urban symbiosis* "as an extension for industrial symbiosis", which addresses similar aspects transferring the symbiotic cooperation from industrial to urban level.

In the literature *industrial symbiosis* is described as an approach through which companies being located in geographic proximity, sharing or exchanging products or by-products, benefit from the symbiosis both environmentally and economically (cf. for example Chertow, 2000; Chertow et al., 2008; Ashton, 2008; Boons et al., 2011; etc.). Ashton broadens the concept by including "ancillary services, such as transportation, landscaping, waste collection, and share in the management of utilities such as energy, water, or waste water treatment" as well (Ashton, 2008, p. 35). In accordance with this broader perspective, Chertow also includes "utilization of by-products, sharing of

utility/infrastructure, joint provision of services" into the concept (Chertow, 2007, p. 12). Similarly, "innovative reuse of by-products as another's raw material; the sharing of power, water and/or steam supplies; and/or the simple sharing of manufacturing capacity, logistics and/or expertise" are identified as key aspects of industrial symbiosis (Jensen et al., 2012, p. 38).
Other authors point out that "material and energy flows and transformations" are highly relevant; and, accordingly, the symbiosis should "rather be conceptualized as a process" (Boons et al, 2011, p. 905).

Chertow substantiates the definition by determining the quantitative requirements for an industrial symbiosis: "at least three entities exchanging at least two different resources" form a symbiosis (Chertow, 2007, p. 12).

Also, socio-cultural aspects of an inter-firm cooperation are discussed in literature. Basic characteristics include a "culture of cooperation, short mental distances, ongoing communication, trust among managers" (Ehrenfeld and Chertow, 2002, p. 432). Boons et al. indicate "the high level of institutional capacity" being necessary as a basic requirement for introducing such a type of industrial collaboration (Boons et al. 2011, p. 908).

Several publications discuss success factors being important for a functioning symbiosis, such as the geographic proximity of the involved companies (Chertow, 2007, p. 12); the commercially soundness of the partnership (Ashton, 2008, p. 36); the importance of coordination through a coordinating body and/or governmental policy (Boons et al, 2011, p. 907); and – last but not least – the availability of large waste streams (Ehrenfeld and Gertler, 1997).

Advantages for the companies that are generated through the symbiotic collaboration are at hand. The environmental and economic benefits which are generated through a reuse of by-products reducing the resource use are pointed out by many authors (e.g. Ashton, 2008, p. 36; Chertow et al., 2008; Chertow, 2007, p. 13; Chertow, Ehrenfeld, 2012, p. 15). Others identify "more sustainable resource flows and transformations" (Boons et al., 2011, p. 905) or detect an "enhancement of connectance, and new possibilities for cooperation" (Korhonen and Snäkin, 2005). Mirata and Emtairah, (2005) add the "fostering of environmental innovation and promotion of a culture of inter-organizational collaboration oriented towards environmental challenges" to the list of advantages, while Chertow (2000, p.314) introduces a "collective benefit and advancement of social relationships" into the debate. Finally, Chertow (2007, p. 13) also understand [the] "revitalization of urban and rural sites, [the] promotion of job growth/retention, and [the] encouragement of sustainable development" as advantages potentially resulting from urban symbiosis.

Urban symbiosis of course does not only provide advantages to the companies involved in it. Disadvantages can be identified as well and include, for example,

conflicting interests potentially leading to a prevention of connectance and interdependency (Korhonen and Snäkin, 2005).

Finally, several authors point out problems in relationship with the concept such as the fact, that the approach is only sensible when "large, continuous waste streams" are generated (Ehrenfeld and Gertler, 1997) which stands in sharp contrast to one of the objectives of the concept: a more sustainable production with less input. Furthermore, Gibbs et al. (2005, p. 179) criticize that "initiatives are few in number and difficult to organize".

Knowing and understanding basic characteristics of industrial symbiosis, similarities between industrial parks and settlements are to be identified. First of all, it should be noted that urban structures are even more complex than industrial systems are. Nevertheless, it is possible to transfer the approach of industrial symbiosis to urban systems as both are composed of various facilities in which "products" as well as "waste/by-products" are generated. In case of the latter other facilities can potentially make use of the waste/by-product by using it as an input stream. However, there are differences between industrial and urban symbiosis. While the first aims to foster the collaboration between private companies producing certain goods in most cases, the focus of urban symbiosis are services for the public such as water supply, waste disposal, energy supply, or waste water treatment. As such, though industries are part of urban systems, they are not in the focus of the contemplation with the phenomenon of urban symbiosis.

In the following chapter the concept of *urban symbiosis* is transferred to the project EUDYSÉ which deals with resource efficiency in settlement development.

3. Development of Scenario-Based Adaptation Strategies

The project EUDYSÉ addresses resource-efficient settlement development in times of spatially and temporally disparate development trends. Within the project one of the main task can be seen in the concretion and identification of possible strategies in the thematic areas of settlement and land use development (water and waste water management, energy supply, agriculture of energy crops, waste management, transport, and urban development). These adaptation strategies are supposed to follow the vision of a resource-efficient and emission-scarce settlement development. The time horizon is the year 2030. As such today's restrictions, conditions and problems do not stand in the foreground of the analysis, but rather the future perspective of the targeted sectors. Therefore, a future-oriented, normative scenario process is pursued in the framework of the project. In a first step, the desired adaptation options are elaborated for the individual thematic areas; consequently, the strategies for a future water supply as well as the strategies for a future waste disposal, etc. are compiled and combined with each other in order to develop an integrated scenario world consisting of all tackled planning sectors. Then, in a second step, these identified adaptation options are discussed with relevant stakeholders which most probably results in a

need for an adjustment of objectives and adaptation options. The third step involves the detection of necessary actions to be taken in order to reach the determined targets. One main objective is to reach integrated well-matched strategies which acknowledge the use of output material produced in one sector as an input replacing virgin material in another sector. For example, the dried solid waste remaining after the treatment in a sewage plant could function as an input for the energy sector, which aims to collect as much organic material as possible. The other important objective is the identification of the way to reach the overall as well as the targets set in the individual sectors.

In the following the concept of urban symbiosis is transferred to EUDYSÉ, contributions, opportunities and difficulties are discussed as well as first results are presented.

3.1 Transfer of Urban Symbiosis to EUDYSÉ

Within the project solutions for a more resource efficient and emission scarce settlement development including infrastructural services are sought. Currently, these services work well as separate infrastructures, though they are scarcely interlinked. In times of dramatic changes due to demographic decline, climate change, resource scarcity etc. a more integrative planning becomes more and more important. Therefore, it is essential to achieve that by-products resulting from processes of one infrastructural service may become an input stream for another sector.

There are several examples of symbiotic approaches that give evidence of the general applicability of the concept, which exist already or a about to be introduced. For example, waste heat from waste water can be recovered through the use of a heat exchanger under the condition that a minimum of 50 kW of heating or cooling demand is provided (König, 2012, p. 25). Another example also coming from waste water treatment deals with the utilization of the energetic content of sewage sludge in order to reduce the carbon footprint (Kraus, 2012, p. 15). Finally, an oversized waste water treatment plant in Cottbus, Germany originally planned for more than 350,00 inhabitants is being developed into a centre for recycling, reuse and disposal for a larger variety of waste including food leftovers (Wegner, 2012, p. 22). However, these examples also prove that, so far, the focus is rather on single technologies and single sectors than on integrative approaches combining the various planning sectors and infrastructures. The approach of urban symbiosis is to go beyond, and include various infrastructural services instead.

Additionally, urban symbiosis shall not only be understood as the exchange of goods and services between one and the other infrastructure or other compartment of the settlement. It also can be used for the exchange between urban areas and rural areas. The region as a whole is the focus of this type of symbiosis. On the one hand, the more rural areas are potential producers of a number of goods such

as food, energy crops, and energy, while on the other hand urban areas with their high number of inhabitants are rather consumers of these goods. Also, urban areas provide services that are demanded by inhabitants of rural areas such as public transport or cultural offers.

In the following paragraph potential contributions, opportunities and difficulties of desired adaptation strategies are presented and it is discussed how and to which extent urban symbiosis effects can be discovered therein.

3.2 Contributions, Opportunities, and Difficulties

The adaptation options contributing to the overall goal of resource efficiency and emission scarcity are developed along two scenarios. In a first approach this is done seperately for the individual sectors. Nevertheless, possible interfaces are to be considered already at this stage. In order to develop a common, comprehensive scenario covering all sectors these options are reconciled with each other as well as possible synergies and symbiotic exchange opportunities are detected. Finally, all options shall be discussed amongst the stakeholders and adapted accordingly aiming for a better collaboration between the sectors and for more efficient solutions in resource utilization.

Figure 1 gives an impression of desired and imaginable contributions and opportunities an urban symbiosis approach offers when implemented into urban and regional development. The list of interconnections as depicted in the figure is not complete. Infrastructural services are marked as boxes, while open space and settlement area are labelled as circles. The settlement areas are in the focus of attention of the symbiosis, and its density or number of inhabitants and industrial consumers determines the demand for the various infrastructural services such as the energy demand (electricity and heating) or the amount of waste to be disposed properly. Additionally, settlements themselves satisfy the demand of inhabitants for living space and of industry and trades for commercial space, while the infrastructure dedicated to transportation provides the oportunities for mobility. The further sectors are integrated into the settlements through their infrastructure and facilities providing water supply, waste disposal, energy supply, etc. as required depending on the demand. The innovative idea of urban symbiosis is the search for and the identification of material flows which originally were generated as by-products or waste products in certain processes, but could be utilized as recycling material in other processes. For example, organic waste could be used as an input stream in the generation of energy; either as an additional input in a co-incineration of conventional fossil fuels, or as an input in a biogas plant. Also, superficially cleared water could be used for the irrigation of energy crops. Moreover, secondary building material could serve as the basis for new buildings. However, the project does not only deal with settlement areas; open space, such as agriculture or forestry, is in the focus as well. Energy crops, therefore, are input for the energy sector generating electricity and heat, ideally in a combined heat and power generation process.

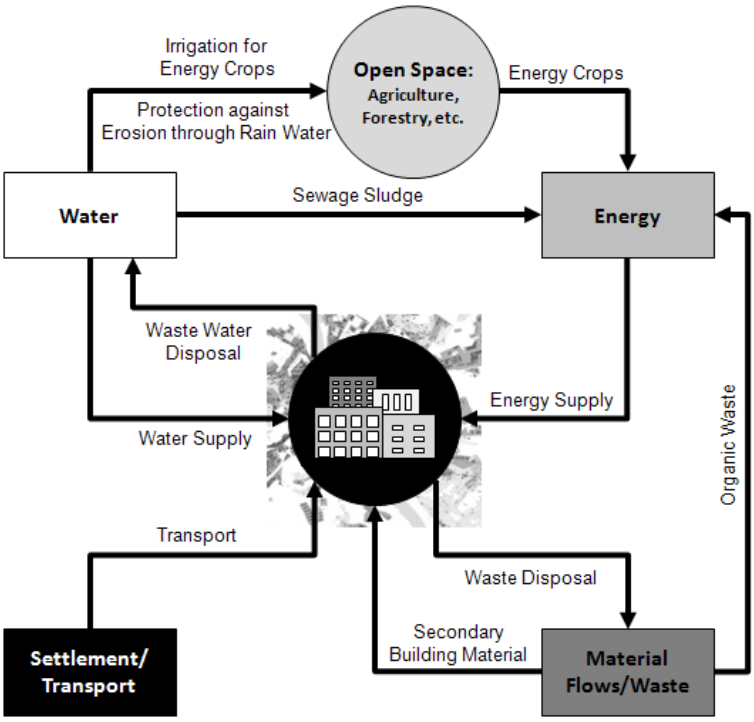

Figure 1. The Concept of Urban Symbiosis

Though the transport sector is not in the focus of the project, it could deserve a particular role in urban symbiosis, as it functions rather as a binding element connecting the different sectors where necessary. E.g. energy crops grown in agriculture are transported to power-generation plants, or the building material needs to be carried over roads as well. Additionally, it demands fuel (fossil fuel in the moment/electricity in the future) in order to allow the required mobility, and thefore, also depends on the supply of energy such as any other sector.

Despite the assumed benefits there are huge obstacles in implementing urban symbiosis over different planning sectors. All in all, the process of introducing the concept of urban symbiosis is a very difficult management task as it must be based on an agreement between very different stakeholders from various disciplines and from various levels. Therefore, it requires an inter-sectoral approach and a collaborative planning of the different sectors of public services. The involvement of various disciplines, however, implies the risk of failure due to several reasons such as communicative misunderstandings, principal doubts concerning the potential benefits to be generated, and/or the fear of losing administrative, political or economic power, etc. As such, the implementation process requires a highly political discourse among the various stakeholders on the various levels; in particular, as the potential benefits are somehow vague, and currently not to be estimated.

The following paragraph presents the potential effects of an implementation of urban symbiosis into urban planning.

3.3 Results

At the time being, urban symbiosis is not implemented in any region or settlement; nevertheless, it could potentially provide advantages and benefits for urban and rural areas. However, these benefits cannot be assessed in terms of quality and quantity in the moment. Settlements or regions, to be more precisely, deciding to follow such a path could potentially gain a competitive advantage over other settlements/regions; particularly in respect of the basic assumption that resources will become more and more scarce, and accordingly an efficient handling of these resources will be vital. The approach to combine several material flows, and use output/by-products as an input again, potentially reduces the total demands for resources, and, therefore, fosters the development towards a more resource-efficient and emission-scarce settlement development. The process of identifying potential synergies itself forms an important result as it sharpens the consciousness for the opportunities of urban symbiosis. As such, urban symbiosis can be regarded as an approach fostering communication among the relevant stakeholders and decision-makers with the aim to generate benefits for the region both environmentally and economically.

Principally, a successful implementation of the approach is based on a number of pre-requisites. First, the steering and management of the process is essential. It must involve all relevant stakeholder of the various sectors providing public services in the region referred to. The potential benefits as well as possible hindrances and risks must be communicated in a transparent way. The stakeholders must be given the opportunity to influence and contribute to the concept and structuring of the urban symbiosis. Second, the material flows, particularly by-products being reused as an input again, quantitatively need to reach a critical mass in order to ensure a certain financial benefit exceeding the efforts necessary for the whole process. Third, the approach should be embedded in an integrated assessment of the environmental and economical impacts generated by the restructuring of the infrastructural services. Without a clear depiction of the gains and losses due to the conversion at least in the central areas (resource-consumption, emissions, etc.) as well as an analysis of the costs involved, the whole process remains vague and unrealistic.

The next paragraph demonstrates the conclusions to be drawn from the current state of the employment with the topic of urban symbiosis.

4. Conclusions

Urban symbiosis as a transfer of the concept of *industrial symbiosis* developed for industrial parks to an urban context, and as an extension of urban metabolism may serve as a sensible approach to foster a resource-efficient development of

settlements. The complexity of urban structures, however, must be acknowledged and referred to in the application of the concept. As well, the relationship between rural areas as producers of goods such as food or energy crops, and urban areas as consumers of these goods must be defined more precisely. In case regions would strictly follow the concept of urban symbiosis in their planning activities, the outcomes for resource-efficiency in the medium and long-run are expected to be remarkable, though at the time being it is not possible to quantify them. As these ecological benefits are often correlated with financial benefits, it is possible, but definitely not inevitable, that also the economic outcomes are positive. Additionally, the process of establishing such a concept with its more integrative approach requires more efforts from the involved planners and stakeholders, and will not be implemented in a short period of time. However, regions understanding themselves as inter-communal cooperation partners involving both urban and rural areas could gain a strategic advantage in developing into this direction of a more integrated planning while finally reaching the point of full urban-rural symbiosis. All-in-all, the overall benefits of this approach cannot be properly assessed in the moment, and further investigation is necessary in order to gain a better understanding of opportunities and threats involved.

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6. References

Ashton, W., 2008. Understanding the Organization of Industrial Ecosystems. A Social Network Approach. In: Journal of Industrial Ecology 12 (1), pp. 34–51.

Boons, F.; Spekkink, W.; Mouzakitis, Y., 2011. The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. In: Journal of Cleaner Production 19, pp. 905–911.

Chertow, M. R., 2000. Industrial Symbiosis. Literature and Taxonomy. In: Annual Review of Energy and the Environment 25, pp. 313–337.

Ehrenfeld, J. and Chertow, M. R., 2002. Industrial symbiosis: The legacy of Kalundborg. In: A Handbook of Industrial Ecology, edited by R. U. Ayres and L. W. Ayres. Cheltenham, UK.: Edward Elgar.

Chertow, M. R., 2007. "Uncovering" Industrial Symbiosis. In: Journal of Industrial Ecology 11 (1), pp. 11–30.

Chertow, M. R.; Ashton, W. S. and Espinosa, J. C., 2008. Industrial Symbiosis in Puerto Rico: Environmentally Related Agglomeration Economies. In: Regional Studies 42 (10), pp. 1299–1312.

Chertow, M. and Ehrenfeld, J., 2012. Organizing Self-Organizing Systems. In: Journal of Industrial Ecology 16 (1), S. 13–27.

Cimren, E.; Fiksel, J.; Posner, M. E.; Sikdar, K., 2011. Material flow optimization in by-product synergy networks. In: Journal of Industrial Ecology 15 (2), pp. 315–332.

Desrochers, Pierre (2002): Cities and Industrial Symbiosis. Some Historical Perspectives and Policy Implications. In: Industrial Ecology 5 (4), pp. 29–44.

Ehrenfeld, J. and Gertler, N., 1997. Industrial ecology in practice: the evolution of interdependence at Kalundborg. In: Journal of Industrial Ecology 1 (1), pp. 67–79.

Gibbs, D.; Deutz, P. and Proctor, A., 2005. Industrial ecology and eco-industrial development: A potential paradigm for local and regional development? In: Regional Studies 39 (2), pp. 171–183.

Herberg, Will (1973): City and Suburb in Symbiosis: The Urban Problem in New Perspective. In: The Intercollegiate Review (Spring), pp. 159–169.

Jensen, P. D.; Basson, L.; Hellawell, E. E. and Leach, M., 2012. 'Habitat' Suitability Index Mapping for Industrial Symbiosis Planning. In: Journal of Industrial Ecology 16 (1), pp. 38–50.

Kanduri, K., 2007. A methodological framework for the application of industrial ecology to enhance sustainability of human settlements in Australia. Dissertation.

Korhonen, J. and Snäkin, J.-P., 2005. Analysing the evolution of industrial ecosystems: concepts and application. In: Ecological Economics 52 (2), pp. 169–186.

König, K. W.,2012. Waste water as recyclable material. What's more obvious concerning climate protection than utilizing waste heat? *Abwasser als Wertstoff. Was liegt im Interesse des Klimaschutzes näher, als Abwärme zu nutzen?* In: wwt (5), S. 25–27.

Kraus, S., 2012. Energy from water and waste water. Water2Energy: How water and waste water management can contribute to energy transition. *Energie aus Wasser und Abwasser. Water2Energy: Wie die Wasser- und Abwasserwirtschaft zur Energiewende beitragen kann*. In: wwt (5), S. 15–19.

Mirata, M. and Emtairah, T., 2005. Industrial symbiosis networks and the contribution to environmental innovation: The case of the Landskrona industrial symbiosis programme. In: Journal of Cleaner Production 13 (10-11). pp. 993–1002.

van Berkel, R.; Fujita, T.; Hashimoto, S.; Geng, Y., 2009. Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006. In: Journal of Environmental Management 90 (3), pp. 1544–1556.

Victor, O. U. and Hope, E. N., 2011. Rural-Urban 'Symbiosis', community self-help, and the new planning mandate: Evidence from Southeast Nigeria. In: Habitat International 35 (2), S. 350–360.

Wegner, J.-E., 2012. Lusatia lost as energy region? The particular challenge: Waste water treatment in economically underdeveloped regions. *Verlorene Energieregion Lausitz? Die besondere Herausforderung: Abwasserbehandlung und Energieerzeugung in strukturschwachen Regionen*. In: wwt (5), S. 20–22.

Wolman, A., 1965. The metabolism of cities, Scientific American, 213(3), pp. 178–193.